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Relationship between fruit fly (Diptera: Tephritidae) infestation and the physicochemical changes in fresh fruits

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Infestation of fruit flies (Diptera: Tephritidae) causes physical and chemical changes in fresh fruit. Moreover, each species of fruit may react differently to the injuries caused by oviposition and larva feeding. In this study, we associated fruit fly infestation with physicochemical changes in five fruit species during six storage times. *Ceratitis capitata* (Wiedemann) infestation caused change in peel firmness (PEF), pulp firmness (PUF), pH, titratable acidity (TA) and total soluble solid (TSS) of star fruit (*Averrhoa carambola* L.). It led to changes in PEF, PUF, TA, TSS and weight loss (WL) of guava (*Psidium guajava* L.) and changes in PEF and TA of apple (*Malus domestica* Borkh). Infestation changed PEF, PUF, TA and WL in mango (*Mangifera indica* L.) and PEF, PUF, TA and TSS of tangerine (*Citrus reticulata* Blanco). *C. capitata* infestation caused significant physicochemical changes in fresh fruits. Our results demonstrated a marked loss of fresh fruit quality after four days of fruit fly infestation. This information can help assessment of fresh fruit quality for consumption and processing. We discuss how the relationship between fly/host fruit might influence physicochemical changes in fresh fruits and recommend applied studies to better understand these relationships.

Key words: *Ceratitis capitata*, fruit damage, quality assessment, postharvest fruit

INTRODUCTION

Fresh fruit have physical and chemical characteristics that best satisfy the sensorial expectations of the consumer. In addition, fresh fruit play an important role in the economy and human nutrition, mainly providing vitamins, fiber and energy (Altendorf, 2019). After harvesting, when the fruit are removed from the plant, the fruit undergo significant physiological changes that can compromise their sensorial quality for consumption and commercial sale (Ares et al., 2009).

The physicochemical characteristics of fresh fruit can be altered by internal and external factors. Internal factors involve changes in metabolic reactions and physiological systems (Chapman et al., 1991; Bashir and Abu-Goukh, 2003), while external factors refer to environmental conditions, such as temperature and relative humidity (Ueda et al., 2000; Plotto et al., 2017),

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diseases and insect attack (Aluja and Liedo, 1986; Umeh et al., 2004).

Infestation of fruit flies (Diptera: Tephritidae) is one of the factors that affects fruit health. Puncture and oviposition of fruit flies, as well as larvae feeding can lead to fruit drop (Keck, 1934; Umeh et al., 2004), accelerated ripening (Keck, 1934; Jayanthi et al., 2015), changes in fruit peel color (Jayanthi et al., 2015), changes in the nutritional composition of juices (Omoloye et al., 2016), pathogen proliferation in fruit peel (Selivon et al., 2002; Engelbrecht et al., 2004; Omoloye et al., 2016) and pulp deterioration (Zart et al., 2010; Jayanthi et al., 2015; Omoloye et al., 2016).

The injuries caused by infestation of fruit flies may impair fruit quality for consumption and commercial sale. However, due to the physicochemical differences of the fruit species (Gonçalves et al., 2012; Hafsi et al., 2016; Plotto et al., 2017) each host species may react differently to the injuries caused by oviposition and larval feeding. In this study, we associated infestation of fruit flies with physicochemical changes in five fruit species and evaluated these changes during the development of immature stages of insects in the laboratory. This information was used to evaluate the quality loss of fresh fruit for consumption and processing.

MATERIALS AND METHODS

Pre-test infestation

Insects

A colony of approximately 7,000 adults of *Ceratitis capitata* (Wiedemann) was developed by rearing them on an artificial diet (Raga et al., 1996). The adults were obtained from the Laboratory of Economic Entomology of the Advanced Research Centre in Plant Protection and Animal Health of the Biological Institute, in Campinas, São Paulo State, Brazil. Adults were kept in cages and fed with a normal diet and water (Raga et al., 2018). Females sexually mature at 8–10 days of age were used for the tests.

Fruit

Apple (*Malus domestica* Borkh, Rosaceae), guava (*Psidium guajava* L., Myrtaceae), mango (*Mangifera indica* L., Anacardiaceae), orange [*Citrus sinensis* (L.) Osbeck, Rutaceae], star fruit (*Averrhoa carambola* L., Oxalidaceae) and tangerine (*Citrus reticulata* Blanco, Rutaceae) were used. Guava and star fruit were collected directly from a fruit growing field (farm Maracujá, Campinas, SP, Brazil), while apple, mango, orange and tangerine fruit were purchased from a wholesale market (Food Supply Centre of Campinas, SP, Brazil). Fruit selection was based on *C. capitata* host preference (Raga et al., 2011) and on ranking of the most produced and commercialized fruit in the Brazilian market. Fruit with uniformity of maturity, weight, length and diameter were used for each species (Table 1).

Infestation

An infestation pre-test was performed to determine adequate exposure time of each fruit species to *C. capitata* infestation. This is because, in previous observations, fruits exposed to *C. capitata* infestation for 24 h or more resulted in infestation index greater than 100 puparia per fruit. This high index of infestation could compromise the study due to excessive stress, collapse and accelerated fruit rot. The relationship between the infestation level and acceleration of the maturation process has been described in another study (Díaz-Fleischer and Aluja, 2003).

Prior to infestation, the fruit were washed in sodium hypochlorite solution (0.5% v/v) for fungal and bacterial disinfection, rinsed with distilled water and dried naturally. For infestation, the fruit were individually arranged in 6-L glass cages with 9 cm at the top opening and 15 cm diameter at the bottom. A 500-mL glass jar was placed on the floor of each cage, upon which each piece of fruit was placed for infestation by ten mated females of *C. capitata* for periods of 3, 6, 12 and 24 h of exposure. The top opening of the cage was covered with a plastic cap with micro holes to allow air to pass through. One fruit per glass cage was considered a replica and we used 5 replicates for each fruit exposure time, totaling 20 replicates of each fruit species. The pre-test was performed in a room with conditions regulated to 25 ± 1ºC, 70 ± 10% relative humidity and no photoperiod.

Storage of fruit

After infestation, the fruit were individually packed in 1-L plastic pots, containing approximately 40 g of vermiculite at the base to allow pupation of *C. capitata*. The pots were covered with voile fabric fastened by a rubber band. The fruit were kept in a room at 25 ± 1°C, 75 ± 5% RH and 12 h of photoperiod. After 15 days, the vermiculite was sieved to count the puparia. The highest value of the infestation index based on number of puparia/fruit determined the ideal time of exposure of each fruit species for oviposition by *C. capitata*.

Experimental design

The experiment comprised a description of the physical-chemical changes in fruit infested by the *C. capitata* fruit fly. The methods of selection, infestation and storage of fruit were the same as those described in the pre-test. The times chosen for the infestation test were 6 h for star fruit, guava and apple and 12 h for mango and tangerine, based on observations of the pre-test. Orange was excluded from the present experiment due to failure of larval development in the variety ‘Pera’ even after three successive attempts of infestation.

Thirty-two fruits of each species at similar and uniform sizes and maturation (Table 1) were chosen. Twenty fruits of each species were submitted to infestation by *C. capitata* but only 12 of them (those having the most obvious signs of punctures) were selected for evaluation. The 12 unexposed fruits formed the control group (non-infested). The evaluation was conducted in six replicates, being a replica with two fruits of each species. The following variables were evaluated at 48 h intervals for 12 days: peel firmness, pulp firmness, pH, titratable acidity, total soluble solids and weight loss.

Initially, peel firmness, pulp firmness and weight loss were evaluated. Thereafter, the fruits were ground with the peel and pulp (for tangerine, only pulp was ground), and the substrate obtained was used to evaluate pH, titratable acidity and total soluble solids.

pH and titratable acidity

A calibrated pH meter (DM-20, brand Digimed) was used with a buffer solution at 20°C. For the tests, 10 g of substrate was separated into a 250-mL beaker, and 90 mL of distilled water was

Table 1. Characteristics of fruits (N = 20) used in *Ceratitis capitata* (Tephritidae) infestation pre-test and in the experiment involving analysis of physicochemical changes in infested fruits.

Fruit species	Variety	Length (cm)	Diameter (cm)	Weight (g)	Peel color
		Average (Range)			
Infestation pre-test					
Averrhoa carambola L.	Malasiana	11.6 (11.2-12.5)	6.6 (6.1-7.4)	120.6 (90-138)	Green
Citrus reticulata Blanco	Tangor Murcott	6.9 (6.5-7.2)	7.3 (7.0-7.7)	201.8 (170-252)	Yellow and green
Citrus sinensis (L.) Osbeck	Pera	7.1 (7.0-7.4)	7.3 (7.0-7.8)	175.9 (146-210)	Green and yellow
Malus domestica Borkh	Gala	6.9 (6.7-7.1)	7.4 (7.0-7.6)	133.1 (124-142)	Red and yellow
Mangifera indica L.	Tommy Atkins	12.0 (11.4-12.8)	9.1 (8.9-9.5)	548.7 (438-742)	Green
Psidium guajava L.	Tailandesa	7.5 (6.9-8.2)	7.3 (6.8-7.5)	191.1 (142-240)	Green
Infestation test					
Averrhoa carambola L.	Malasiana	10.6 (9.8-11.5)	6.1 (5.1-6.7)	107.3 (98-144)	Green
Citrus reticulata Blanco	Tangor Murcott	6.1 (5.9-6.4)	7.6 (7.4-8.1)	202.0 (180-230)	Yellow and green
Malus domestica Borkh	Gala	6.5 (5.9-7.5)	7.2 (6.9-7.7)	166.0 (150-182)	Red and yellow
Mangifera indica L.	Tommy Atkins	10.6 (10.1-11.6)	9.0 (8.6-9.4)	437.0 (390-490)	Green and red
Psidium guajava L.	Tailandesa	7.5 (7.0-8.3)	7.2 (6.9-7.9)	205.0 (174-232)	Green

added. The beaker was placed on an agitator, and the electrode was immersed into the substrate solution in the beaker for pH measurement. Thereafter, it was titrated with NaOH 0.09772 to reach a pH of 8.1–8.2. The titratable acidity was expressed as a percentage of citric acid.

Peel and pulp firmness

A texture analyser model TA-XT2i (Stable Micro Systems, Godalming, Surrey, England) was used with Texture Expert software for Windows system. Samples were evaluated by the drilling test using a 2-mm probe at a constant speed of 1 mm/s. Pre- and post-test speeds were 1 and 10 mm/s, respectively. The probe penetration distance was selected according to the fruit species analyzed; that is, 10 mm for star fruit, guava and apple and 15 mm for mango and tangerine. We performed ten perforations in each of 2 fruits per fruit species, totalling 20 holes per replica.

The results were expressed in terms of the maximum force (N) measured for peel rupture and pulp region penetration. We used the average force of peel rupture and pulp region penetration to represent the replica.

Total soluble solids

A digital refractometer (Reichert r2i300 of Ametek) was calibrated with distilled water at 20°C. For the analysis, a small amount of milled fruit substrate was used, and was wrapped in cotton and pressed until one or two drops fell into the refractometer prism to perform the reading.

Weight loss

Weight loss (WL) was assessed according to the calculation (Shahkoomahally et al., 2015):

$$\%WL = (W_0 - W_t) / W_0 \times 100$$

where W_0 = initial weight, and W_t = fruit weight after six storage times.

Statistical analysis

The physicochemical variables of infested and non-infested fruits were compared and the descriptive analysis was performed by infestation [infested fruit (yes) or non-infested fruit (no)], comparing values of the mean, standard deviation, minimum, maximum, median and quartiles for each fruit species. To compare the values of variables obtained for infestation (yes or no) and fruit storage time (2, 4, 6, 8, 10 and 12 days), the two-way analysis of variance (two-way ANOVA) was used with a test of the interaction effect between infestation and storage time, followed by the Tukey post-hoc test for multiple comparisons. The variables having non-normal distributions were transformed into ranks in the analyses.

Pearson's correlation was determined between peel firmness, pulp firmness, pH, total soluble solids, titratable acidity and weight loss with fruit storage time (2, 4, 6, 8, 10 and 12 days). The significance level adopted for the tests was 95% (Zhao et al., 2017). For all analyses, SAS System for Windows (Statistical Analysis System) software was used.

RESULTS

pH and titratable acidity

C. capitata infestation caused changes in pH only in star fruit (Table 2), increasing the values by 29 and 12% in relation to the control at 10 and 12 days after infestation (DAI), respectively. In mango and tangerine, the pH change occurred in the interaction of infestation and storage time. For guava, only storage time influenced the pH. In apple, the pH did not show interactions in any combination of variables.

Titratable acidity was altered by infestation in apple, guava, mango, star fruit and tangerine (Table 2). The

Table 2. Two-way ANOVA results for comparison of physicochemical parameters between fruit infested and non-infested and between infestation and storage time.

Fruit species	Quality requirements	Fruit infested vs. non-infested	Storage time	Infestation vs. storage time
Averrhoa carambola	pH	$F_{(1, 24)} = 32.95$; $P < 0.001$	$F_{(5, 24)} = 9.92$; $P < 0.001$	$F_{(5, 24)} = 8.95$; $P < 0.001$
	Peel firmness	$F_{(1, 228)} = 6.46$; $P = 0.012$	$F_{(5, 228)} = 74.79$; $P < 0.001$	$F_{(5, 228)} = 4.51$; $P < 0.001$
	Pulp firmness	$F_{(1, 228)} = 9.47$; $P = 0.002$	$F_{(5, 228)} = 57.35$; $P < 0.001$	$F_{(5, 228)} = 8.35$; $P < 0.001$
	Titratable acidity	$F_{(1, 24)} = 8.63$; $P = 0.007$	$F_{(5, 24)} = 39.77$; $P < 0.001$	$F_{(5, 24)} = 29.32$; $P < 0.001$
	Total soluble solid	$F_{(1, 24)} = 40.17$; $P < 0.001$	$F_{(5, 24)} = 55.30$; $P < 0.001$	$F_{(5, 24)} = 17.60$; $P < 0.001$
	Weight loss	$F_{(1, 12)} = 2.28$; $P = 0.157$	$F_{(5, 12)} = 16.02$; $P < 0.001$	$F_{(5, 12)} = 1.25$; $P = 0.346$
Citrus reticulata	pH	$F_{(1, 24)} = 0.00$; $P = 0.962$	$F_{(5, 24)} = 52.80$; $P < 0.001$	$F_{(5, 24)} = 5.13$; $P = 0.002$
	Peel firmness	$F_{(1, 228)} = 5.81$; $P = 0.017$	$F_{(5, 228)} = 16.87$; $P < 0.001$	$F_{(5, 228)} = 5.41$; $P < 0.001$
	Pulp firmness	$F_{(1, 228)} = 16.14$; $P < 0.001$	$F_{(5, 228)} = 4.31$; $P < 0.001$	$F_{(5, 228)} = 4.67$; $P < 0.001$
	Titratable acidity	$F_{(1, 24)} = 4.70$; $P = 0.040$	$F_{(5, 24)} = 63.28$; $P < 0.001$	$F_{(5, 24)} = 26.47$; $P < 0.001$
	Total soluble solid	$F_{(1, 24)} = 8.11$; $P = 0.009$	$F_{(5, 24)} = 40.39$; $P < 0.001$	$F_{(5, 24)} = 27.63$; $P < 0.001$
	Weight loss	$F_{(1, 12)} = 0.55$; $P = 0.474$	$F_{(5, 12)} = 33.86$; $P < 0.001$	$F_{(5, 12)} = 0.72$; $P = 0.619$
Malus domestica	pH	$F_{(1, 24)} = 1.10$; $P = 0.306$	$F_{(5, 24)} = 2.77$; $P = 0.051$	$F_{(5, 24)} = 0.74$; $P = 0.600$
	Peel firmness	$F_{(1, 228)} = 7.87$; $P = 0.006$	$F_{(5, 228)} = 7.32$; $P < 0.001$	$F_{(5, 228)} = 4.18$; $P = 0.001$
	Pulp firmness	$F_{(1, 228)} = 1.45$; $P = 0.231$	$F_{(5, 228)} = 7.80$; $P < 0.001$	$F_{(5, 228)} = 7.26$; $P < 0.001$
	Titratable acidity	$F_{(1, 24)} = 5.79$; $P = 0.024$	$F_{(5, 24)} = 21.37$; $P < 0.001$	$F_{(5, 24)} = 8.04$; $P < 0.001$
	Total soluble solid	$F_{(1, 24)} = 0.63$; $P = 0.433$	$F_{(5, 24)} = 29.37$; $P < 0.001$	$F_{(5, 24)} = 5.49$; $P = 0.002$
	Weight loss	$F_{(1, 12)} = 2.82$; $P = 0.119$	$F_{(5, 12)} = 16.24$; $P < 0.001$	$F_{(5, 12)} = 5.42$; $P = 0.008$
Mangifera indica	pH	$F_{(1, 24)} = 1.71$; $P = 0.204$	$F_{(5, 24)} = 22.49$; $P < 0.001$	$F_{(5, 24)} = 10.29$; $P < 0.001$
	Peel firmness	$F_{(1, 228)} = 227.13$; $P < 0.001$	$F_{(5, 228)} = 138.39$; $P < 0.001$	$F_{(5, 228)} = 15.84$; $P < 0.001$
	Pulp firmness	$F_{(1, 228)} = 128.20$; $P < 0.001$	$F_{(5, 228)} = 53.06$; $P < 0.001$	$F_{(5, 228)} = 5.26$; $P < 0.001$
	Titratable acidity	$F_{(1, 24)} = 219.86$; $P < 0.001$	$F_{(5, 24)} = 200.86$; $P < 0.001$	$F_{(5, 24)} = 101.74$; $P < 0.001$
	Total soluble solid	$F_{(1, 24)} = 0.53$; $P = 0.476$	$F_{(5, 24)} = 46.34$; $P < 0.001$	$F_{(5, 24)} = 22.93$; $P < 0.001$
	Weight loss	$F_{(1, 12)} = 28.58$; $P < 0.001$	$F_{(5, 12)} = 56.12$; $P < 0.001$	$F_{(5, 12)} = 1.36$; $P = 0.305$
Psidium guajava	pH	$F_{(1, 24)} = 0.33$; $P = 0.572$	$F_{(5, 24)} = 3.06$; $P = 0.028$	$F_{(5, 24)} = 1.50$; $P = 0.227$
	Peel firmness	$F_{(1, 228)} = 44.12$; $P < 0.001$	$F_{(5, 228)} = 148.66$; $P < 0.001$	$F_{(5, 228)} = 9.05$; $P < 0.001$
	Pulp firmness	$F_{(1, 228)} = 63.41$; $P < 0.001$	$F_{(5, 228)} = 65.29$; $P < 0.001$	$F_{(5, 228)} = 17.75$; $P < 0.001$
	Titratable acidity	$F_{(1, 24)} = 23.83$; $P < 0.001$	$F_{(5, 24)} = 18.19$; $P < 0.001$	$F_{(5, 24)} = 27.92$; $P < 0.001$
	Total soluble solid	$F_{(1, 24)} = 16.33$; $P < 0.001$	$F_{(5, 24)} = 39.07$; $P < 0.001$	$F_{(5, 24)} = 14.34$; $P < 0.001$
	Weight loss	$F_{(1, 12)} = 9.09$; $P = 0.011$	$F_{(5, 12)} = 119.73$; $P < 0.001$	$F_{(5, 12)} = 1.40$; $P = 0.292$

acidity decreased by 26% in star fruit, 22% in guava and 8% tangerine at 10 DAI, and 13% in apple at 8 DAI, besides increasing by 50% in mango at 10 DAI.

The behaviour of pH and acidity was different in each fruit species, following a trend of increase, decrease or strong variations. However, for the most fruit, the behaviour of pH (Figure 1) and titratable acidity (Figure 2) varied between infested and non-infested fruit. The pH of infested guava, star fruit, and tangerine increased proportionally during the storage time, whereas the titratable acidity decreased in infested apple, guava, mango, and star fruit over the time (Table 3).

Peel firmness and pulp firmness

Peel firmness of apple, guava, mango, star fruit and tangerine were altered due to *C. capitata* infestation (Table 2). Peel firmness decreased by 36, 52, 18, 46 and 20% at 10 DAI for star fruit, guava, apple, mango and tangerine, respectively.

Pulp firmness of guava, mango, star fruit and tangerine were also altered due to infestation (Table 2), whereas in apple, pulp firmness was not changed, although it demonstrated an interaction between infestation and storage time. Reduction of pulp firmness was 46% in star

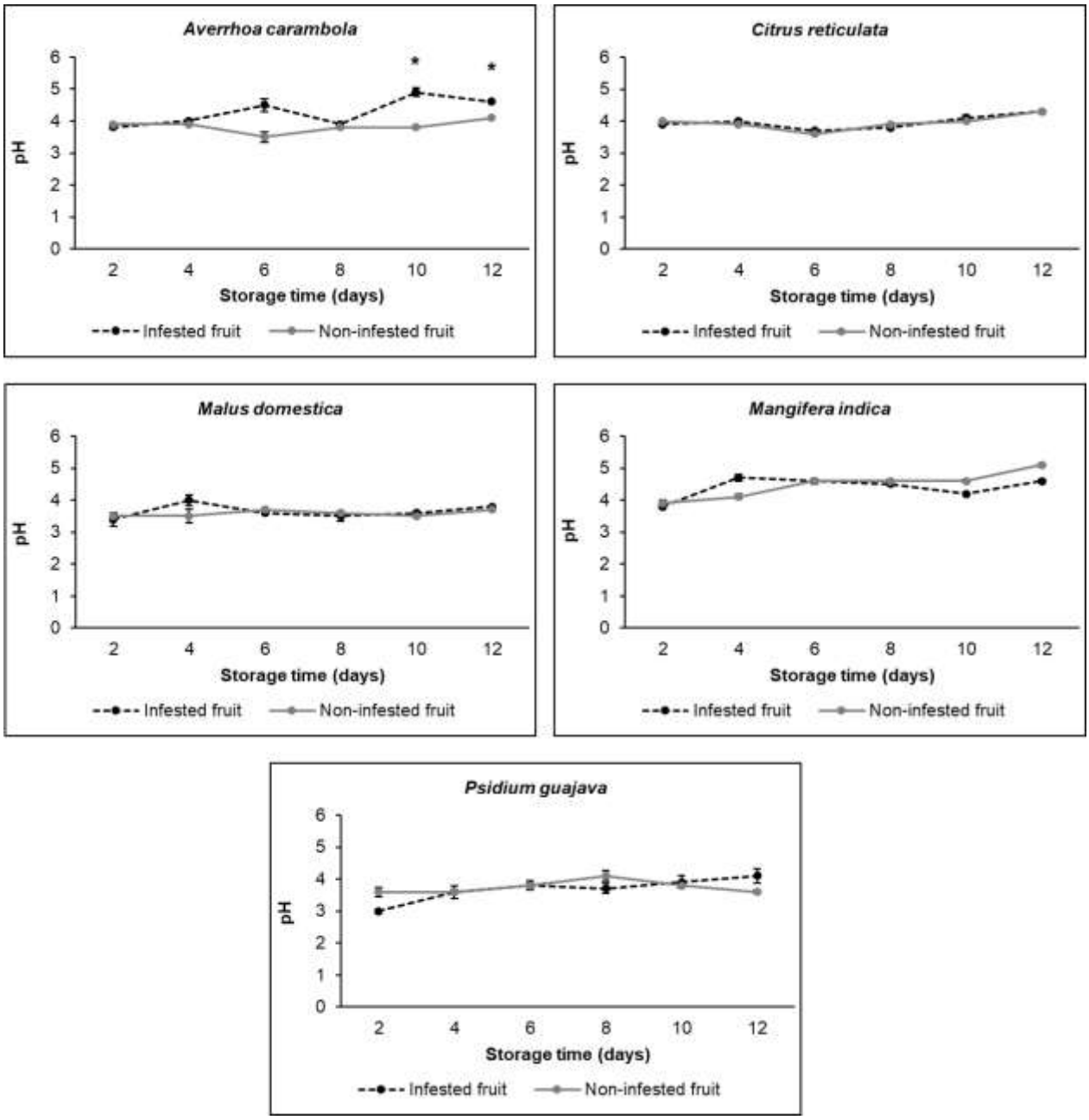

Figure 1. Mean values (± standard error) pH of fruit infested and non-infested by *Ceratitis capitata* (Tephritidae) during 12 days of storage. *Represents the storage time when infested and non-infested fruits presented statistical difference by Tukey test at 5%.

fruit, 5% in guava and 54% in mango at 10 DAI and 61% in tangerine at 12 DAI.

The behaviour of peel firmness (Figure 3) and pulp firmness (Figure 4) followed a trend of decreasing with storage time for guava, mango, star fruit and tangerine, but for apple this behaviour was observed only with respect to peel firmness (Table 3). Although peel and pulp firmness of infested and non-infested fruit followed a downward trend with storage time, firmness of infested fruit was lower in comparison with non-infested fruit.

Total soluble solids

Total soluble solids in guava, star fruit and tangerine were altered due to *C. capitata* infestation (Table 2). Total soluble solids decreased by 30% in star fruit and 11% in guava at 10 DAI and by 8% in tangerine at 12 DAI. For

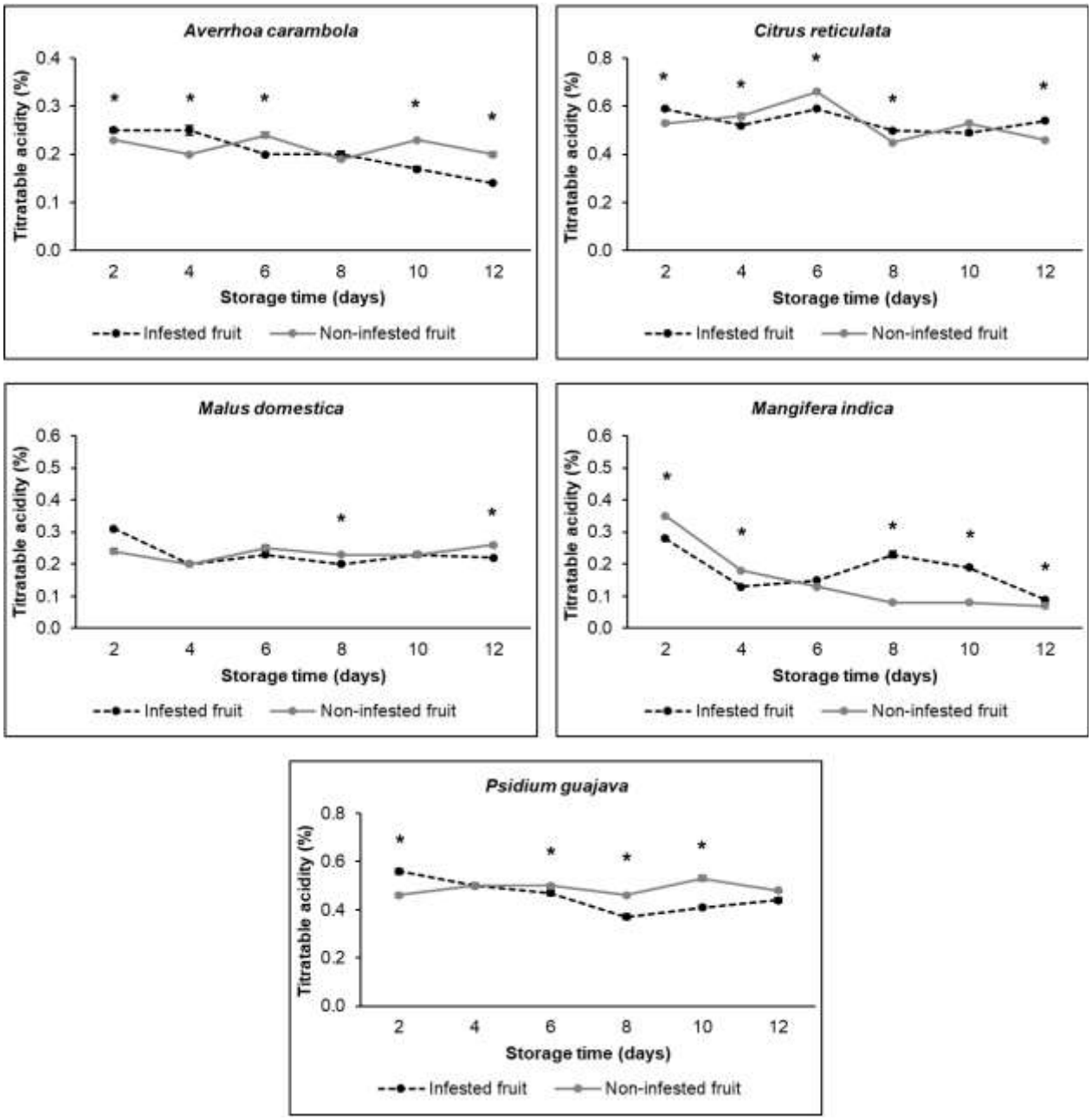

Figure 2. Mean values (± standard error) titratable acidity of fruit infested and non-infested by *Ceratitis capitata* (Tephritidae) during 12 days of storage. *Represents the storage time when infested and non-infested fruits presented statistical difference by Tukey test at 5%.

apple and mango, there was an interaction between infestation and storage time.

The behaviour of the total soluble solids was different for each fruit species, following a downward trend for guava, mango and star fruit (Table 3), while for apple and tangerine there was no increasing or decreasing trend, but instead variations among the samples (Figure 5). However, the total soluble solids of infested fruit had a different behaviour from that of non-infested fruit.

Weight loss

C. capitata infestation caused changes in weight loss in guava and mango (Table 2). Weight loss reached 40 and 45% at 8 DAI and 36 and 40% at 10 DAI for guava and mango, respectively. In star fruit and tangerine, only storage time influenced weight loss, regardless of infestation. In apple, there was an interaction between infestation and storage time.

Table 3. Pearson's correlation results between storage time and physicochemical parameters of fruits infested and non-infested by *Ceratitis capitata* (Tephritidae).

Dependent variable	Fruit infested (IN) or non-infested (NI)	*Averrhoa carambola*		*Citrus reticulata*		*Malus domestica*		*Mangifera indica*		*Psidium guajava*	
		r	*p*-value	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value
pH	IN	0.7373	0.0005	0.5849	0.0108	0.0276	0.9133	0.3845	0.1151	0.7568	0.0003
	NI	0.3306	0.1802	0.4339	0.0720	0.1107	0.6616	0.9203	< 0.0001	0.1479	0.5578
Peel firmness	IN	-0.7267	< 0.0001	-0.4485	< 0.0001	-0.2515	0.0056	-0.7381	< 0.0001	-0.7547	< 0.0001
	NI	-0.7381	< 0.0001	-0.1571	0.0865	0.0095	0.9177	-0.6654	< 0.0001	-0.7852	< 0.0001
Pulp firmness	IN	-0.6556	< 0.0001	-0.1655	0.0708	-0.0838	0.3625	-0.4942	< 0.0001	-0.6133	< 0.0001
	NI	-0.5541	< 0.0001	0.1774	0.0525	-0.3374	0.0002	-0.5585	< 0.0001	-0.7580	< 0.0001
Titratable acidity	IN	-0.9442	< 0.0001	-0.4491	0.0615	-0.5339	0.0225	-0.4968	0.0359	-0.6805	0.0019
	NI	-0.3084	0.2130	-0.4408	0.0671	0.4151	0.0867	-0.8698	< 0.0001	0.2414	0.3345
Total soluble solids	IN	-0.5979	0.0088	-0.2631	0.2913	0.1282	0.6121	-0.7417	0.0004	-0.4755	0.0461
	NI	-0.6150	0.0066	0.2378	0.3420	0.3674	0.1336	-0.2610	0.2955	-0.1635	0.5167
Weight loss	IN	0.8160	0.0012	0.9267	< 0.0001	0.8039	0.0016	0.9313	< 0.0001	0.9424	< 0.0001
	NI	0.8945	< 0.0001	0.9588	< 0.0001	0.7833	0.0026	0.9833	< 0.0001	0.9458	< 0.0001

In apple, guava, mango, star fruit and tangerine, weight loss presented an upward trend in relation to the storage time (Table 3). In infested fruit, weight loss was higher in relation to non-infested fruit (Figure 6). The highest percentages of weight loss were observed from the 6th day of storage onward, when the infested fruit showed 1st instar larvae of *C. capitata*.

DISCUSSION

C. capitata infestation changed the physicochemical composition of apple, guava, mango, star fruit and tangerine. However, each fruit species presented different physicochemical changes and with different intensities between them. It is likely that the physical and chemical differences of the fruit species tested (Plotto et al., 2017), as well as, the interrelationship of *C. capitata* with host fruits may partially explain how each fruit exhibited distinct physicochemical changes during storage time.

The trophic fly/host fruit relationship may also be involved in the different responses of each fruit species because the nutritional quality of fruit for larval development is a factor that determines preference for hosts in polyphagous insects (Thompson, 1988; Danks, 2007), such as *C. capitata* (Liquido et al., 1990). The nutritional quality of fruit for feeding *C. capitata* larvae (Costa et al., 2011; Hafsi et al., 2016) may explain the susceptibility to physicochemical changes in guava, mango, star fruit and tangerine (Raga et al., 2011) and non-susceptibility of apple, which is not considered an appropriate feeding substrate for *C. capitata* larvae (Joachim-Bravo et al., 2001; Follett et al., 2019).

We observed that the behaviour of physicochemical changes caused by *C. capitata* infestation during storage was different in each fruit species. However, this behaviour was directly proportional to the development of immature stages of the fly; that is, small changes when the insect was at the egg stage, until 4 DAI, and significant changes when the larvae began to feed at 4 DAI. The physicochemical changes observed in the first evaluations, until 4 DAI, were caused by puncture and oviposition. When the female makes a puncture, a small opening occurs in the fruit peel. This opening may allow the release of volatiles and consequently promote enzymatic reactions that alter the fruit chemical composition (Plotto et al., 2017). Eggs deposited inside the fruit can cause cell stress, resulting in unexpected metabolic reactions (Omoloye et al., 2016). In addition, at oviposition, females release symbiotic bacteria (Selivon et al., 2002), which help the larvae feed and establish an environment conducive to their development (Díaz-Fleischer and Aluja, 2003). All these phenomena caused by puncture and oviposition of fruit flies are responsible for the first physicochemical changes in infested fruit.

The feeding of larvae, after 4 DAI, caused significant physicochemical changes. In a study on oranges infested by fruit flies in the field, the most significant damage to the enzymatic and metabolic structure of the fruit was also observed from larval feeding (Omoloye et al., 2016). In this study, physical changes caused by larval feeding significantly reduced firmness and accelerated the weight loss process in the fruit. Fruit fly infestation promotes premature fruit maturation (Keck, 1934; Jayanthi et al., 2015), and because the maturation level is directly related to fruit firmness (Messina and Jones, 1990; Plotto et al., 2017), changes caused by larval feeding that

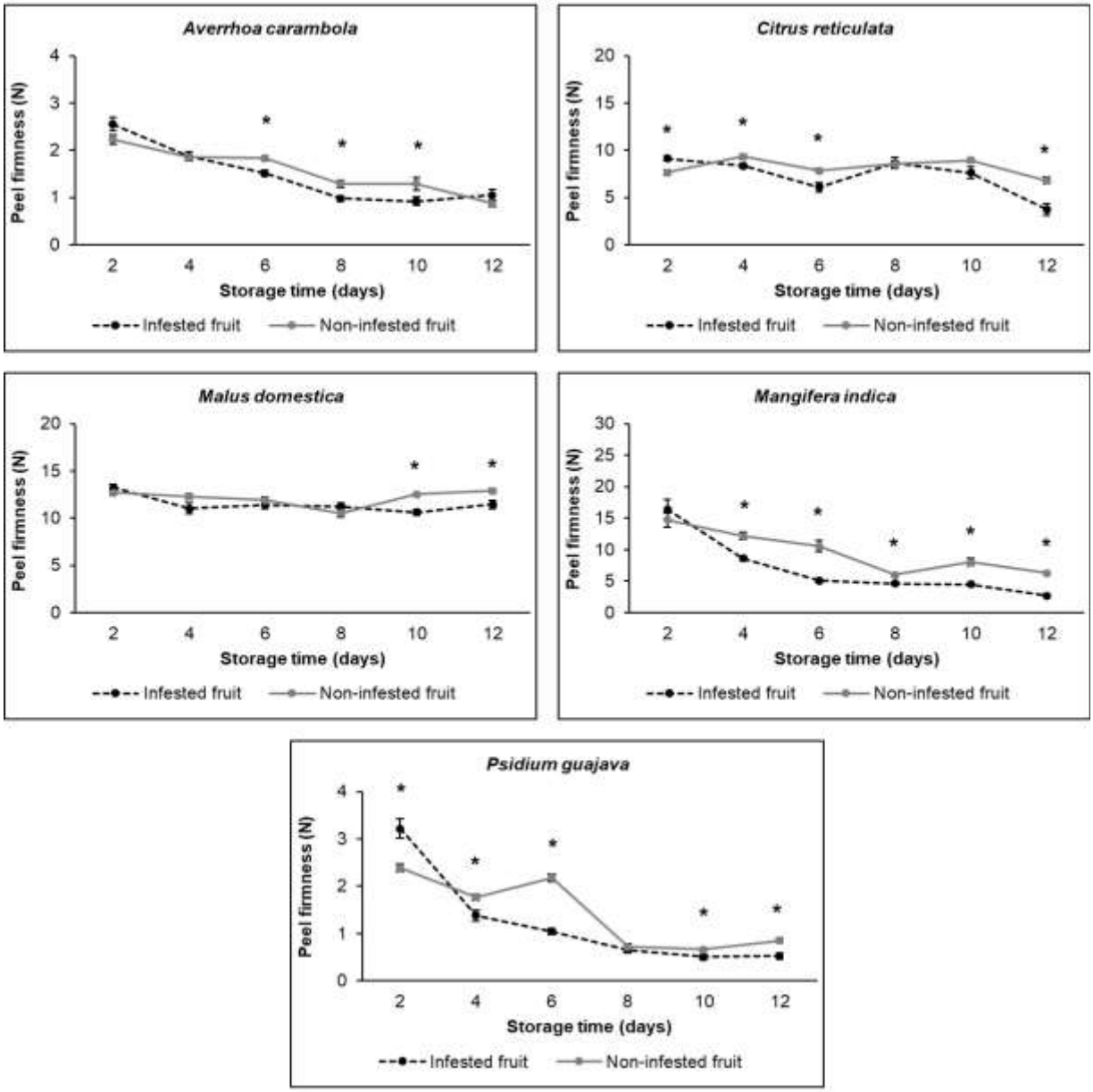

Figure 3. Mean values (± standard error) peel firmness of fruit infested and non-infested by *Ceratitis capitata* (Tephritidae) during 12 days of storage. *Represents the storage time when infested and non-infested fruits presented statistical difference by Tukey test at 5%.

promote premature maturation can also influence peel and pulp firmness of the fruit as observed in this study. Fruit weight loss may be related to reduced dry matter content in fruit and increased fluid production due to cell stress (Messina and Jones, 1990; Omoloye et al., 2016). Cell stress is attributed to larval feeding as well as digestive activities of bacteria associated with fruit fly infestation (Omoloye et al., 2016).

Changes in titratable acidity, pH and total soluble solids observed mainly in guava, mango and star fruit may also be related to cell stress caused by larval feeding and extracellular digestive activities of bacteria that degrade nutritional components of fruit (Omoloye et al., 2016). This was observed mainly from the 4th DAI, when the larvae began to feed, suggesting that puncture and oviposition of fruit flies do not alter the acidity, pH and total soluble solids of fruit.

Feeding of the *C. capitata* larvae reduced fruit quality for fresh consumption and caused processing limitations. Losses for fresh consumption are associated with firmness reduction and accelerated maturation (Keck, 1934; Jayanthi et al., 2015); consequently, reduction of

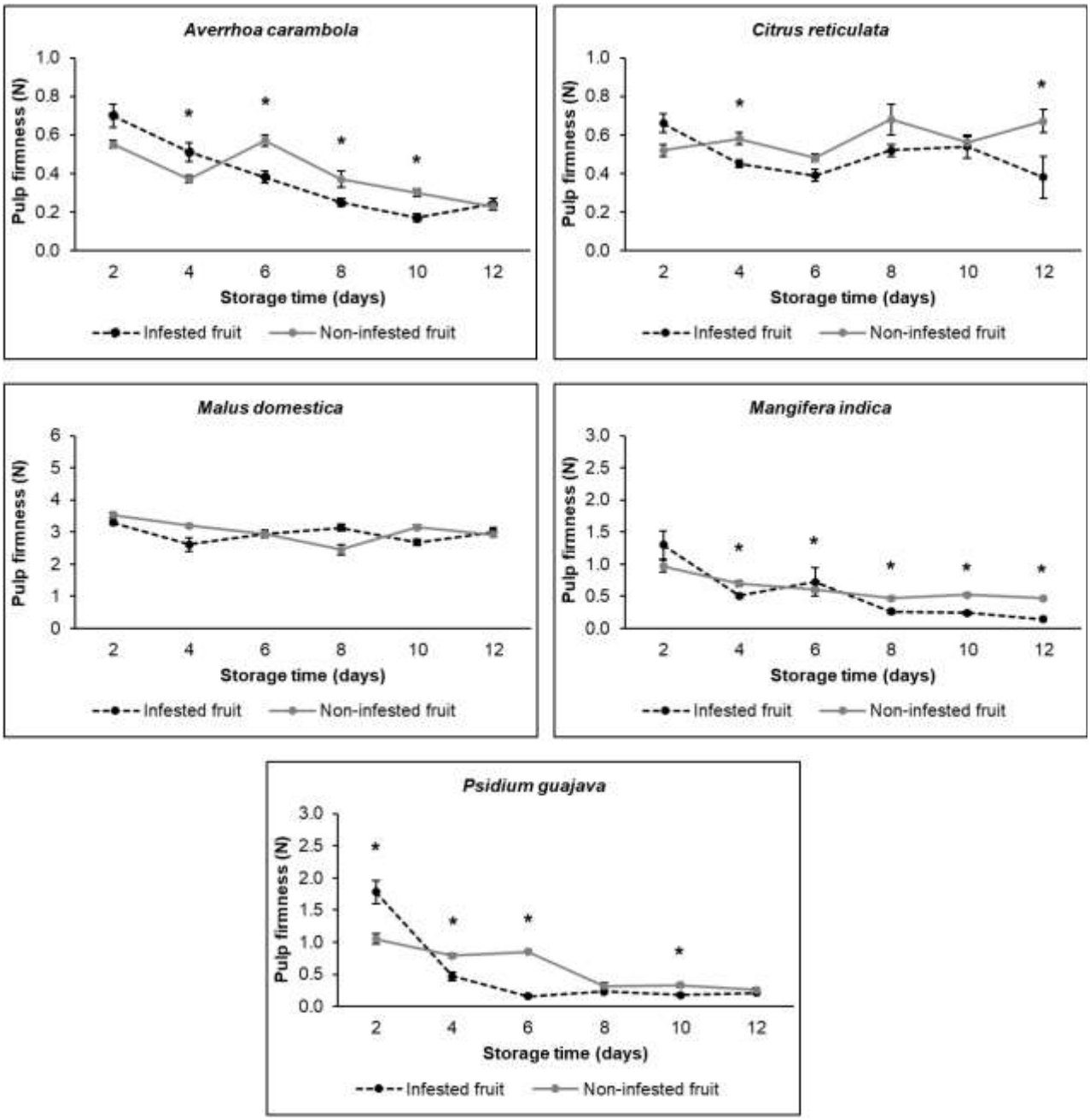

Figure 4. Mean values (± standard error) pulp firmness of fruit infested and non-infested by *Ceratitis capitata* (Tephritidae) during 12 days of storage. *Represents the storage time when infested and non-infested fruits presented statistical difference by Tukey test at 5%.

shelf life and changes in fruit flavour result, because infestation affects the ratio sweetness/acid (total soluble solids per titratable acidity) in addition to conferring a bitter taste to citrus juice (Omoloye et al., 2016). Losses in processing are associated with proliferation of microorganisms in the fruit peel and pulp. Moreover, chemical changes caused by *C. capitata* infestation compromised the processing of mango and star fruit to pulp, preserves, and sweets because the pH of these fruit does not comply with processing requirements and must be submitted to pasteurization treatment for preservation (Ministério da Agricultura Pecuária e Abastecimento, 2000, 2002).

Conclusion

The infestation of medfly *C. capitata* causes physical and

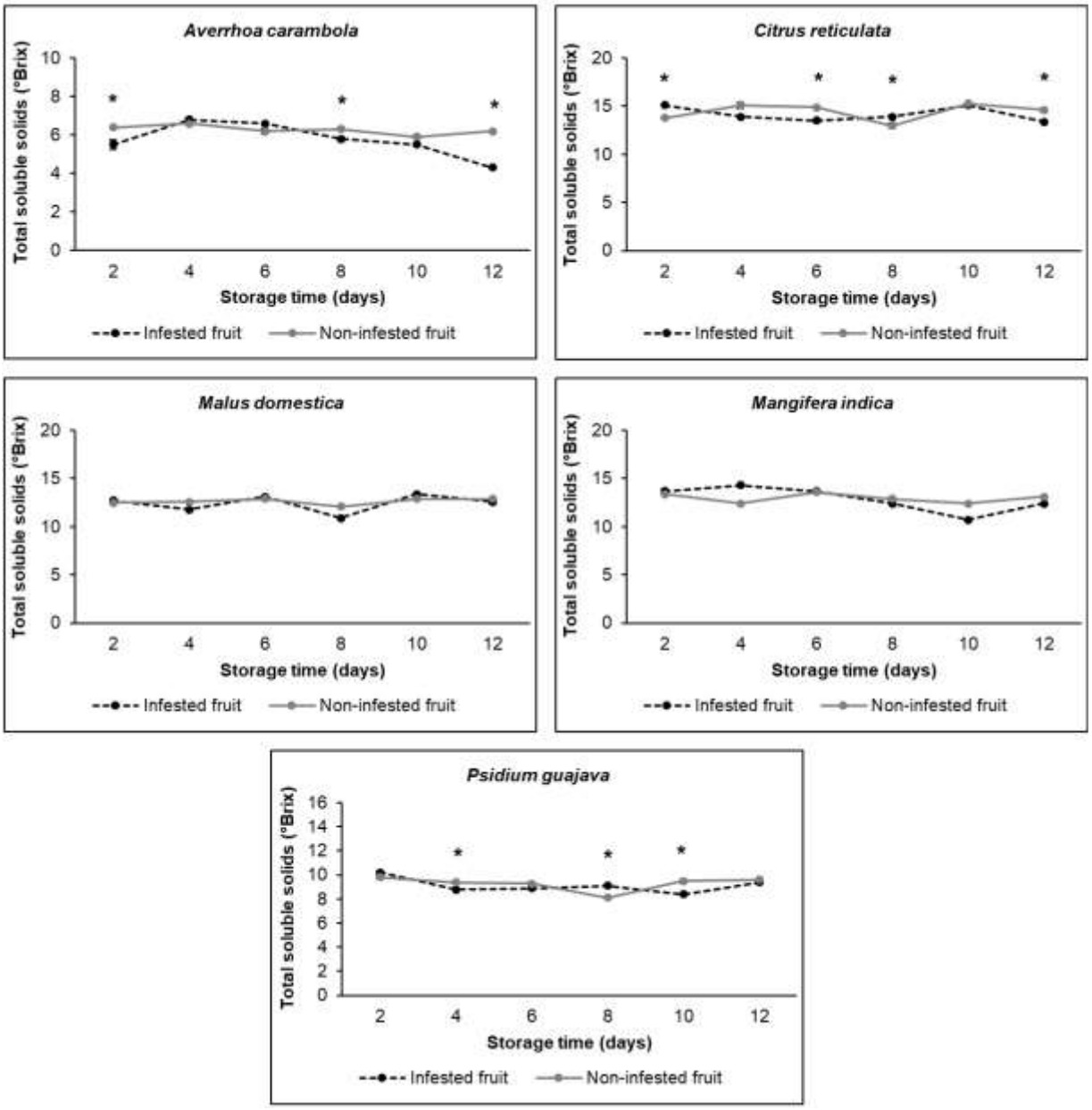

Figure 5. Mean values (± standard error) total soluble solids of fruit infested and non-infested by *Ceratitis capitata* (Tephritidae) during 12 days of storage. *Represents the storage time when infested and non-infested fruits presented statistical difference by Tukey test at 5%.

chemical changes in fresh fruit. All species of fruit undergo physicochemical changes caused by infestation of fruit flies. These changes considerably hamper the quality of fresh fruit for consumption and processing. Each fruit species presents distinct changes in peel firmness, pulp firmness, pH, titratable acidity, total soluble solids and weight loss as a specific response to stress caused by puncture, oviposition and feeding of *C. capitata* larvae. The fruits that suffered the most physicochemical changes were those with soft peel (< 4 N) and ratio total soluble solids/titratable acidity between 20 and 30, such as *A. carambola* and *P. guajava*. This can be explained by the intimate fly/host fruit relationship (Costa et al., 2011; Oliveira et al., 2014; Ruiz et al., 2015). Soft-skinned fruits allow for easy penetration of the aculeus, and fruits that provide a good balance of sweet/acid enhance larval development. *A. carambola*, *C. reticulata*, *M. indica* and *P. guajava* are more susceptible than *M. domestica* to the physicochemical changes caused by the infestation of fruit flies, most likely due to preference and adaptation of polyphagous insects to different larval feeding substrates (Thompson, 1988;

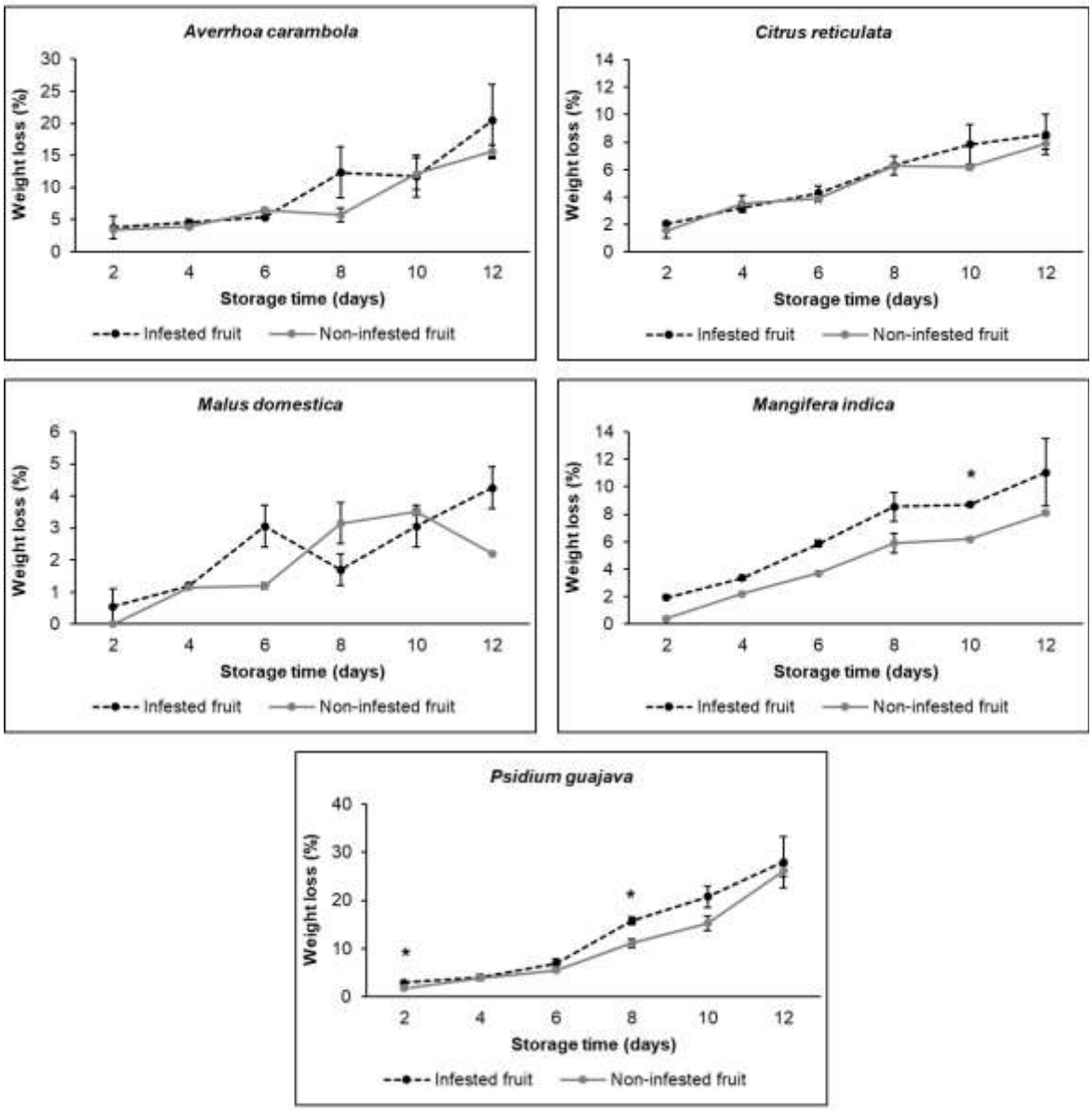

Figure 6. Mean values (± standard error) weight loss of fruit infested and non-infested by *Ceratitis capitata* (Tephritidae) during 12 days of storage. *Represents the storage time when infested and non-infested fruits presented statistical difference by Tukey test at 5%.

Danks, 2007). Thus, the preference of larval development substrate and diversity in the physicochemical composition of each fruit species probably influenced fruit status as susceptible or tolerant to changes caused by fruit fly infestation. However, basic studies should be developed to explain how host preference may be associated with the favorable substrate for fruit fly development and its physicochemical changes in fruits.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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