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The biology and fecundity of the citrus red mite *Panonychus citri* (McGregor) (Acari: Tetranychidae) at different temperatures under laboratory conditions

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Abstract: The developmental time and fecundity of *Panonychus citri* (McGregor 1916) (Acari: Tetranychidae) on Washington navel sweet orange (*Citrus sinensis* (L.) Osb.) leaves were determined at 15, 20, 25, 30 and 35 ± 1 °C, 65 ± 10% RH, and a 16:8-h (L:D) photoperiod under laboratory conditions. Total development time of *P. citri* females was 37.2, 16.6, 12.2, 9.8, and 9.0 days at 15, 20, 25, 30, and 35 ± 1 °C, respectively. Total and daily egg production levels of *P. citri* were highest at 25 °C (25.6 and 2.1 eggs), followed by 20 °C (22.1 and 1.8 eggs) and 30 °C (16.6 and 1.7 eggs). The lowest total and daily egg production levels were at 15 °C (16.5 and 0.8 eggs). The development threshold for female eggs and egg to adult stages was 9.22 °C and 9.77 °C, respectively, while total effective temperature was 100 and 192.30 degree-days, respectively. The intrinsic rate of increase (r_m) at 30, 25, 20, and 15 °C was 0.148, 0.160, 0.111, and 0.042 females female⁻¹ day⁻¹, respectively.

Key words: Citrus Red Mite, degree-day, development, life table, *Panonychus citri*

Turunçgil Kırmızıörümceği *Panonychus citri* (McGregor) (Acari: Tetranychidae)'nin laboratuvar koşullarında farklı sıcaklıklarda biyolojisi ve üreme gücü

Özet: Bu çalışmada, 15, 20, 25, 30 ve 35 ± 1 °C sıcaklık, % 65 ± 10 nem değerlerine ve 16:8 saat ışıklanma süresine ayarlı laboratuvar koşullarında, Turunçgil Kırmızıörümceği *Panonychus citri* (McGregor) (Acari: Tetranychidae)'nin biyolojisi ve üreme gücü araştırılmıştır. *P. citri*'nin 15, 20, 25, 30 ve 35 ± 1 °C sıcaklıklardaki gelişme süresi sırasıyla dişi bireyler için 37.2, 16.6, 12.2, 9.8 ve 9.0 gün, erkek bireyler için ise 35.7, 15.7, 11.7, 9.7 ve 9.0 gün olarak belirlenmiştir. *P. citri*'nin toplam ve günlük yumurta üretimi 25 °C de en yüksek (25.6 ve 0.87 yumurta) iken, bu sıcaklığı 20 °C (22.1 ve 1.8 yumurta) takip etmiş, daha sonra ise 30 °C (16.6 ve 1.83 yumurta) izlemiş ve en düşük değerler 15 °C sıcaklıkta (16.5 ve 0.8 yumurta) elde edilmiştir. *P. citri*'nin gelişme eşiği dişi bireylerin yumurta dönemleri için 9.22 °C, ergin öncesi dönemleri için ise 9.77 °C olarak belirlenirken, akarın gelişebilmesi için ihtiyaç duyduğu etkili sıcaklıklar toplamının, sırası ile 100 ve 192.30 gün - derece olduğu hesaplanmıştır. *P. citri*'nin kalıtsal üreme yeteneği (r_m) 30, 25, 20 ve 15 °C sıcaklıklarda sırası ile 0.148, 0.160, 0.111 ve 0.042 dişi /dişi / gün olarak saptanmıştır.

Anahtar sözcükler: Turunçgil Kırmızıörümceği, gün - derece, gelişme, yaşam tablosu, *Panonychus citri*

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Introduction

The citrus red mite *Panonychus citri* (McGregor) (Acari: Tetranychidae) is an important phytophagous species present in citrus-growing regions of the world (Munger 1963; McMurtry 1969; Jeppson et al. 1975; Delrio 1985; Takafuji and Fujimoto 1985; Delrio and Monagheddu 1986; Takafuji 1986; Emmanouel and Papadoulis 1987; Gotoh et al. 2003; Lei et al. 2004; Osakabe et al. 2005). Although *P. citri* was first reported on citrus in Turkey in 1952 (Düzgüneş 1952), no detailed studies have been conducted due to its low priority as a pest. Nonetheless, *P. citri* has attained the status of economically damaging pest in Turkey's eastern Mediterranean region. Recent population outbreaks of *P. citri* may be attributed to a disruption in the orchard ecosystem, caused mainly by the application of broad-spectrum pesticides targeting other pests, leading to decreases in the natural enemy pressure on *P. citri* in the Çukurova region and transforming *P. citri* into a serious pest in certain localities (Düzgüneş 1977; McMurtry 1977; Karaca 1994; Kasap et al. 1998; Uygun et al. 2000; Kasap 2005). *P. citri* prefers to feed on lemon, grapefruit, orange, and mandarin, and when its population increases to high densities during early summer, foliage bronzing can be observed. *P. citri* has 2 well-defined peak population densities in the coastal region of Adana, one in spring or early summer and another in autumn, when there is a new growth flush. *P. citri* remains at low densities in mid-summer and throughout winter (Kasap 2005). The dynamics of spider mites and their natural enemies are critically affected by climatic conditions, especially temperature (Van de Vrie et al. 1972; Jeppson et al. 1975). The present study was designed primarily to provide data on the development time and fecundity of a local population of *P. citri* at constant temperatures in the laboratory. This knowledge may prove useful to our understanding of the population dynamics of *P. citri* on citrus.

Materials and methods

Mite cultures

The initial population of *P. citri* was collected from orange trees (Washington navel sweet orange (*Citrus sinensis* (L.) Osb.) in Adana, Turkey, in April 2000.

The stock culture was maintained on sour orange trees (*Citrus aurantium* L.) in a rearing chamber (25 ± 2 °C, $65 \pm 10\%$ RH, and 16:8-h (L:D) photoperiod). This culture was the source of all mites used in this study. Mites were reared for at least 3 consecutive generations prior to the experiments. All experiments were carried out between late May and late November 2000.

Development and biology of *Panonychus citri* at different temperatures

Experiments were conducted on Washington navel sweet orange leaf discs at 15, 20, 25, 30, and 35 ± 1 °C, $65 \pm 10\%$ RH, and a 16:8-h (L:D) photoperiod. The constant temperatures used in the experiments were chosen according to the average summer temperatures in Adana, Turkey, which may rise above 32 °C and negatively affect development of the *P. citri* population. Mature, but non-senescing citrus leaf discs were used as experimental areas. Each area consisted of a leaf placed on a layer of filter paper over a polystyrene pad saturated with distilled water in a 100 × 15-mm petri dish. Each leaf was covered with filter paper that had a 40-mm diameter opening in the center as a barrier to prevent the mites from escaping. Water was added daily to keep the filter paper and polystyrene pad moist, and to cover the base of the petri dish to prevent the mites from escaping. Only fully expanded leaves from 3-year-old Washington navel sweet orange seedlings were used. All leaves were placed ventral-side up. Leaf discs were renewed weekly, if necessary. Approximately 25 adult females from the stock culture were introduced onto each leaf disc and allowed to lay eggs for a 12-h period. Eggs were transferred one at a time and reared on a fresh leaf disc, as described above. *P. citri* developmental stages were observed every 12 h, until the mites reached adulthood. The presence of an exuvium was used as the criterion for successful molting to the next developmental stage. Upon the emergence of a female deutonymph, 1 adult male from the stock colony was introduced onto the leaf disc for mating, and then was removed 24 h later. The duration of egg incubation, protonymph and deutonymph stages, pre-oviposition, oviposition, and post-oviposition (after the last egg was laid), as well as sex ratios were recorded for each temperature treatment.

Life tables of *Panonychus citri* at different temperatures

Newly molted adult *P. citri* females from the previous test were collected to construct life tables under similar conditions as above. Females were transferred one at a time onto a new leaf disc with a single young male, as described above. Males were removed after 24 h. Eggs were collected daily and reared to adulthood. Leaf discs were renewed weekly, egg laying and survival rates were recorded daily, and sex ratios were determined visually. Life tables were constructed using data collected from all immature instars and adult *P. citri* reared at 15, 20, 25, 30, and 35 \pm 1 $^{\circ}$ C, 65 \pm 10% RH, and a 16:8-h (L:D) photoperiod, as described above. Life tables were constructed according to Birch (1948) ($l = \sum l_x \cdot m_x$), using data on age-specific survival rates (l_x) and the number of female offspring per female (m_x) for each age interval (x) per day to calculate the net reproductive rate (R_0 = females female $^{-1}$ generation $^{-1}$), intrinsic rate of natural increase (r_m = females female $^{-1}$ day $^{-1}$), mean generation time ($T_0 = \ln(R_0/r)$, (days), and doubling time ($DT = \ln(2)/r_m$) (the time required for doubling of the initial population (days)) at each temperature.

Statistical analysis

Data were analyzed using one-way analysis of variance (ANOVA) and Duncan's multiple range test ($P \leq 0.05$). A linear equation using growth-rate data (day $^{-1}$) as the dependent variable and temperature treatment as the independent variable was used to compute both the temperature threshold of the egg stage and developmental time. The lower developmental threshold was identified as the x-intercept of the linear equation, and the degree-day (DD) requirement was identified as the inverse of the slope of the linear equation. The regression equation is $v = a + bt$ (where a is the intercept and b is the slope) (Sharov 1998). Differences in r_m , R_0 , and T_0 values were tested for significance by estimating the variance using the jack-knife method, which facilitated the calculation of standard errors of the r_m , R_0 , and T_0 estimates. The jack-knife pseudo-value r_j was calculated for n samples using the following equation: $r_j = nxr_{a11} - (n-1) xr_i$ (Sokal and Rolf 1981; Krebs 1998). The mean $(n-1)$ of the jack-knife pseudo-value for the mean growth rate of each treatment was subjected to ANOVA and Duncan's multiple range test (DMRT).

All statistical analyses were conducted using the SAS statistical software package (SAS 1998).

Results

Developmental times of *P. citri* are shown in Table 1. Development time decreased as the temperature increased from 15 to 35 $^{\circ}$ C, for both females (DMRT: $F = 499.32$; $df = 84$; $P = 0.0001$) and males (DMRT: $F = 1125.71$; $df = 27$; $P = 0.0001$), but the differences between 30 and 35 $^{\circ}$ C for both sexes were not statistically significant (Table 1). While overall development time was shorter for males than for females, the difference between the 2 was not statistically significant (t test = 0.7825; $df = 20$; $P > 0.005$). While the longest development time was observed at 15 $^{\circ}$ C and the shortest at 35 $^{\circ}$ C, the differences between development time values at 30 $^{\circ}$ C and 35 $^{\circ}$ C were not statistically significant (Table 1) (DMRT: $F = 499.32$; $df = 84$; $P = 0.0001$). Linear regression analysis showed that at 15-30 $^{\circ}$ C the overall developmental rate ($r_{[DT]}$) of *P. citri* females increased linearly with increasing temperature (Figure 1). The theoretical development threshold was estimated as 9.77 $^{\circ}$ C. Based on this threshold, complete development from egg to adult required 192.30 degree-days. Oviposition of *P. citri* adults at 35 $^{\circ}$ C could not be determined due to the high mortality rate (75.8%); at this temperature adult females died after 4.3 days, without laying any eggs. The lowest mortality rate (22.5%) occurred at 25 $^{\circ}$ C (Table 1) and the maximum longevity (32.2 days) was at 15 $^{\circ}$ C. Longevity was shorter at 30 $^{\circ}$ C than at 25 $^{\circ}$ C and 20 $^{\circ}$ C, but the differences were not statistically significant (Table 2) (DMRT: $F = 55.45$; $df = 50$; $P = 0.0001$). The daily age-specific survival rate of females (l_x) and age-specific fecundity rates (m_x) of *P. citri* are given in Figure 2. The daily age-specific survival rate was highest at 15 $^{\circ}$ C and decreased as the temperature increased. The maximum number of eggs was produced at 25 $^{\circ}$ C (day 16: 2.10 eggs female $^{-1}$ day $^{-1}$), followed by 20 $^{\circ}$ C (day 21: 1.68 eggs female $^{-1}$ day $^{-1}$), 30 $^{\circ}$ C (day 14: 1.38 eggs female $^{-1}$ day $^{-1}$), and 15 $^{\circ}$ C (day 50: 0.58 eggs female $^{-1}$ day $^{-1}$), with daily egg production gradually decreasing thereafter. The majority of adult mortality occurred towards the end of the oviposition period, at all temperatures (Figure 2). Mean generation time (T_0) of *P. citri* on Washington navel

Table 1. Duration (days) of immature stages and total mortality in *Panonychus citri* at 5 different temperatures (°C) (\pm SEM)^{1,2}

Female						
	15 °C	20 °C	25 °C	30 °C	35 °C	F ratio
n	16	14	21	16	22	
Egg	18.3 \pm 0.23 a	7.8 \pm 0.15 b	6.4 \pm 0.15 c	4.9 \pm 0.15 d	4.3 \pm 0.10 e	1168.31
Larva	5.8 \pm 0.39 a	2.5 \pm 0.12 b	1.9 \pm 0.09 c	1.3 \pm 0.05 d	1.4 \pm 0.07 cd	101.23
Protonymph	5.5 \pm 0.33 a	2.7 \pm 0.37 b	1.8 \pm 0.14 c	1.7 \pm 0.09 c	1.4 \pm 0.09 c	61.30
Deutonymph	7.5 \pm 0.87 a	3.6 \pm 0.26 b	2.1 \pm 0.08 c	2.0 \pm 0.14 c	2.0 \pm 0.16 c	35.92
Total Development (egg to adult)	37.2 \pm 1.08 a	16.6 \pm 0.47 b	12.2 \pm 0.22 c	9.8 \pm 0.24 d	9.0 \pm 0.17 d	499.32
Mortality (%)	25.6	23.2	22.5	30.3	75.8	
Male						
n	7	7	7	5	6	
Egg	17.6 \pm 0.97 a	7.3 \pm 0.57 b	6.3 \pm 0.13 c	4.8 \pm 0.45 d	4.2 \pm 0.82 d	456.82
Larva	5.7 \pm 0.94 a	2.4 \pm 0.32 b	1.7 \pm 0.41 c	1.3 \pm 0.10 c	1.4 \pm 0.33 c	78.37
Protonymph	5.3 \pm 0.83 a	2.5 \pm 0.36 b	1.7 \pm 0.29 c	1.6 \pm 0.18 c	1.5 \pm 0.44 c	71.13
Deutonymph	7.2 \pm 1.21 a	3.5 \pm 0.71 b	2.0 \pm 0.25 c	2.0 \pm 0.54 c	2.1 \pm 0.15 c	69.28
Total Development (egg to adult)	35.7 \pm 0.96 a	15.7 \pm 0.83 b	11.7 \pm 0.53 c	9.7 \pm 1.08 d	9.0 \pm 0.89 d	1125.71

¹Means in a row followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test).

²For both sexes, within column means are significantly different (t test: $P > 0.05$).

Total: Total development time (egg to adult); n: number of replicates included in the analysis

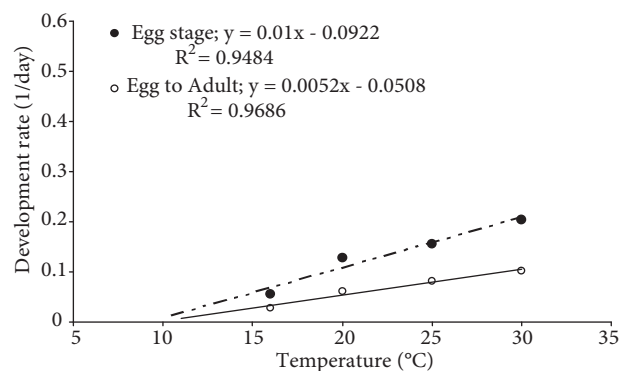


Figure 1. Total developmental rate (egg to adult) of *Panonychus citri* females. Lines represent linear regressions of developmental rates on temperature within the range of 15-30 °C

sweet orange decreased as the temperature increased, from 52.2 days at 15 °C to 23.9 days at 20 °C, 18.3 days at 25 °C, and 17.2 days at 30 °C (Table 3) (DMRT: $F = 97872.2$; $df = 38$; $P = 0.0001$). The intrinsic rate of increase (r_m) increased significantly from 0.042 females female⁻¹ day⁻¹ at 15 °C to 0.111 and 0.160 females female⁻¹ day⁻¹ at 20 and 25 °C, respectively,

and then decreased to 0.148 females female⁻¹ day⁻¹ at 30 °C. The differences between all values were statistically significant, with the exception of the difference between 25 °C and 30 °C (Table 3) (DMRT: $F = 106.16$; $df = 38$; $P = 0.0001$). Along with increasing r_m values, the net reproductive rate (R_0) increased from 8.8 females female⁻¹ at 15 °C to 13.3 females female⁻¹ at 20 °C and 16.5 females female⁻¹ at 25 °C, and then decreased to 11.5 females female⁻¹ at 30 °C (DMRT: $F = 1920.78$; $df = 38$; $P = 0.0001$). Population doubling time (DT) was less than 5 days at 25 °C and 30 °C, 6.24 days at 20 °C, and 16.50 days at 15 °C (Table 3).

Discussion

During the present study significant differences were observed between the performance of *P. citri* at 5 different temperatures. *P. citri* developed successfully to the adult stage over the range of temperatures tested; however, at 35 °C there was high mortality (75.8%), and the oviposition rate and r_m value were not determined. The increase in the

Table 2. Pre-oviposition, oviposition, post-oviposition, and longevity (days), total and daily fecundity (eggs female⁻¹), and sex ratios of *Panonychus citri* at 5 temperatures (°C) (± SEM)¹

	15 °C	20 °C	25 °C	30 °C	35 °C	F ratio
n	12	10	12	10	15	
Pre-Oviposition	5.4 ± 0.67 a	1.8 ± 0.16 b	1.3 ± 0.19 b	2.2 ± 0.17 b	–	21.10
Oviposition	22.1 ± 1.60 a	10.8 ± 0.64 b	9.9 ± 0.94 b	9.4 ± 0.67 b	–	28.47
Post-Oviposition	5.6 ± 1.10 a	2.9 ± 0.35 b	2.6 ± 0.27 b	1.2 ± 0.12 b	–	6.85
Total Longevity	32.2 ± 2.61 a	15.5 ± 0.75 b	14.6 ± 1.00 b	13.6 ± 0.90 b	4.3 ± 0.69 c	55.45
Daily Fecundity	0.8 ± 0.18 b	1.8 ± 0.57 a	2.1 ± 0.87 a	1.7 ± 0.48 a	–	28.85
Total Fecundity	16.5 ± 1.17 b	22.1 ± 1.64 ab	25.6 ± 2.55 a	16.6 ± 1.83 b	–	5.71
Sex ratio (♀/♂)	0.53	0.61	0.66	0.69	–	–

¹Means in a row followed by the same letter are not significantly different (P > 0.05; Duncan's multiple range test) (n: number observed)

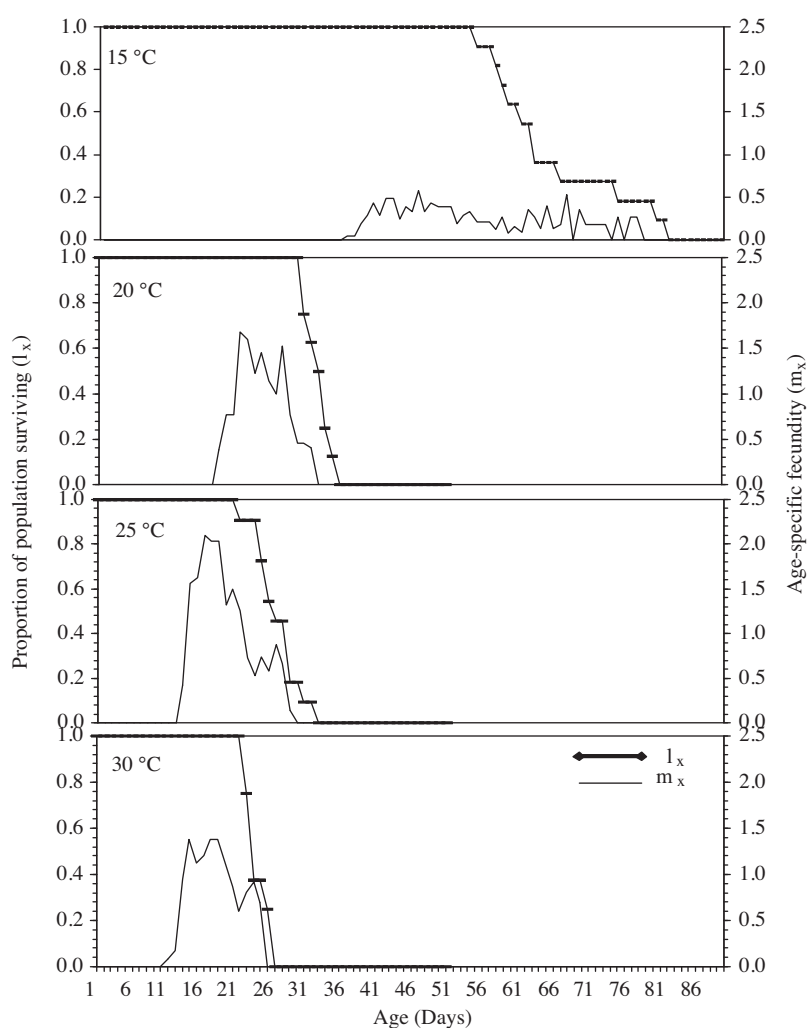


Figure 2. Adult survival (l_x) and age-specific fecundity rate (m_x) in *Panonychus citri* at 4 different temperatures

Table 3. Net reproductive rate (R_0), intrinsic rate of increase (r_m), generation time (T_0), and doubling time (DT) in *Panonychus citri* at 4 different temperatures (\pm SEM)¹

	Net reproductive rate (R_0) (females female ⁻¹)	Intrinsic rate of increase (r_m) (females female ⁻¹ day ⁻¹)	Generation time (T_0) (days)	Doubling time (DT) (days)
15 °C	8.8 \pm 0.044 d	0.042 \pm 0.001 c	52.2 \pm 0.0136 a	16.50
20 °C	13.3 \pm 0.133 b	0.111 \pm 0.003 b	23.9 \pm 0.0283 b	6.24
25 °C	16.5 \pm 0.172 a	0.160 \pm 0.001 a	18.3 \pm 0.0506 c	4.33
30 °C	11.5 \pm 0.159 c	0.148 \pm 0.002 a	17.2 \pm 0.0676 d	4.68
F ratio	1920.78	106.16	97872.2	

¹Means in a row followed by the same letter are not significantly different ($P > 0.05$: Duncan's multiple range test)

mortality rate at 35 °C indicates the proximity of the upper thermal threshold. Considering that the average temperature in Adana may rise to above 32 °C in summer, population development of spider mites may be negatively affected (Sabelis 1985). *P. citri* performed best at 25 °C. This was due mainly to a short development time (12.2 days), high daily and total egg production (2.1 and 25.6 eggs, respectively), and an early peak in reproduction (2.10 eggs on the 16th day). Development time, oviposition rate, and early peak in oviposition are important determinants of r_m values. Previous studies of spider mites have shown that r_m is more dependent upon developmental time than oviposition rate when both values change at similar rates (Sabelis 1985; Gotoh et al. 2003). The intrinsic rate of natural increase (r_m) and the net reproduction rate (R_0) describe the growth potential of a population under specific climatic conditions, and reflect the overall effect of temperature on mite development, reproduction, and survival. In the present study both r_m and R_0 were higher at 25 °C than at the other temperatures tested, which is similar to other studies, i.e. Yasuda (1982) reported that 24 °C was the most favorable temperature for the reproduction and development of *P. citri*. At this temperature the intrinsic rate of natural increase (r_m), net reproduction rate (R_0), mean generation time (T_0), and total egg production in the present study were 0.171 females female⁻¹ day⁻¹, 28.3 females female⁻¹, 19.4 days, and 42.6 eggs female⁻¹, respectively. This may have been due to the lower daily rate of offspring production and later peak in reproduction observed

at the other temperatures tested, especially at 15 and 20 °C. There are few reports in the literature on the biology, life history traits, and degree-day models of *P. citri*. Yasuda (1982) reported a development threshold of 7.9 °C and a total effective temperature of 227.4 degree-days. In the present study the development threshold was 9.77 °C and the total effective temperature was 192.30 degree-days. Ragusa et al. (1983) reported development time and total egg production of *P. citri* were 10.12 days and 72.8 eggs, respectively. Gotoh et al. (2003) reported development time, total egg production, and r_m values as 11.6 days, 67.2 eggs, and 0.209 day⁻¹ for *P. citri* on bitter orange (*Citrus aurantium* L.), respectively, at 25 °C. In the present study total fecundity (25.6 eggs) and r_m (0.160 day⁻¹) values at 25 °C were lower than those reported in previous studies. The differences in study results may be attributed to differences in host plants, local populations, and the time of year during which the studies were implemented. For instance, among 14 citrus varieties tested, egg production in *P. citri* was the highest on Taiwan bampeiyou pummel and the lowest on Ponkan NL (Lei et al. 2004).

Two studies by Sabelis (1985, 1991) provide extensive reviews of the life-history parameters of tetranychid mites. Reported r_m values ranged from 0.160 to 0.336 at around 25 °C; for example, r_m values of *Amphitetranynchus viennensis* (Acari: Tetranychidae) reared on 3 different plants varied from 0.195 (apple) to 0.222 (cherry) (Gotoh and Takayama 1992), and r_m values of *Tetranychus kanzawai* (Acari: Tetranychidae) reared on 4 different plants varied from 0.187 (tea) to

0.283 (mulberry) (Gotoh and Gomi 2003). In the present study, *P. citri* r_m values increased with temperature, from 0.042 to 0.160. Additional studies that examine the effects of other biotic and abiotic

factors on the biology of *P. citri* should be conducted in order to determine the main factors responsible for changes in population dynamics, so that a suitable mite-control program can be implemented.

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