RESEARCH ARTICLE

Effect of the type of citrus fruit on the biological parameters of *Panonychus citri* (Acari: Tetranychidae) under laboratory conditions

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ABSTRACT

The citrus red mite, *Panonychus citri* (McGregor, 1916), is considered a very important pest in most citrus-growing countries. The developmental periods, reproduction rates, and population growth parameters of *P. citri* were evaluated using the fruit peel under experimental conditions (25 ± 1 °C, 50 ± 5% RH and 14:10 h photoperiod) on five *Citrus* species: Mexican lime (*C. ×aurantiifolia* (Christm.) Swingle), grapefruit (*C. ×paradisi* Macfad.), sweet orange (*C. ×sinensis* (L.) Osbeck), mandarin (*C. reticulata* Blanco), and tangelo fruit (*C. ×tangelo* J.W. Ingram & H.E. Moore). The developmental period of the immature stages of *P. citri* averaged 26.64, 25.93 and 25.75 d for sweet orange, mandarin, and tangelo fruit, respectively. The adult stage was not achieved in Mexican lime and grapefruit. Immature survival was less than 50% in mandarin and tangelo fruit, in contrast, in sweet orange it was 57%. On average, oviposition was 3.55, 4.95 and 5.00 eggs female^{-1}, on sweet orange, mandarin, and tangelo fruit, respectively. The intrinsic natural growth rate (r_m), net reproduction rate (R_0), generation time (T), and finite growth rate (λ) of *P. citri* showed significant differences among the tested species ($p < 0.05$). The r_m and R_0 values were 0.005 and 1.209 for sweet orange, 0.026 and 2.474 for mandarin and 0.020 and 2.000 for tangelo fruit. The results indicated that mandarin was the most suitable species for the *P. citri* population growth, whereas sweet orange was less suitable to proliferate. These differences are important in the integrated management of *P. citri* on citrus.

Key words: *Citrus ×aurantiifolia*, *Citrus ×paradisi*, *Citrus reticulata*, *Citrus ×sinensis*, *Citrus ×tangelo* fruit peel.

INTRODUCTION

The citrus red mite *Panonychus citri* (McGregor, 1916) is a very important pest mite due to its wide geographic distribution, biotic potential, high levels of damage, and a large number of host citrus plants (Pan et al., 2006; Faez et al., 2018; Korhayli et al., 2019; Tello et al., 2020). *Panonychus citri* has shown different population parameters when it has developed on different species of citrus trees (Lei et al., 2004; Kasap, 2009; Zanardi et al., 2015; Shirinbeik et al., 2022). It feeds on more than 112 different plant species (Ding et al., 2013). At high levels of infestation, defoliation, twig death, fruit drop, and negative effects on the quantity and quality of production can occur (Jeppson et al., 1975; Kasap, 2009; Tello et al., 2013; Shen et al., 2016).

In Chile, it is distributed from the Arica and Parinacota Region to La Araucanía Region (Klein Koch and Waterhouse, 2000). This pest is considered of primary economic importance, causing direct damage to citrus production (Vargas and Rodríguez, 2008). These damages reduce the photosynthetic capacity of leaves (Pan et al., 2006). The most important damage occurs on the fruits, which acquire a pale yellow-gray hue, which reduces their commercial quality, changes in sugar content, loss of flavor, and discards of damaged fruits (Ding et al., 2013).

Citrus fruits have a characteristic fragrance due, partially, to the presence of flavonoids and limonoids in the exocarp (Manthey, 2004). The GC-MS analyses showed that the orange peel oil extract is mainly composed of terpene hydrocarbons and oxygenated nonvolatile compounds (Chede, 2013). Cholke et al. (2017) described the presence of 15 compounds in the oil of orange peel, limonene being the compound with the highest

concentration (65%) in the extracted oil. According to Dugo et al. (2011), citrus species peels normally contain more than 70% limonene. Limonene is highly useful in agriculture as it is insect repellent (Khushwaha et al., 2012; Ngele et al., 2014).

Araújo Júnior et al. (2010) evaluated the repellency and fumigant toxicity of the essential oils of *Citrus ×sinensis* (L.) Osbeck 'Pera' and 'Mimo', and *C. ×aurantium* L. against *Tetranychus urticae* Koch. These authors concluded that the associated fumigant and repellent properties of these citrus peel oils, particularly those of *C. ×aurantium* and *C. ×sinensis* var. Mimo could be used advantageously for the control of *T. urticae.*

The objective of this study was to evaluate the effect of the fruit peel of five citrus species (*C. ×sinensis*, *C. ×aurantiifolia* (Christm.) Swingle, *C. reticulata* Blanco, *C. ×tangelo* J.W. Ingram & H.E. Moore, and *C. paradisi* Macfad.), on the life parameters of *P. citri* under laboratory conditions.

MATERIALS AND METHODS

The bioassays were carried out in the laboratories of the Faculty of Renewable Natural Resources of the Arturo Prat University, Iquique city, Chile. Bioassays were performed on 3 cm diameter citrus peel discs. Glue (Point Sticken Glue, Point Chile S.A.) was placed in the margin of the discs to prevent mites from escaping. The observations were made with a stereoscopic microscope (Zeiss Stemi, Jena, Germany) at 40X magnification during all the periods of work. Temperature and relative humidity were recorded using a data logger (RC-4HC, Elitech Technology, San Jose, California, USA).

Biological material
Panonychus citri (McGregor, 1916) was collected in the Pica oasis (20º29′12.4″ S, 69º19′33.9″ W), Tarapacá Region, Chile. Later they were reared on tangelo fruits (*C. ×tangelo*) in the laboratories of the Arturo Prat University. Citrus red mite was identified by keys (Ehara and Gotoh, 1992; Khaing et al., 2015) and comparison with reference material deposited in the Faculty of Renewable Natural Resources of the Arturo University Prat. Fruits of sweet orange (*C. ×sinensis* (L.) Osbeck), mandarin (*C. reticulata* Blanco), grapefruit (*C. ×paradisi* Macfad.), tangelo (*C. ×tangelo*), and Mexican lime (*C. ×aurantiifolia* (Christm.) Swingle) were used for the tests.

Rearing of *P. citri*
The breeding of *P. citri* was carried out on tangelo fruits, infesting new of these fruits weekly, for 4 wk, before starting the experiments. Polyvinyl chloride (PVC) cylinders 7 cm diameter by 5 cm high were cut; later, tangelo fruits were taken, and glue was applied to the basal pole with a brush to prevent the mites from escaping. In the upper part of the fruit, around the peduncle insertion zone, 10 females and 10 adult males of *P. citri* were deposited. The infested fruits were kept in rearing chambers in conditions of 25 ± 2 °C, $60 \pm 10\%$ RH, and 14:10 h photoperiod.

Development of *P. citri*
Fresh fruit peel discs with a diameter of 3 cm were cut from each citrus species. An adult female and two males were placed in the epicarp of each fruit peel to ensure fertilization. The disks were placed on a cotton bed saturated with water in 12 cm diameter Petri dishes. After 24 h, 1 egg per disk was left, removing excess eggs and adults. These eggs were observed daily until the individuals reached the adult stage. The survival percentage and the development time of each stage were determined. The evaluations of the development time of each stage, from eggs to adults (males and females), were carried out twice a day (09:00 and 17:00 h). The Petri dishes were placed inside plastic containers ($41 \times 31 \times 7$ cm; length, width and height, respectively) with a hydrated polyurethane sponge, to prevent the desiccation of both the discs and the eggs. Sixty *P. citri* eggs were used for each citrus species.

Life table parameters of *P. citri*
The life table parameters of *P. citri* were determined only in sweet orange, mandarin, and tangelo fruit discs since in Mexican lime and grapefruit there was 100% mortality. For these trials, the methodology described by Birch (1948), Tello et al. (2009a; 2009b; 2013) was used. The parameters evaluated were the intrinsic rate of growth ($r_m = \ln R_0/T$), net rate of reproduction ($R_0 = \Sigma l_x m_x$), generational time ($T = \Sigma x\ l_x m_x/\Sigma l_x m_x$), and the finite rate of natural growth (λ). The survival rate (l_x) was expressed as the number of individuals alive at time x, while the

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fertility at a specific age (m_x) was calculated based on the number of descendant females produced from a female in a time x.

Due to the low number of adults obtained in the development of *P. citri*, for the life table, one female theliochrysalid and two males were placed onto each citrus peel discs (30 discs for each fruit species). After the females oviposited, both sex adults were removed from discs. From the new generation of females emerged, 20 replicates for sweet orange, 19 replicates by mandarin, and 22 replicates by tangelo, were obtained. A pair of tetranychids of both sexes was placed in each dish; the oviposition was recorded every 12 h until the female died. The dead males were replaced to fertilize the female constantly.

Once the last female in the cohort died, the adult periods were determined: pre-oviposition, oviposition, and post-oviposition, as well as fertility rates (number of eggs female^{-1} and number of eggs female^{-1} d^{-1}). To determine the sex ratio and survival of the juveniles, the eggs laid by each female were removed and placed in other leaf discs (aforementioned citrus species), contained in Petri dishes until they reached adulthood.

Juvenile survival was determined through the quotient, S_j = Number of adults obtained/Number of initial eggs. The sex ratio was calculated using the equation: SR = (Number of females/Number of males + Number of females) $\times 100$.

Statistical analysis

A completely randomized design was used in all trials. An ANOVA was applied for post-embryonic development and adult data (Zar, 2010). Before the analysis, survival percentages were transformed by arcsin $\sqrt{x\%/100}$. To compare the means of survival, duration of juvenile and adult stages, oviposition rates, and life table parameters, Tukey test was applied ($\alpha = 0.05$). The determination of the life table parameters and the comparison between the different citrus species was carried out with the statistical program R (R Foundation for Statistical Computing, Vienna, Austria). For comparisons between the life table parameters of the *P. citrus* on three citrus species, the standard deviation was estimated at a confidence interval of 95% using Jackknife's statistical technique (Maia et al., 2014) available in the program lifetable.r (http://www.cnpma.embrapa.br/forms/Rlifetable.php3). Subsequently, the biological parameters were compared using Tukey's multiple comparison tests.

RESULTS AND DISCUSSION

Survival and duration of the life cycle of *P. citri*

Citrus discs peel had a highly significant effect ($F = 14.52$; df = 4, 145; $p < 0.0001$) on the development of *P. citri* (Table 1). There was no survival of *P. citri* on Mexican lime and grapefruit peel discs. In sweet orange, mandarin, and tangelo peel discs, survival ranged from 44.33% to 56.67%. In the case of Mexican lime, only five specimens managed to reach the protonymph stage and in grapefruit, three specimens achieved the deutonymph stage.

Table 1. Effect of host plant on the survival of *Panonychus citri* reared in the laboratory at 25.0 ± 2.0 °C, $50.0 \pm 10.0\%$ RH, and 14:10 h photoperiod. [1]Number of individuals. Means with different letters in each column are significantly different according to Tukey's tests (P < 0.05).

Host plant	N[1]	Larvae	Protonymphs	Deutonymphs	Adults Female	Male	Survival (% ± SE)
Mexican lime	30	16	5	-	-	-	0.00 ± 00b
Grapefruit	30	12	8	3	-	-	0.00 ± 00b
Sweet orange	30	28	16	13	11	2	43.33 ± 9.20a
Mandarin	30	25	21	18	15	2	56.67 ± 9.20a
Tangelo	30	25	16	14	12	2	46.67 ± 9.26a

Table 2 shows the statistics for the duration of the different stages of development of *P. citri*. The duration time of each stage showed significant differences between eggs ($F = 37.55$; fd = 4, 145; $p < 0.0001$), larvae ($F = 12.06$; fd = 4, 101; $p < 0.0001$), protonymphs ($F = 30.31$; fd = 4, 61; $p < 0.0001$) and deutonymphs ($F = 8.60$; fd = 3, 44; $p < 0.0001$). The incubation period of the eggs varied from 6.47 to 8.93 d (mandarin disc peel had a

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shorter time), larval from 5.19 to 7.44 d, protonymph stage from 1.40 to 6.10 d, and the deutonymph from 3.33 to 5.69 d. The complete development of the adult female varied from 25.75 to 26.64 d, without nonsignificant differences on the citrus peel (F = 1.85; fd = 2, 35; p = 0.1729). In the case of males, their development varied from 25.50 to 26.00 d, without presenting significant differences (F = 0.60; fd = 2, 3; p = 0.6037). There were only significant differences in the duration of development between males and females for tangelo (sweet orange: t = 0.63; fd = 1; p = 0.6425; mandarin: t = 0.36; fd = 15; p = 0.7275; tangelo: t = 3.45; fd = 11; p < 0.01).

Table 2. Mean duration (± SE) of the egg and postembryonic stages of *Panonychus citri* (n = 30) on different citrus species at 25.0 °C, 50.0% RH, and 14:10 h photoperiod. Means with different lowercase letters within each column are significantly different according to Tukey's test (P < 0.05). Means with different capital letters within each row are significantly different according to Student's t-test. (P < 0.05). [1]Number of individuals. [2]Insufficient data for an analysis of variances. [3]SE: Standard error.

Diet	N[1]	Duration (d) of post-embryonic development ± SE[3]				Egg-Adult	
		Egg	Larvae	Protonymph	Deutonymph	Female	Male
Mexican lime	30	8.77 ± 0.29c	5.19 ± 0.40a	1.40 ± 0.24a	-[2]	-	-
Grapefruit	30	8.93 ± 0.14c	6.17 ± 0.21ab	4.25 ± 0.59b	3.33 ± 0.33a	-	-
Sweet orange	30	7.63 ± 0.10b	7.11 ± 0.16bc	6.06 ± 0.17c	5.69 ± 0.13b	26.64 ± 0.15aA	26.00 ± 1.00aA
Mandarin	30	6.47 ± 0.11a	7.44 ± 0.27c	6.10 ± 0.21c	5.56 ± 0.25b	25.93 ± 0.43aA	25.50 ± 0.50aA
Tangelo	30	7.80 ± 0.07b	6.88 ± 0.17bc	5.69 ± 0.20c	5.29 ± 0.13b	25.75 ± 0.22aB	25.00 ± 0.00aA

Duration of adult phases and oviposition rates of *P. citri*
Pre-oviposition period did not show significant differences among the studied citrus cultivars (F = 2.63; fd = 2.58; p = 0.0806) (Table 3). The oviposition period varied between 5.70 and 7.82 d, with significant differences and with a shorter duration in sweet orange (F = 5.55; fd = 2.58; p < 0.01). The postoviposition period was calculated between 6.20 and 8.59 d, with significant differences and the shortest duration on sweet orange (F = 60.49; fd = 2.58; p < 0.0001). Longevity showed significant differences (F = 22.68; fd = 2.58; p < 0.0001) varying between 17.95 and 21.95 d (with the longest female longevity on tangelo).

The average daily oviposition rate varied between 0.65 and 0.69 eggs female[-1] d^{-1} with nonsignificant differences (F = 0.54; fd = 2.58; p = 0.5834) (Table 3). Mandarin and tangelo citrus peel had more total eggs produced. The variation interval in the total number of eggs female[-1] was 3.55-5.00, with significant differences (F = 5.92; fd = 2.58; p < 0.01). On average, a female of *P. citri* laid 4.38 eggs during her fertile life.

Table 3. Mean duration (± SE) of the adult stage and the oviposition rates of *Panonychus citri* fed on sweet orange, mandarin, and tangelo peel at 25.0 ± 2.0 °C, 50.0 ± 10.0% RH and 14:10 h photoperiod. Means within each row followed by different letters differ significantly based on Tukey's test (p < 0.05). Data are reported as the mean ± standard error.

	Sweet orange (n = 20)	Mandarin (n = 19)	Tangelo (n = 22)
Periods	Duration of the stages (d)		
Preoviposition	6.05 ± 0.19a	5.63 ± 0.17a	5.55 ± 0.14a
Oviposition	5.70 ± 0.57b	7.58 ± 0.41a	7.82 ± 0.47a
Postoviposition	6.20 ± 0.14c	6.84 ± 0.18b	8.59 ± 0.17a
Longevity	17.95 ± 0.46c	20.05 ± 0.35b	21.95 ± 0.45a
Oviposition	Number of eggs		
Total eggs female[-1]	3.55 ± 0.30b	4.95 ± 0.34a	5.00 ± 0.36a
Eggs female[-1] d^{-1}	0.69 ± 0.04a	0.65 ± 0.02a	0.65 ± 0.03a

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Life table parameters of *P. citri*

For the fertility life table (Table 4), net reproduction rate (R_0) varied significantly ($F = 19.87$; fd = 2.58; $p < 0.0001$) among the three citrus species (1.209-2.474). Also, the generation time (T) varied significantly ($F = 3.8761$; fd = 2.58; $p < 0.05$) among the three citrus species (35.055-35.678 d), which indicated that the spider mite can increase, on average, 1.89 times in approximately 35.353 d. The intrinsic growth rate (r_m) varied significantly ($F = 0.54$; fd = 2.58; $p = 0.5834$) between 0.005 and 0.026 per individual d^{-1}, which means that at any moment the number of individuals in the population of *P. citri* is expected to increase on average about 1.7% overnight. Converting this value to a finite growth rate (λ) per individual d^{-1} gives, on average, 1.017, which means that, for every spider mite present in 1 d, there would be almost 1.017 spiderlings the next day. This last parameter also showed significant differences among the studied citrus fruits ($F = 23.46$; fd = 2.58; $p < 0.0001$); according to these results, mandarin and tangelo peel discs presented the highest growth rates (r_m and R_0).

Table 4. Life table parameters of the *Panonychus citri* reared on three citrus species. Means within each row followed by different letters differ significantly based on Tukey's test ($p < 0.05$). Data are means ± standard errors.

	Jackknife estimates of life table parameters (95% CI)		
Parameters	Sweet orange (n = 20)	Mandarin (n = 19)	Tangelo (n = 22)
Net reproduction rate (R_0)	1.209 ± 0.103b	2.474 ± 0.169a	2.000 ± 0.144a
Intrinsic natural growth rate (r_m)	0.005 ± 0.002b	0.026 ± 0.002a	0.020 ± 0.002a
Generation time (T)	35.679 ± 0.175a	35.325 ± 0.193ab	35.055 ± 0.136b
Finite growth rate (λ)	1.005 ± 0.002b	1.026 ± 0.002a	1.020 ± 0.002a

Age-specific survivorship (l_x), and age-stage-specific fecundity (m_x) of *P. citri* when reared on sweet orange, mandarin, and tangelo are shown in Figure 1. The curves show that *P. citri* completed its development and reproduced on the tested fruits peel. The mean number of offspring produced by *P. citri* individuals of the age x was shown with the age-stage-specific fecundity. The start of oviposition of the first female on sweet orange, mandarin and tangelo occurred at the age 6, 5 and 5 d, respectively. The highest daily fecundity of the females of *P. citri* on the three mentioned citrus fruits was 0.60, 0.74 and 0.86 eggs female^{-1} d^{-1}, that occurred at the age of 7, 12 and 9 d, respectively.

The results obtained in this study (values of the present study: 25.0-26.6 d) differ from those reported by Karaca (1994), using leaves of *C.* ×*aurantium*, who obtained a mean development time from egg to adult of 11.2 d. The average duration of incubation obtained by this author was 5.5 d and the active or mobile stages (larva, protonymph, and deutonymph) averaged 5.7 d before reaching the adult stage.

Zanardi et al. (2015) evaluated, in leaf discs, the development and reproduction of *P. citri* in four varieties of sweet orange cultivated in Brazil ('Valencia', 'Pera', 'Natal', and 'Hamlin'), also in mandarin ('Ponkan') and Sicilian lemon. The results were also different from those obtained in our study (6.47-8.93 d) since the egg incubation period was approximately 6.6 d for all the species and varieties of citrus plants that these authors evaluated. At a temperature similar to that of our study and in sweet orange leaf discs, Kasap (2009) obtained an incubation time (6.4 d) shorter than that obtained in our study (7.63 d). The egg-adult cycle was 12.0 to 12.2 d for the females and 11.6 to 11.7 d for the males, reared at 15 to 35 ± 1 °C, 65 ± 10% RH and 16:8 h photoperiod.

Consequently, the mites reared on the fruit peel of Mexican lime and grapefruit did not complete their life cycle, which shows that, in these species, the effect of the fruit peel was not adequate for their full growth compared to the other citrus species. These hosts also affected the incubation time, delaying hatching (8.77 d for Mexican lime and 8.93 d for grapefruit). This variation in the incubation period could be attributed to the different constitutions of the fruit peel (Elhag, 2000; Aslan et al., 2004; Hollingsworth, 2005), which served as food for the females during their development.

Both the post-embryonic development and the average number of eggs per female obtained in our study (4.38) differ from some results obtained by other authors (Childers, 1983; Ragusa et al., 1983; Karaca, 1994; Kasap, 2009; Zanardi et al., 2015). The differences observed may be due to the use of citrus peel and differences in the

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experimental conditions. Also, it is possible that the reproductive capacity of the female *P. citri* can be determined by the citrus species used as host (Katsoyannos et al., 2004). Likewise, the different nutritional composition of the peels also seems to significantly affect the oviposition capacity of the mite.
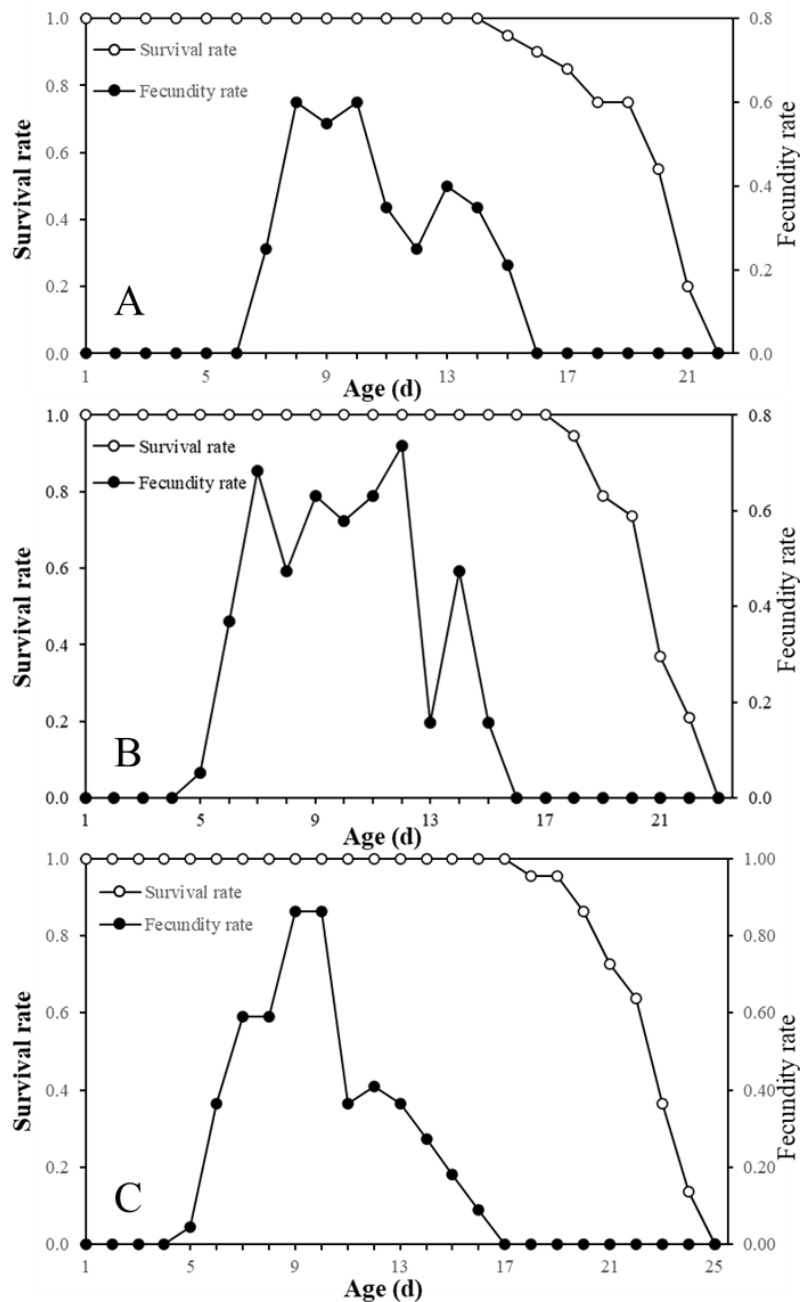

Figure 1. Age-specific survival rate (l_x) and age-specific fecundity rate (m_x) of *Panonychus citri* females on sweet orange (A), mandarin (B), and tangelo (C) at 25.0 ± 2.0 °C, $60.0 \pm 10.0\%$ RH and 14:10 h photoperiod.

Many mechanisms may be responsible for the differences observed in this study. In this sense, the citrus species would offer different conditions that would affect the biology of *P. citri*. These conditions could involve chemical and nutritional aspects, physical aspects such as the surface structure and resistance of the peel tissue, the area available for each individual, and other components, such as the essential oils present.

These factors can reduce food quality, decreasing digestibility, and affecting fertility, growth, population density, survival, development, and mortality of juvenile *P. citri*.

The notable differences found between our results and that described in the literature (Karaca, 1994; Kasap, 2009; Zanardi et al., 2015) can be attributed to the substrate used in the assays (citrus fruit peels) to feed *P. citri*. The possible presence of anti-nutritional factors in these may have influenced the feeding process of this mite, which may be one of the possible causes to explain the lower development and survival rate in its immature stages. Following this argument, the essential oils of *Citrus* species have been reported for their insecticidal properties against various arthropods of agricultural importance. In this regard, Chinniah et al. (2020) evaluated the effect of citrus peel oil on *P. citri*, registering a 74.0% reduction in the population of this mite.

In this same sense, Araújo Júnior et al. (2010) demonstrated that the essential oils present in the peel of different species of the *Citrus* genus have insecticidal properties. These could be attributable to the toxic monoterpenoids present in oils, such as limonene, myrcene, linalool, and α-pinene. The fumigant and repellent properties of these oils present in citrus peel, in particular those of *C. ×aurantium* and *C. ×sinensis* 'Mimo', could be used to control *T. urticae* (Aslan et al., 2004).

According to da Camara et al. (2015), D-limonene was the main constituent found in fruit peels in *C. ×aurantium* and *C. ×sinensis* 'Pear' and its repellency against *T. urticae*, evaluated in laboratory and greenhouse bioassays (da Camara et al., 2015). These authors identified 27 compounds in fruit peels that represent 98.1% and 98.9% of their total constituents, respectively. Those compounds showed repellent effects comparable to eugenol, up to 3 h during laboratory bioassays. Both the main and secondary components of both oils were responsible for this effect and even though they were similar, where *C. ×aurantium* oil prevented the movement of mites between plants for a week. D-Limonene has great potential for development as a commercial repellent against mites and could prevent their spread in commercial greenhouses.

Ayedoun et al. (1996) showed that the main constituents of the *C. ×limon* (L.) Burm. f. peel oil are limonene (70.4%), γ-terpinene (11.8%), and *P*-pinene (4.2%). The leaf oil consisted mainly of limonene (40.8%), *P*-pinene (18.5%), and citronellal (l6.5%). The most prominent compounds in the peel oil of *C.×limettioides* Tanaka is limonene (73.2%), while in the leaf oil the major components are limonene (32.1%), citronellal (21.7%), and linalool (15.5%) (Pino et al., 2010).

Citrus oils and their constituents are potentially useful for the future integrated management of *T. urticae* due to their lethal and sublethal properties (Ribeiro et al., 2019).

Analysis of *C. ×sinensis* 'Pera', and 'Mimo', and *C. ×aurantium* oils by GC and GC/MS led to the identification of 28 components, which represented 99.9%, 99.7%, and 99.3% of the total constituents, respectively, and limonene was the main component found in these three oils. The associated fumigant and repellent properties of these *Citrus* peel oils, particularly those of *C. ×aurantium* and *C. ×sinensis* 'Mimo', could be used to advantage for the control of *T. urticae* (Araújo Júnior et al., 2010).

Other studies were carried out using essential oils extracted from the citrus peel (*C. ×aurantiifolia*, *C. ×limon*, *C. reticulata*, and *C. reticulata × C. ×sinensis*) against *T. urticae* (Ribeiro et al., 2019). These authors identified 127 compounds, revealing a predominance of monoterpenes. Limonene was the main constituent, and substantial amounts of α-pinene, ß-pinene, linalool, and α-terpineol were found. The results showed that *C. reticulata* oil was the most toxic by fumigation and *C. ×limon* oil was the most toxic by residual contact. Applying sublethal concentrations, these oils had significant effects on the fertility, food preference and oviposition of the mite.

CONCLUSIONS

The differences in the stages of the life cycle of *Panonychus citri* may be due to the peel of citrus species. The reproductive capacity of the female *P. citri*, in this study, may also be determined by the citrus species on which she feeds. Likewise, the different nutritional composition of the peels also seems to significantly affect the oviposition capacity of the mite. The most suitable citrus species for the development of *P. citri* are mandarin and tangelo.

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Author contributions

Methodology: V.T., G.V. Formal analysis: M.Z., V.T. Investigation: G.V., V.T. Data curation: G.V. V.T., M.Z. Writing-original draft: V.T., G.V., M.Z. Writing-review & editing: V.T., M.Z. Supervision: G.V., V.T., M.Z. Funding acquisition: V.T., M.Z. All co-authors reviewed the final version and approved the manuscript before submission.

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