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Spatio-temporal distribution of *Anastrepha fraterculus* and *Ceratitis capitata* (Diptera: Tephritidae) captures and their relationship with fruit infestation in farms with a diversity of hosts

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Abstract

Ceratitis capitata (Wiedemann) and *Anastrepha fraterculus* (Wiedemann) (both Diptera: Tephritidae) cause severe economic losses to fruit production; thus, it is important to know the population fluctuations of these pests that share the same habitat and compete for similar niches, as well as to know their relationship with fruit infestation, all of which are fundamental components for understanding how to manage the risks of infestation in farms with a diversity of susceptible hosts. In the present research, the spatio-temporal distribution of *C. capitata* and *A. fraterculus* in 3 fruit farms was analyzed together with the incidence of fruit damage in different host species and cultivars. Seventy-nine Jackson traps baited with trimedlure and 88 McPhail traps baited with Torula yeast were monitored from Sep 2014 to Jun 2016, and a total of 5,700 fruits were sampled during the 2 seasons. The Spearman correlation coefficient between captures and fruit infestation was calculated, and maps of accumulated captures and fruit infestation distribution were built by site and season. Population fluctuation and fruit infestation were plotted for both fruit fly species, whereas population fluctuation discriminated by sex was analyzed for *C. capitata*. The Spearman correlation coefficient between *C. capitata* captures in McPhail traps during the 2 wk prior to harvest and the percentage of infested fruits was 0.62 (P = 0.0001), whereas for Jackson traps it was 0.34 (P = 0.02). The correlation between *A. fraterculus* captures in McPhail traps and fruit infestation was 0.59 (P = 0.0001). The variation observed in the number of adults and fruit infestation of both pest species between sites and host species groups is discussed.

Key Words: Mediterranean fruit fly; South American fruit fly; captures; fruit damage; correlation

Resumen

Ceratitis capitata (Wiedemann) y *Anastrepha fraterculus* (Wiedemann) (ambos Diptera: Tephritidae) causan graves pérdidas económicas en la producción de frutas; por ello, es importante conocer las fluctuaciones poblacionales de estas plagas que comparten el mismo hábitat y compiten por nichos similares, así como conocer su relación con la infestación de frutos, todos los cuales son componentes fundamentales para entender cómo manejar los riesgos de infestación en fincas con diversidad de hospedantes susceptibles. En la presente investigación se analizó la distribución espacio-temporal de *C. capitata* y *A. fraterculus* en 3 fincas frutícolas junto con la incidencia de daño en fruto en diferentes especies y cultivares hospedantes. Se monitorearon 79 trampas Jackson cebadas con trimedlure y 88 trampas McPhail cebadas con levadura Torula desde septiembre de 2014 hasta junio de 2016, y se muestrearon un total de 5.700 frutos durante las 2 temporadas. Se calculó el coeficiente de correlación de Spearman entre capturas e infestación de frutos, y se construyeron mapas de capturas acumuladas y distribución de infestación de frutos por sitio y temporada. Se graficaron la fluctuación de la población y la infestación de los frutos para ambas especies de moscas de la fruta, mientras que la fluctuación de la población discriminada por sexo se analizó para *C. capitata*. El coeficiente de correlación de Spearman entre las capturas de *C. capitata* en trampas McPhail durante las 2 semanas previas a la cosecha y el porcentaje de frutos infestados fue 0,62 (P = 0,0001), mientras que para las trampas Jackson fue 0,34 (P = 0,02). La correlación entre las capturas de *A. fraterculus* en trampas McPhail y la infestación de frutos fue de 0.59 (P = 0,0001). Se discute la variación observada en el número de adultos e infestación de frutos de ambas especies de plagas entre sitios y grupos de especies hospedantes.

Palabras Claves: Mosca mediterránea de la fruta; Mosca de la fruta sudamericana; capturas; daño a la fruta; correlación

Ceratitis capitata (Wiedemann) (Diptera: Tephritidae) is one of the most important pest species of fruit trees in the world (Paiva & Parra 2013), whereas *Anastrepha fraterculus* (Wiedemann) (Diptera: Tephritidae) is restricted to the American continent, from northern Mexico to southern Argentina (Garcia et al. 2020). Both species are present in Uruguay, and their importance is due to the direct injury they cause to the

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fruit, and to the restrictions on trade imposed by the countries that are free of these pests, principally in citrus production, where 44% is exported (Malavasi et al. 1994; Zefferino 2019; DIEA-MGAP 2020).

To define which control strategy to apply, it is necessary to know fruit fly population abundance; therefore, it is important to develop an efficient monitoring system that allows identifying areas with different levels of fruit fly populations. The spatial variation of fruit flies is associated with the availability of susceptible hosts throughout the yr. Fruit flies are known to adjust their foraging behavior in response to changes in the spatial, temporal, and seasonal distribution of food and other resources (Hendrichs et al. 1991). There also are differences associated with sex; male and female spatial dispersal patterns appear to be linked to the need and differential use of resources, and the physiological status of its populations. Sexually mature females are expected to seek suitable egg-laying sites, so aggregation would occur where the fruit has ripened and is favorable for egg-laying in addition to providing food sources. Males, however, in addition to foraging, likely concentrate in areas that provide shelter and appropriate sites to exhibit calling and lekking behavior outside of female egg-laying areas (Shelly 2000; Papadopoulos et al. 2001).

The polyphagia of *C. capitata* and *A. fraterculus* (Liquido et al. 2019), and continuous presence of mature fruits from cultivated and wild hosts (Grové et al. 2017) could explain the abundance of fruit flies throughout the yr in some regions. *Ceratitis capitata* thrives best in disturbed environments, whereas *A. fraterculus* prefers areas with native vegetation or sites where its native hosts predominate over exotic hosts (Ovruski et al. 2003).

Fruit is attractive for oviposition and suitable for the development of fruit fly larvae in a period close to maturation (Joachim-Bravo et al. 2001; Aluja & Mangan 2008). In Uruguay, the first stone fruits (*Prunus* sp. L.; Rosaceae) begin to ripe in Nov and continue until Feb. In Jan, the ripening of pears (*Pyrus communis* L.; Rosaceae) and the first apple cultivars (*Malus domestica* Borkhausen; Rosaceae) begin, ending in Apr to May. The ripening of citrus fruits (*Citrus* sp. L.; Rutaceae) begins toward the end of Feb and extends until Sep (DIEA-MGAP 2017). Considering only citrus and deciduous fruit trees, fruit flies have an appropriate substrate to develop throughout the yr uninterrupted.

Segura et al. (2006) studied the relative abundance of *A. fraterculus* and *C. capitata* in several hosts and localities in Argentina, and demonstrated that both species coexist in several areas and exhibit similar ecological requirements. This study was carried out on a large scale through fruit sampling and at specific times. On the other hand, there are studies related to the spatio-temporal distribution of *C. capitata* at the farm level (Papadopoulos et al. 2003; Sciarretta &Trematerra 2011), but the spatio-temporal variability of *A. fraterculus* and *C. capitata* simultaneously has not been analyzed. Furthermore, these researchers analyzed only the distribution of adults, generally as captures in *C. capitata* traps, without considering the larval stages (Papadopoulos et al. 2003; Sciarretta &Trematerra 2011; Sciarretta et al. 2018). The objectives of this study were to analyze the population fluctuation of adults of *C. capitata* and *A. fraterculus* sharing the same habitat, and the relationship of their captures in traps with fruit infestation, as well as to describe the spatial distribution of both pests together with the incidence of fruit damage in different host species and cultivars.

Materials and Methods

STUDY LOCATION

The studies were carried out between Sep 2014 and Jun 2016 in 3 commercial farms. A farm composed exclusively of deciduous fruit trees, located in Canelones (34.6841230°S, 56.3912460°W), another located in San José (34.6376560°S, 6.7284920°W) with a combination of citrus and deciduous fruit trees, and the third one with only citrus orchards, located in Paysandú (31.5273320°S, 57.9258940°W) (Table 1). In San José and Paysandú the shelterbelts were composed of *Casuarina cunninghamiana* Miquel (Casuarinaceae), whereas in Canelones in addition to casuarinas there were diverse tree species, such as *Acacia caven* (Molina) and *Bauhinia forficata* Link (both Fabaceae); *Acca sellowiana* (Berg) Burret, *Eucalyptus globules* La Billardieri, *Blepharocalyx salicifolius* (Kunth) Berg, and *Eugenia uniflora* L. (all Myrtaceae); *Crataegus oxyacantha* L., *Eriobotrya japonica* (Thunberg) Lindley, and *Rubus ulmifolius* Schott (all Rosaceae); *Populus alba* L. and *Salix humboldtiana* Willdenow (both Salicaceae); as well as *Schinus longifolia* (Lindley) Spegazzini (Anacardiaceae), *Celtis tala* Gillies ex Planchon (Cannabaceae), *Melia azedarach* L. (Meliaceae), *Morus alba* L. (Moraceae), *Ligustrum lucidum* W.T. Aiton (Oleaceae), *Myrsine laetevirens* Mez (Primulaceae), *Jodina rhombifolia* (Hooker & Arnott) Reissek (Santalaceae), and *Lantana camara* L. (Verbenaceae).

ADULT MONITORING AND FRUIT SAMPLING

A monitoring grid of Jackson traps baited with parapheromone (trimedlure, (Süsbin S.A., Mendoza, Argentina) for monitoring *C. capitata* males, and McPhail traps baited with Torula yeast (Süsbin S.A., Mendoza, Argentina) for monitoring *C. capitata* and *A. fraterculus*, were set up in all farms (OIEA 2005). The monitoring materials evaluated are those used in the national surveillance system for fruit flies (Zefferino 2019). A distance of 50 m between traps of the same kind and at least 30 m between Jackson and McPhail traps was maintained. The traps were monitored each wk, and McPhail traps were re-baited at each visit with 4 pellets of Torula yeast and 300 mL of water, whereas the trimedlure was replaced every 45 d and the sticky bottom was replaced as necessary. Fruit flies captured in McPhail traps were counted and separated by species and sex.

In Canelones and Paysandú, 60 and 50 traps were set up on 30 Oct and 1 Nov 2014, respectively. In San José, traps were set up on 2 dates, 37 McPhail traps on 1 Sep 2014, and 30 Jackson traps were added on 29 Jun 2015 (Table 1).

To evaluate fruit infestation during the wk prior to harvest, 10 plants were sampled randomly per cultivar plot, extracting 10 fruit per plant in stone fruit, and 15 fruit per plant in citrus and pome fruit, sampling a total of 5,700 fruit during the 2 seasons. The fruit was taken to the laboratory to be weighed, identified, and placed in containers individually with sand as a substrate for the larvae pupation. The containers were covered with organza to allow ventilation. The fruit was kept at 25 °C and 70% RH, and was checked each wk. The pupae were extracted from the sand and transferred to a Petri dish until the emergence of adults. The adults were classified by species and sex, maintaining the identification of the fruit from which they were collected. The fruit sampling dates are shown in Table 1.

DATA ANALYSIS

For each species of fruit fly and season, the accumulated captures in McPhail traps were calculated. The period considered for the accumulation of captures was from the date that traps were set up in 2014 (see Adult Monitoring and Fruit Sampling) until Jun 2015, and for the same period from spring 2015 until Jun 2016. Then the differences in captures between host species and between groups of cultivars of the same species in each study area were

Table 1. Fruit sampling dates and number of traps by species and cultivar at each farm.[1]Traps were set up in the spring of 2014, except those marked with an asterisk (*) that were set up in Jun 2015.

Site	Species	Cultivar	Area (ha)	No. of traps		Fruit sampling date	
				Jackson[1]	McPhail	First yr	Second yr
Canelones	*Prunus persica* (Peach)	June Gold	0.3	1	1	13 Nov 2014	25 Nov 2015
		Forastero	0.8	2	2	9 Dec 2014	–
		Elegant Lady	0.9	2	2	17 Dec 2014	–
		Dixieland	0.6	2	2	–	14 Jan 2016
		Pavía Canario	0.5	2	2	–	18 Feb 2016
	Prunus persica var. *nucipersica* (Nectarine)	Lara	1.2	3	3	27 Nov 2014	2 Nov 2015
		Fantasía	0.3	1	1	–	5 Jan 2016
	Pyrus communis (Pear)	William's	2.5	6	6	13 Jan 2015, 21 Jan 2015	7 Mar 2016
	Malus domestica (Apple)	Early Red One	2.1	6	6	23 Feb 2015	4 Mar 2016
		Red Chief	1.7	3	4	23 Feb 2015	4 Mar 2016
		Red Delicious	0.5	1	2	–	4 Mar 2016
		Sub total	11.3	29	31		
San José	*Citrus sinensis* (Orange)	Washington Navel	2.5	3	3	12 Jun 2015	24 May 2016
	Citrus reticulata (Mandarin)	Ellendale	4.0	3* / 8	8	20 Jul 2015	26 Jun 2016
	Prunus persica (Peach)	Rich Lady	1.2	3*	3	–	19 Jan 2016
		Elegant Lady	1.2	3*	3	–	5 Jan 2016
		Rey del Monte	1.95	6*	6	–	4 Feb 2016
		Pavía Canario	0.85	3*	3	–	18 Feb 2016
	Prunus persica var. *nucipersica* (Nectarine)	Fantasía	1.2	4*	5	–	19 Jan 2016
	Malus domestica (Apple)	Red Delicious	3.6	3*	3	–	17 Mar 2016
		Sub total	16.5	33	34		
Paysandú	*Citrus sinensis* (Orange)	Valencia	3.2	3	4	17 Nov 2015	11 Oct 2016
		Washington Navel	3.0	5	7	16 Jun 2015	12 Jun 2016
	Citrus reticulata (Mandarin)	Satsuma	0.9	4	4	3 Mar 2015	5 May 2016
		Ortanique	1.6	3	4	19 Aug 2015	23 Aug 2016
	Citrus paradisi (Grapefruit)	Star Rubí	1.3	1	2	23 Jul 2015	27 Jul 2016
	Citrus limon (Lemon)	Lisbon	1.3	1	2	–	–
		Sub total	11.4	17	23		

tested. The median was used as a measure of central tendency, and the interquartile range is used as a measure of the dispersion of the set of values.

The accumulated captures per trap and season were compared between host species and between cultivars of the same species in each study area using the non-parametric Kruskal-Wallis analysis of variance (ANOVA) test with subsequent analysis of multiple comparisons by pairs with the Conover test. In the cases where the comparisons were between 2 groups, such as when comparing fruit fly species, *C. capitata* males and females, difference between the 2 seasons or between 2 cultivars, the Kolmogorov-Smirnov test was used (Infostat 2018).

The Spearman correlation coefficients between captures and fruit infestation were calculated. Captures were expressed as fly per trap per d taking into consideration for each cultivar the mean daily captures during the 2 wk before harvest, analyzing separately *C. capitata* and *A. fraterculus* captured in McPhail traps, and *C. capitata* males captured in Jackson traps.

Spatial Distribution

Accumulated captures and fruit infestation distribution maps were made by site and season. The capture distribution maps were built with the GS + Version 7.0 program (Gamma Design 2006) using the Inverse Distance Weighted method. A layer was added using Power Point (Microsoft 2010) with the level of fruit infestation per plot to observe both distribution patterns simultaneously.

Relationship between Captures and Fruit Infestation

Additionally, to show the relationship between the population fluctuation of both fly species in McPhail traps and the fruit infestation in different host species and sites, some representative graphs were presented for pear, peaches, mandarins, and orange.

Distribution of Males and Females of *Ceratitis capitata* in Hosts with and without Fruit Infestation

To visualize different distribution patterns of *C. capitata* discriminated by sex, the population fluctuation of males and females for a sample of host species by study site was plotted. In this analysis were considered the host species with the highest captures in McPhail traps, and within these, those cultivars with the highest and lowest infestations in fruit. The records in the Jackson traps were considered as the male population indicator, and the female population was obtained from the records in the McPhail traps. The accumulated captures of males and females per cultivar were compared statistically. The same analysis was excluded for *A. fraterculus* because there were not enough traps for adequate monitoring of males. The captures of lemon trees also were included, assuming that it is not a host chosen by the females to oviposit under natural conditions (Spitler et al. 1984; Staub et al. 2008).

Results

POPULATION FLUCTUATION

The accumulated captures of *C. capitata* per McPhail trap were much higher than those of *A. fraterculus*. The median of captures per trap of *C. capitata* was 125, with an interquartile range of 313, whereas for *A. fraterculus* the median was 2 captures per trap with an interquartile range of 17 (Kolmogorov-Smirnov, $n = 178$; $P = 0.01$). The increase in captures of *A. fraterculus* in the 2 sites where it was found, took place before the increase in captures of *C. capitata* (Fig. 1). The captures of *A. fraterculus* in San José were almost zero in both seasons.

ACCUMULATED CAPTURES PER HOST

When we compared the fruit fly populations among host species, it was observed that in the Canelones farm, composed solely of deciduous fruit trees, the captures of *C. capitata* in pear (*P. communis*) were higher than in apple (*M. domestica*), peach (*Prunus persicae* [L.] Batsch; Rosaceae) and nectarine (*Prunus persicae* var. *nucipersica* [L.] Batsch; Rosaceae) trees. In the case of *A. fraterculus*, in addition to pear trees, nectarines also showed significant differences with apple and peach trees (Table 2). In San José, the citrus species had a higher population of *C. capitata* than the deciduous fruit trees, whereas the population of *A. fraterculus* was extremely low in both seasons, so no differences between hosts species were analyzed (Table 3). In Paysandú, in the farm composed only of citrus, the population of *C. capitata* was higher in mandarins (*Citrus reticulata* Blanco) and orange (*Citrus sinensis* L.) trees than in lemon (*Citrus limon* [L.] Osbeck) and grapefruit (*Citrus paradisi* L.) (all Rutaceae), while for *A. fraterculus* the grapefruit and mandarin had the highest captures (Table 4).

In the comparison to *C. capitata* captures between cultivars of the same species, in Paysandú in the orange trees, no significant differences were observed between 'Valencia' (median = 712.5; interquartile range = 1393) and 'Washington Navel' (median = 70.5; interquartile range = 326), nor in mandarins between 'Ortanique' (median = 197.5; interquartile range = 623) and 'Satsuma' (median = 240.0; interquartile range = 51). In Canelones, no significant differences were found between the apple cultivars 'Red Chief' (median = 47; interquartile range = 150), 'Early Red One' (median = 20; interquartile range = 37), and 'Red Delicious' (median = 40; interquartile range = 139). On the other hand, in San José, significant differences were found between peaches, with *C. capitata* captures being lower in 'Pavía Canario' (median = 4; interquartile range = 1) and 'Rey del Monte' (median = 4.5; interquartile range = 5), intermediate in 'Rich Lady' (median = 35.5; interquartile range = 65), and higher in 'Elegant Lady' (median = 35.5; interquartile range = 24), which did not have significant differences with Rich Lady, but did have significant differences with the other 2 cultivars (Kruskal-Wallis, $H = 10.3$; $P = 0.01$; Conover, $P < 0.05$). For the captures of *A. fraterculus* in Ortanique mandarin (median = 58; interquartile range = 135) a tendency was observed to be higher than in Satsuma (median = 7; interquartile range = 7) (Kolmogorov-Smirnov, $P = 0.1$), whereas no significant differences were detected between cultivars of orange, apple, or peach trees, which had low captures in both seasons (Tables 2, 3, 4).

SPATIAL DISTRIBUTION

In the maps (Fig. 2), it shows that there is a pattern of capture distribution that is repeated in both seasons and in both fruit fly species. In Canelones the foci of *C. capitata* are observed in the pear orchard and its surroundings, in the central area of the farm, whereas the foci of *A. fraterculus* appear associated with the nectarine cv. 'Lara' in 2 orchards located in opposite corners of the farm. Regarding the fruit infestation distribution, the season in which the highest captures of *C. capitata* occurred (Fig. 2), fruit infestation was recorded in a single orchard in pear, whereas in the 2015–2016 season when the captures were significantly lower (Kolmogorov-Smirnov, $P < 0.05$), fruit infestation was recorded in almost all the orchards around the focus of captures. In relation to the fruit damage caused by *A. fraterculus*, a more erratic behavior was observed, because although the fruit infestation levels were higher around the capture foci, fruit damage was recorded in orchards with a low number of captures in both seasons.

In Paysandú it was observed that the foci of *C. capitata* were located in Valencia orange and Ortanique mandarin, while *A. fraterculus* is located in Ortanique mandarin and 'Star Rubí' grapefruit. In this case, the incidence of damage by *C. capitata* showed a pattern quite similar to the distribution of the captures, while no fruit infestation caused by *A. fraterculus* was recorded despite being detected in the traps.

In San José, the foci of *C. capitata* captures were associated with citrus, Elenadalle and Washington Navel, although neither of the 2 cultivars had fruit damage, but damage was recorded in the cultivars Red

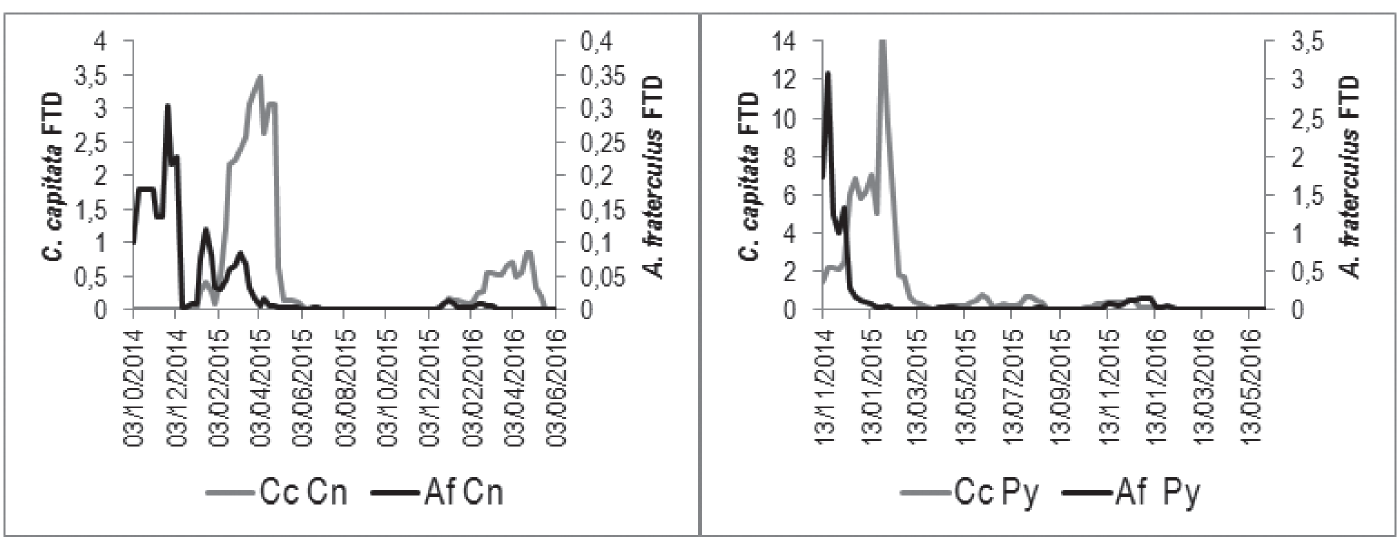

Fig. 1. Average number of fruit flies per McPhail trap per d (FTD) of *Ceratitis capitata* (Cc) and *Anastrepha fraterculus* (Af) in Paysandú (Py) and Canelones (Cn).

Table 2. Accumulated captures[1] of *Ceratitis capitata* and *Anastrepha fraterculus* by host species in Canelones.

Species	Area (ha)	No. of traps × 2 seasons	*C. capitata* median	*C. capitata* interquartile range	*A. fraterculus* median	*A. fraterculus* interquartile range
Apple	4.3	23	35.0 a[2]	50	2.0 A	6
Peach	3.16	18	50.5 ab	51	3.0 A	4
Nectarine	1.6	12	79.5 b	42	26.5 B	95
Pear	2.5	12	355.0 c	766	16.0 B	20

[1]The accumulated captures per season were calculated by adding captures from 30 Oct 2014 until 30 Jun 2015, and for the same period from spring 2015 until Jun 2016. [2]Identical letters in the columns indicate that there is no significant difference between the variables. Kruskal-Wallis *C. capitata*, $P = 0.0015$; *A. fraterculus*, $P = 0.0001$; Conover, $P < 0.05$.

Delicious and Rich Lady where the record of captures was relatively low. On the other hand, the presence of *A. fraterculus* was near zero and there was no incidence on fruit in either of the 2 seasons.

RELATIONSHIP BETWEEN CAPTURES AND FRUIT INFESTATION

The Spearman correlation coefficient between *C. capitata* captures in McPhail traps in the 2 wk prior to harvest and the percentage of infested fruits was 0.62 ($N = 37$; $P = 0.0001$), whereas for Jackson traps it was 0.34 ($N = 37$; $P = 0.02$). The correlation between *A. fraterculus* captures and fruit infestation was 0.59 ($N = 37$; $P = 0.0001$).

Regarding the relationship between captures over time and fruit infestation, in the deciduous fruit trees it was observed that the highest increases of *C. capitata* always occurred after harvest when there was no fruit left on the plants in most fruit orchards (Fig. 3A, B), whereas in citrus greater variation between species and cultivars was observed. In Ortanique mandarin the population increase was during and after harvest (Fig. 4A). In Washington Navel orange and Ellendale mandarin, fruit infestation was not recorded in either of the 2 seasons whereas captures were recorded in McPhail traps, with the largest population increase registered at least 3 mo before the beginning of harvest (Fig. 4B).

In the case of *A. fraterculus* the population fluctuation was more erratic between host species and cultivars, sometimes detected before and near harvests, and sometimes detected long after harvest (Fig. 5A, B, C).

Distribution of Males and Females of *Ceratitis capitata* in Hosts with and without Fruit Infestation

Regarding the distribution of *C. capitata*, it was observed that in all cultivars with fruit infestation (Fig. 6A, B, C) the population of females (median = 157) was higher than males (median = 72.5) (Kolmogorov-Smirnov, $P = 0.02$), and that the increase in female population in some cases occurred earlier. On the other hand, in grapefruit and lemon trees in Paysandú (Fig. 6E, F), as well as in citrus hosts in San José where no fruit infestation was recorded (Fig. 6G, H), the proportion of males (median = 228.5) was higher significantly than females (median = 45) (Kolmogorov-Smirnov, $P = 0.01$).

Discussion

Great variation was found in the number of adults and fruit infestation of both fruit fly species among localities and the compared groups of host species. The population increases of *A. fraterculus* observed before the increase of *C. capitata* could be due to the preference of *A. fraterculus* to oviposit on unripe fruit (Malavasi et al. 1983), whereas *C. capitata* prefers ripe fruit (Joachim-Bravo et al. 2001), favoring its earlier detection in susceptible hosts. Likewise, the lower competitive capacity of *A. fraterculus* concerning *C. capitata* (Duyck et al. 2004) might diminish the presence of *A. fraterculus* in the orchards in certain situations.

Table 3. Accumulated captures[1] of *Ceratitis capitata* and *Anastrepha fraterculus* by host species in San José.

Species	Area (ha)	No. of traps × 2 seasons	*C. capitata* median	*C. capitata* interquartile range	*A. fraterculus* median	*A. fraterculus* interquartile range
Apple	3.6	6	7.0 a[2]	7	0 A	1
Peach	5.2	30	5.5 a	17	0 A	0
Nectarine	1.2	10	12.0 a	13	0 A	0
Mandarin	8	16	67.0 b	95	0 A	0
Orange	2.5	6	57.0 b	58	1 A	1

[1]The accumulated captures per season were calculated by adding captures from 1 Nov 2014 until 30 Jun 2015, and for the same period from spring 2015 until Jun 2016. [2]Identical letters in the columns indicate that there is no significant difference between the variables. Kruskal-Wallis *C. capitata*, $P = 0.0001$; *A. fraterculus*, $P = 0.02$; Conover, $P < 0.05$.

Table 4. Accumulated captures[1] of *Ceratitis capitata* and *Anastrepha fraterculus* by host species in Paysandú.

Species	Area (ha)	No. of traps × 2 seasons	*C. capitata* median	*C. capitata* interquartile range	*A. fraterculus* median	*A. fraterculus* interquartile range
Lemon	1.4	4	11.0 a[2]	11	20.5 AB	15
Grapefruit	1.3	4	22.0 ab	13	138.0 B	32
Orange	6.2	22	98.0 bc	1,013	13.0 A	30
Mandarin	2.2	16	197.5 c	525	73.0 B	136

[1]The accumulated captures per season were calculated by adding captures from 1 Sep 2014 until 30 Jun 2015, and for the same period from spring 2015 until Jun 2016. [2]Identical letters in the columns indicate that there is no significant difference between the variables. Kruskal-Wallis *C. capitata*, $P = 0.0001$; *A. fraterculus*, $P = 0.06$; Conover, $P < 0.05$.

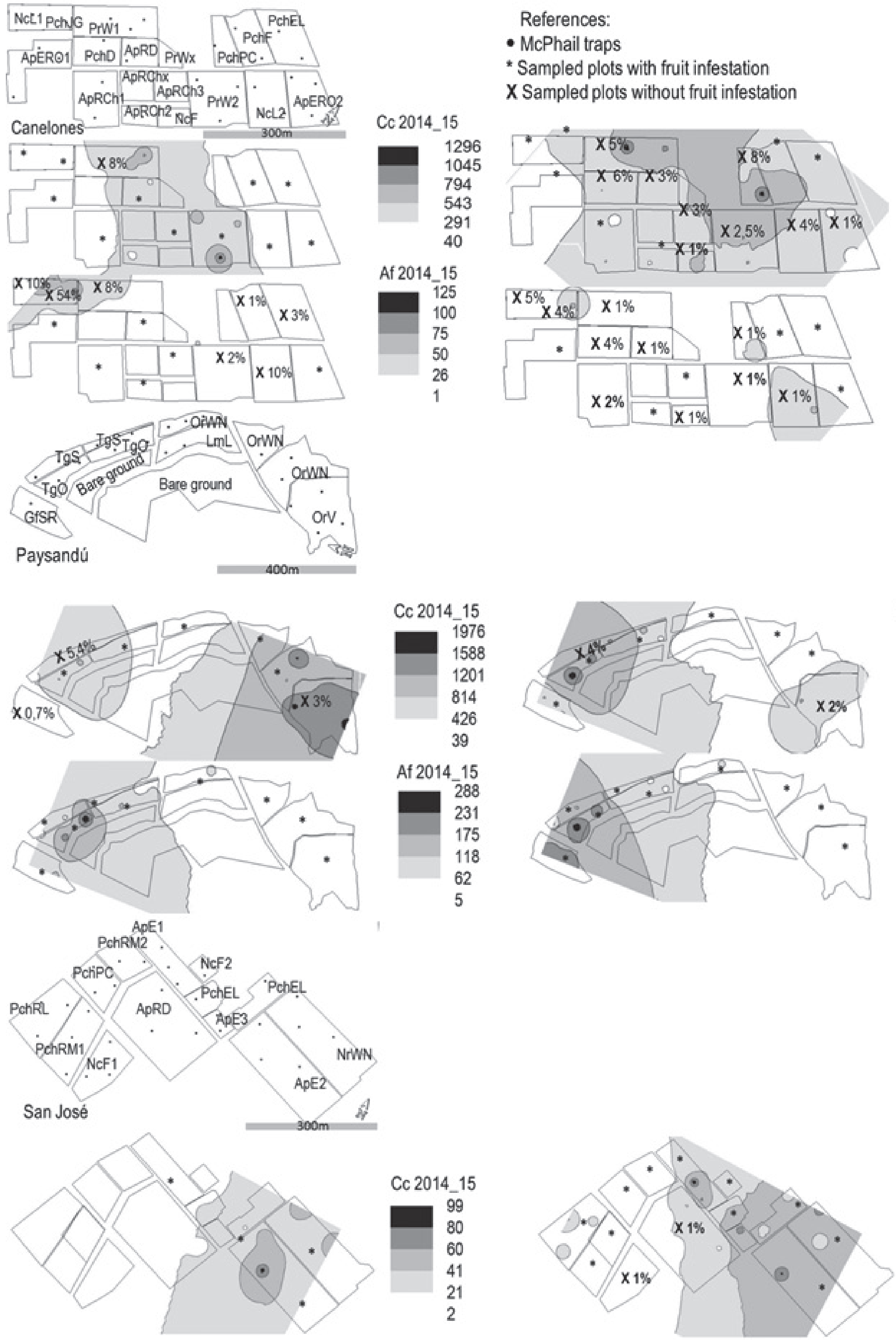

Fig. 2. Spatial distribution of accumulated captures and fruit infestation of *Ceratitis capitata* and *Anastrepha fraterculus* during the 2014–2015 and 2015–2016 seasons. Ap = Apple: ERO = Early Red One, RCh = Red Chief, RD = Red Delicious; Pch = Peach: JG = June Gold, EL = Elegant Lady, RM = Rey del Monte, PC = Pavía Canario, F = Forastero; Nc = Nectarine: L = Lara, F = Fantasía; Pr = Pear: W = William's; Mn = Mandarin: E = Elenadalle, O = Ortanique, S = Satsuma; Or = Orange: V = Valencia, WN = Washington Navel; Gf = Grapefruit: SR = Star Rubí. Cc = *C. capitata*, Af = *A. fraterculus*. The accumulated captures per season were calculated by adding captures from the date that traps were installed (1 Sep, 30 Oct, and 1 Nov 2014 in San José, Canelones, and Paysandú, respectively) until 30 Jun 2015, and for the same period from spring 2015 until Jun 2016.

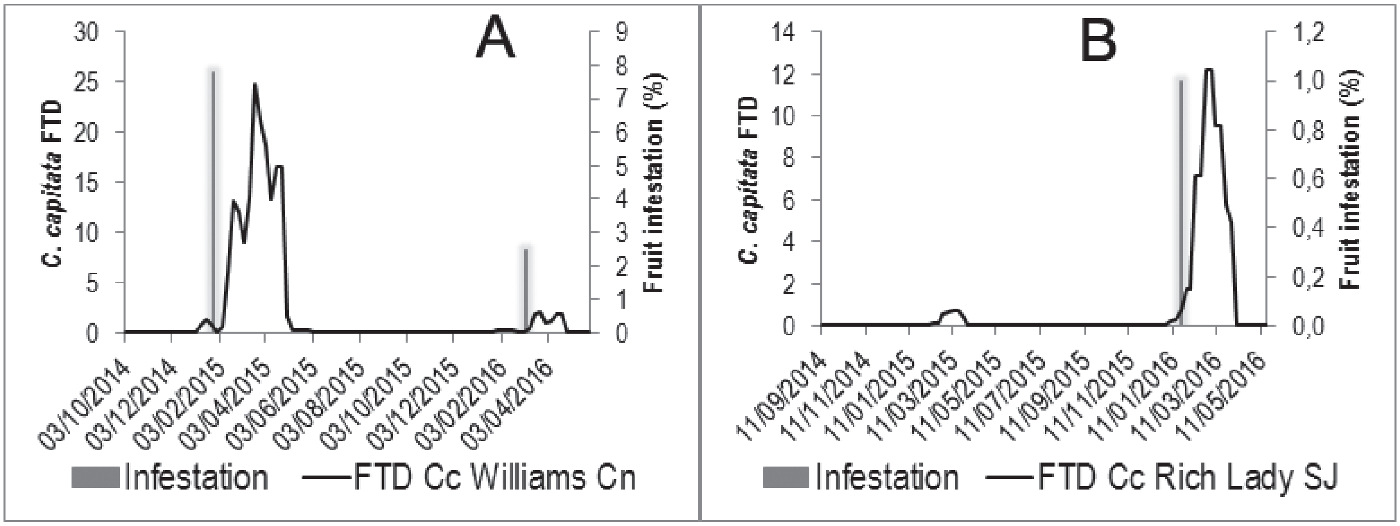

Fig. 3. Fruit infestation and population fluctuation of *Ceratitis capitata* registered in McPhail traps in (A) pears and (B) peaches. Cn = Canelones, SJ = San José; FTD = flies per trap per d; Cc = *Ceratitis capitata*.

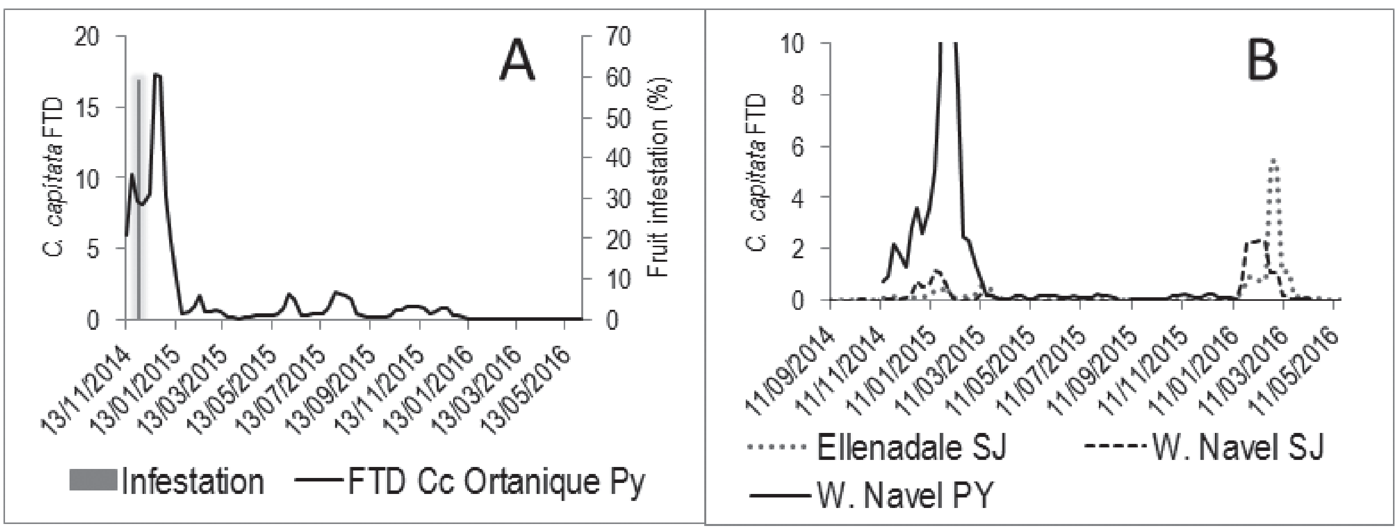

Fig. 4. Population fluctuation of *Ceratitis capitata* registered in McPhail traps in mandarins (A) with fruit infestation and (B) without fruit infestation. Py = Paysandú, SJ = San José, W = Washington; FTD: flies per trap per d; Cc = *Ceratitis capitata*.

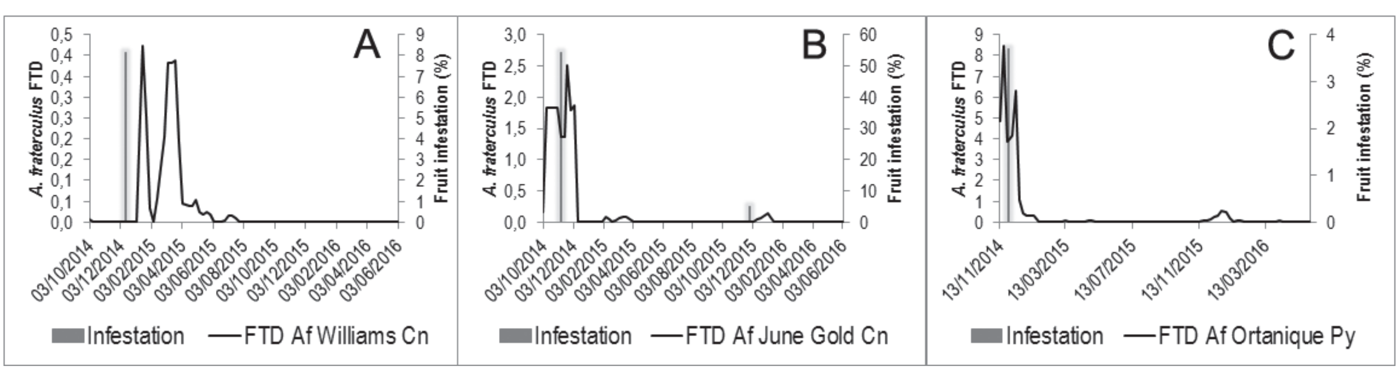

Fig. 5. Fruit infestation and population fluctuation of *Anastrepha fraterculus* in (A) pears, (B) peaches, and (C) mandarins. Cn = Canelones, Py = Paysandú; FTD = flies per trap per d; Af = *Anastrepha fraterculus*.

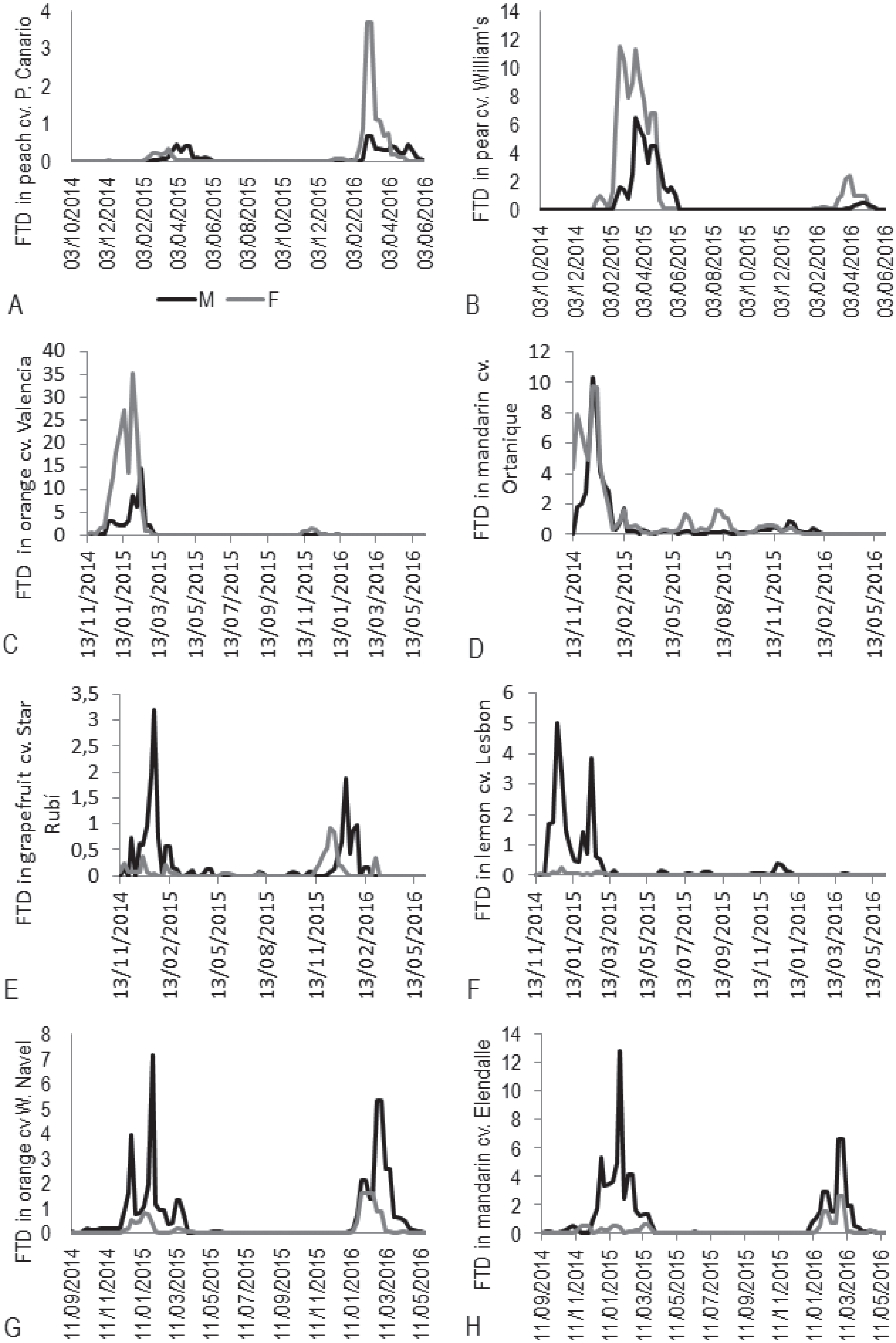

Fig. 6. Population fluctuation of *Ceratitis capitata* males (M) in Jackson traps (Cc) and females (H) in McPhail traps. A, B, C, D = cultivars where fruit infestation was recorded (A, B = Canelones; C, D = Paysandú); E, F, G, H = cultivars where no fruit infestation was recorded (E, F = Paysandú; G, H = San José).

RELATIONSHIP BETWEEN *ANASTREPHA FRATERCULUS* CAPTURES AND FRUIT INFESTATION IN DIFFERENT HOSTS

Anastrepha fraterculus populations exhibited greater variation over time and space; they almost were absent in San José, whereas adults were captured in traps but without fruit infestation in Paysandú, and the presence of adults and fruit infestation was observed in Canelones. Although there was a significant correlation between captures and fruit infestation, it was not very strong, and in the spatial distribution maps, a well-defined pattern was not observed. This weak relationship in Canelones could be due to females that were already mated coming from neighboring wild vegetation to oviposit on the crop. In Rio Grande do Sul, early peach cultivars are affected by *A. fraterculus* more so than mid- and late-cycle cultivars, and this is attributed to migration from other wild plants or citrus hosts (Branco et al. 2000). In apple orchards in southern Brazil, Kovaleski et al. (1997) suggest that *A. fraterculus* populations are not established in orchards but rather the infestation source is the native host of the surroundings, especially those that belong to the Myrtaceae family (Selivon 2000). This approach supports the hypothesis that in Canelones the shelterbelts composed of several wild species, some of them belonging to the Myrtaceae family, could serve as potential hosts. Besides, this farm is in the influence area of the Wetlands of Santa Lucía, which is part of the National System of Protected Areas (MITUR 2020), with abundance of native species that favor the maintenance of *A. fraterculus* in the area. On the other hand, in Paysandú the absence of fruit infestation could be associated with the absence of susceptible citrus fruit during the periods with the highest population of fruit flies. Some authors attribute the absence of damage in early harvest cultivars because there are no susceptible fruits at the time of highest incidence of flies (Branco et al. 2000).

RELATIONSHIPS BETWEEN *CERATITIS CAPITATA* CAPTURES AND FRUIT INFESTATION IN DIFFERENT HOSTS

In the case of *C. capitata*, the Pearson correlation coefficient showed a significant relationship between *C. capitata* captures in McPhail traps and fruit infestation. Comparing different cultivars, this relationship seemed stronger in cultivars harvested during spring, summer, and autumn, as is the case of deciduous fruit trees, but is less strong in those cultivars harvested in winter, such as some citrus cultivars, where captures but no fruit infestations were recorded. Despite being considered one of the main pests in citrus, some authors affirm that fruit flies are not perfectly adapted to development in these fruits. Among the most critical parameters that determine the difference in performance in different cultivars are the resistance of the skin and the presence of essential oils, which have lethal effects on neonatal larvae (Branco et al. 2000; Papachristos & Papadopoulus 2009). Dias et al. (2017) determined that *C. capitata* laid eggs deeper in orange and mandarin pulp compared to *A. fraterculus*, which they associate with greater survival by not exposing the eggs to the essential oil glands (Back & Pemberton 1915). Besides, in some cultivars, the presence of susceptible fruit occurs during the winter period only when the population decrease also could reduce the risk of infestation. Within the deciduous fruit trees group, pears were the host with the highest presence of *C. capitata* adults and fruit infestation. However, in the 2014–2015 season, when fly populations were higher, fruit injury was recorded only in 1 pear plot. An explanation is that the harvest in this plot was carried out a wk later than in the orchard where fruit infestation was not observed. Aluja and Mangan (2008) mention that there is an inverse relationship between the resistance of the fruit and its degree of maturity. The extra wk of exposure to fruit fly attack when the populations were increasing, and the fruit being susceptible, possibly was a determining factor in the infestation level. Something similar happened on the farm located in Canelones during the second study season. The fruit ripening in most cultivars occurred up to 20 d earlier than in the 2015–2016 season, and the peaches and nectarines were harvested when the fruits were still unripe. It is possible that reducing the exposure time of susceptible fruits favored the low infestation level despite the high captures that were recorded on the farm throughout the season. In the present research it was found that the populations of *C. capitata* in the deciduous fruit trees tend to increase in late summer and autumn, regardless of the harvest period, which suggests a marked seasonal influence.

Distribution of Males and Females of *Ceratitis capitata*

The low correlation between captures of *C. capitata* in Jackson traps and fruit infestation probably is because the presence of males in the orchard is not always directly related to the presence and oviposition of females, as observed in Ellendale and Washington Navel cultivars. The spatial and temporal variation of males and females in the orchards suggests that citrus trees would be suitable sites of refuge for adult males, whereas the proportion of females varies, probably depending on the susceptibility of the host. Sciarretta et al. (2018) observed that when fruit was available in several cultivars, males and females of *C. capitata* had a similar distribution, but when few late cultivars remained, the distribution of males and unfertilized females tended to diverge from that of fertilized females, adding males in nonfruiting cultivars.

According to these results, the captures of *C. capitata* and *A. fraterculus* in McPhail traps baited with torula and captures of *C. capitata* in Jackson traps baited with trimedlure are not always associated with fruit infestation; therefore, to base the management decisions only on the number of fruit flies collected in traps occasionally can lead to control failures. Early season fruit infestation could be a good measure of fly activity to complement trap captures to guide management decisions when the commercial value of the crop justifies it. Another aspect to consider is the large increase in captures observed post-harvest, so concentrating monitoring and control measures only on the commercial value of the crop in its susceptible state involves the risk of entry of these pests from these areas. When planning a monitoring and control strategy, including already harvested plots could help anticipate this risk and reduce damage.

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