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Original article (Orijinal araştırma)

Bioecological characteristics of *Planococcus citri* Risso, 1813 (Hemiptera: Pseudococcidae) under constant and alternating temperatures[1]

Planococcus citri Risso, 1813 (Hemiptera: Pseudococcidae)'nin sabit ve değişken sıcaklıklarda bazı biyoekolojik özellikleri

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Summary

Planococcus citri Risso, 1813 (Hemiptera: Pseudococcidae), is one of the major pest of citrus and many other orchards crops, and ornamental plants in subtropical and tropical regions of the world. The influence of temperature on *P. citri* development and fecundity has a critical role in integrated pest management strategies to reduce the population to below the economic threshold by biological or chemical control methods. The study investigated some bioecological characteristics, such as, development time, duration of biological stages, sex ratio, daily and total fecundity per female, and longevity of *P. citri*, under different temperature regimes during 2015-2016 in Citrus Pest Laboratory at Çukurova University. The shortest egg stage development for females and males were determined as 2.7 and 2.7 d with alternating temperatures of 25/30°C (12:12 h), respectively. The first nymph stage lasted 7.86 d for females, and 8.1 d for males at 25°C. The longest duration for the second nymph stage was obtained at 15°C with 25.7 and 22.5 d for females and males, respectively. The third nymph stage for *P. citri* females completed in 7.0 d at 25°C, and the pupal stage for *P. citri* males lasted 7.8 d at 25°C. The development thresholds of females and males were calculated as 8.5 and 9.5°C, respectively. Also, thermal constants of females and males were 666.67 and 500.00 degree-days. The optimum development temperature was determined as 25/30°C.

Keywords: Citrus mealybug, development time, life table, *Planococcus citri*, thermal constant

Özet

Planococcus citri Risso, 1813 (Hemiptera: Pseudococcidae) dünyanın subtropikal ve tropikal bölgelerinde bulunan başta turunçgil olmak üzere pek çok bahçe ve süs bitkileri üzerindeki ana zararlılardan birisidir. *P. citri*'nin gelişme süresi ve üremesi üzerinde sıcaklığın etkisi zararlının popülasyon seviyesini ekonomik zarar eşiğinin altına düşürmek için uygulanacak bir biyolojik veya kimyasal mücadele programı için kritik bir role sahiptir. Çukurova Üniversitesi Turunçgil Zararlıları Laboratuvarı'nda 2015-2016 yılları arasında, *P. citri*'nin toplam gelişme süresi, cinsiyet oranı, günlük ve toplam yavru sayıları ve ergin ömrü gibi bazı biyoekolojik özellikleri farklı sıcaklıklar altında çalışılmıştır. En kısa yumurta gelişme süresi sırasıyla dişi ve erkekler için 2.7 ve 2.7 gün olarak 25/30°C'de (12:12 h) tespit edilmiştir. Birinci dönem nimflerin gelişme süresi ise 25°C'de dişiler için 7.9 gün sürerken erkekler için ise 8.1 gün olmuştur. En uzun ikinci nimf dönemi gelişme süresi ise 15°C'de dişiler için 25.7, erkekler için ise 22.5 gün olarak hesap edilmiştir. Ergin olma öncesi son gelişme dönemi olarak dişilerin üçüncü dönem nimfler gelişimini 25°C'de 7.0 günde tamamlarken, erkek bireylerin pupa dönemleri ise 7.8 gün sürmüştür. Dişi ve erkek bireylerin gelişme eşikleri ise sırasıyla 8.5 ve 9.5°C olarak hesaplanmıştır. Yumurtadan ergin olması için gerekli sıcaklıklar toplamı olan thermal konstant ise ise dişiler için 666.67, erkekler için ise 500.00 gün-derecedir. Turunçgil unlubitinin optimum gelişme sıcaklığı ise 25/30°C olarak belirlenmiştir.

Anahtar sözcükler: Turunçgil unlubiti, gelişme süresi, yaşam tablosu, *Planococcus citri*, termal konstant

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Introduction

Citrus mealybug, *Planococcus citri* Risso, 1813 (Hemiptera: Pseudococcidae), is one of the major pest of citrus and many other orchards crops, and ornamental plants in subtropical and tropical region of the world (Williams & Watson, 1988; Blumberg et al., 1995). This pest is also recognized as a major pest of citrus in Turkey (Bodenheimer, 1953; McKenzie, 1967; Düzgüneş, 1982; Lodos, 1986; Williams & Watson, 1988; Ben-Dov, 1994; Uygun, 2001; Franco et al., 2004; Uygun & Satar 2008). It feeds on fruits and twigs of citrus by sucking the sap, and therefore, the plants often become stunted, distorted, or yellowed and show reduced vigor. A dark-colored sooty mold, known as fumagine, grows on the honeydew secreted during its feeding on the host plant (Uygun, 2001; Polat et al., 2007; Uygun & Satar, 2008). Moreover, fruits attacked by *P. citri* often drop in early maturity (August-September) because of injury to the calyx of the fruit. The population density of this pest can reach a level that may cause serious damage in citrus orchards if not controlled. The damage of this pest causes a decrease in the market value of citrus fruit and thus, the pest affects adversely the citrus exports. Several studies determined that there is a significant number of natural enemies of this mealybug in the East Mediterranean Region of Turkey (Alkan, 1953; Soylu & Ürel, 1977; Kansu & Uygun, 1980; Uygun, 1981; Lodos, 1986; Yayla & Satar, 2012; Satar et al., 2013; Kütük et al., 2014). These natural enemies are important in integrated pest management of *P. citri* in Turkey. However, chemical control is often the preferred method to control the pest because it is easy use and requires less knowledge and labor (Yiğit et al., 1994; Satar et al., 2013; Birgücü et al., 2014, 2015).

Cryptolaemus montrouzieri Mulsant, 1850 (Coleoptera: Coccinellidae) and *Leptomastix dactylopii* Howard, 1885 (Hymenoptera: Encyrtidae), which are mass reared and released, are the most commonly used natural enemies of *P. citri* (Yiğit et al., 1994; Erkılıç & Demirbaş, 2007). However, the increasing chemical applications to control *P. citri* in citrus orchards leads to a decline in natural enemy populations and has conversely resulted in a rise in *P. citri* populations in last two decades (Karacaoğlu & Satar, 2010; Satar et al., 2011). Successful application of pesticide also depends on appropriate timing relative to the pest population. So, the influence of temperature on *P. citri* development and fecundity has a critical role of integrated pest management (IPM) strategies to reduce populations to below the economic threshold by both biological and chemical control methods. The temperature conditions also provide information about population dynamics of insects (Keena, 2006), and are important in their bioecological characteristics. Therefore, the effects of temperature on insects in citrus orchards need to be investigated.

To this end, the study investigated some bioecological characteristics, such as, development time, sex ratio, duration of biological stages, daily and total fecundity per female, and longevity of *P. citri*, under different temperature regimes. This knowledge is key for further understanding of the arthropod's biology, especially its adaptation to different temperatures and should provide the basis for better pest management strategies. Furthermore, it can be used to estimate the potential damage level (Sánchez-Ramos & Castañera, 2005) and thus to improve pest management (Satar et al., 2005; Ebrahimi et al., 2009). Also, the model of best fit for the effect of temperate on the development rate of the pest was assessed by linear regression.

Material and Methods

Breeding of the plant and pest

Grapefruit seedlings (*Citrus paradise* Macfad.) cv. Star Ruby obtained from the Subtropical Fruits Research and Application Center of Çukurova University in Adana, Turkey were planted in 20 l plastic pots containing a mixture of soil and peat (1:1 v/v) and then kept in climate room at 26±1ºC and 60±10% RH with a 12:12 h L:D photoperiod.

The leaves, twigs and fruits of grapefruit trees infected with *P. citri* were collected from Alata Horticultural Research Institute in Mersin, Turkey and brought to laboratory within culture plates. Then, citrus mealybug individuals were gently transferred to the grapefruit seedling using the fine paintbrush, under a binocular microscope. Afterwards, the infected grapefruit seedlings were transferred to cages (100x85x67 cm) with the upper and lateral sides of which was covered by net, in a climate room at 26±1ºC and 60±10% RH with a 16:8 h L:D photoperiod. These were the stock cultures of *P. citri* used in the experiments described below. Maintenance and control for the plant and pest were done daily and irrigation was applied as necessary.

Experimental establishment

A total of 10 individual *P. citri* in the third nymph stage from stock culture were randomly selected and transferred using a fine paintbrush to dissected grapefruit (cv. Star Ruby) leaf discs in 5-cm diameter petri dishes containing 1% water agar. Each of egg mass deposited by females in the petri dish were transferred using a fine paintbrush to new petri dishes with fresh leaf discs containing 1% water agar and monitored for hatching. Each neonate crawler (first-instar nymph) was separately transferred using a fine paintbrush to new petri dishes containing 1% water agar and observed every day to record biological parameters, such as the development time, sex ratio.

Then an experiment was designed to provide mating opportunity, so that each petri contained two males and one female. All replicates in which the nymphs died within 24 h after transfer were omitted from the experiment. The durations of biological stages, daily and total fecundity per female and longevity of adults were observed. Also, new egg masses deposited by females were removed from the petri dishes after recorded and the grapefruit leaf disc in the Petri dishes was renewed every 3 to 5 d, if necessary. The experiment was conducted under five constant (15, 20, 25, 30 and 35±1ºC) and one alternating (25/30±1ºC) temperature regimes under constant relative humidity and photoperiod conditions (65±10% RH with 16:8 h L:D photoperiod for constant temperatures and 12:12 h L:D photoperiod for alternating temperatures at 8-10 klux light intensity). At least 20 replicates were included for each temperature regime. The experiment continued until the death of all individuals. All the experiments were conducted in Citrus pest laboratory at Department of Plant Protection, Faculty of Agriculture Çukurova University, Adana Turkey during 2015-2016.

Life table and statistical analyses

Life table parameters were calculated using the following formulas:

The age-specific survival rate (l_x) and fecundity (m_x, female/female) was computed by multiplying the mean number of offspring by the sex ratio (Birch, 1948),

Net reproductive rate ($R_0 = \sum l_x.m_x$) (female/female/offspring), i.e. the mean number of offspring which are laid by a female in her lifetime (Birch, 1948) were assed individually for each replication in each temperature then, all cohort in each temperature were used in bootstrap (Efron & Tibshirani, 1993) techniques to estimate the means, variances, and standard errors of the population net reproductive rate.

Intrinsic rate of increase (r_m, female/female/day) by taking advantage from Euler-Lotka equation ($\sum e^{(-r_m.x)}\, l_x.m_x = 1$) (Birch, 1948),

Mean generation time (day), $T_o = \frac{\ln R_0}{r_m}$ (Birch, 1948),

Gross reproduction rate, $GRR = \sum m_x$ (Birch, 1948),

Where *x* is female age in days, *e* is Euler's number which is a mathematical constant (approx. 2.71828).

Pseudo-r_{mj} values of the intrinsic rate of increase (r_m) values were calculated according to the jackknife resampling method (Meyer et al., 1986) for the comparison test, and then, Tukey multiple comparison test (Tukey, 1949) was applied after one-way ANOVA for these pseudo-r_{mj} values of the intrinsic rates. Statistical analyses were performed by using IBM® SPSS® Statistics (Version 20.0) (SPSS 2011).

Also, development rates of the individuals bred under the different temperature regimes were determined by linear regression (y = a ± bx). The mean of the alternating temperatures (27.5°C for 25/30°C) was used in the regression analysis. Afterwards, the development threshold (-a/b) and thermal constant (the total effective temperature required to complete a generation, 1/b) of *P. citri* was calculated according to the linear regression equation (Campbell et al., 1974).

Results and Discussion

The individuals from both sexes of *P. citri* reached adult stage at temperatures between 15 and 30°C; however, eggs of *P. citri* showed no development at 35°C. When neonate crawlers that hatched at 30°C were kept at 35°C, only 5% of them progressed to the second nymph stage. However, these individuals did not progress to further biological stages, and they all died within a month. The development durations of different biological stages of *P. citri* females on grapefruit leaves under different temperature regimes are given in Table 1. Those of *P. citri* males are also given in Table 2.

Table 1. Development durations (d) of immature biological stages of *Planococcus citri* females on grapefruit leaves under different temperature regimes (mean ± SE)*

Temperature (°C)	n	Egg stage	First nymph stage	Second nymph stage	Third nymph stage	Total development
15	16	8.00±0.22 c	14.9±0.81 c	25.7±2.34 c	20.2±1.19 c	68.8±3.00 d
20	15	7.73±1.22 c	13.4±0.77 c	13.0±1.24 b	14.7±0.78 b	48.9±1.55 c
25	23	4.34±0.14 b	7.9±0.29 a	6.4±0.74 a	7.0±0.29 a	25.6±0.95 a
25/30	30	2.73±0.82 a	7.9±0.26 a	7.4±0.50 a	5.8±0.26 a	23.9±0.60 a
30	11	3.70±0.19 a	11.1±0.99 b	9.5±1.07 ab	12.2±0.92 b	36.5±0.86 b
35	50	No development				

* Means (± SE) sharing same letter within same column are not significantly different from each other (Tukey's HSD multiple range test at $P < 0.05$) ($F_{egg} = 181.467$, df = 4,90, P = 0.000; $F_{Nymph\_1} = 36.260$, df = 4,90, P = 0.000; $F_{Nymph\_2} = 43.241$, df = 4,90, P = 0.000; $F_{Nymph\_3} = 91.780$, df = 4,90, P = 0.000; $F_{Total\_development} = 167.759$, df = 4,90, P = 0.000).

Table 2. Development durations (d) of different biological stages of *Planococcus citri* males on grapefruit leaves under different temperature regimes (mean ± SE)*

Temperature (°C)	n	Egg stage	First nymph stage	Second nymph stage	Pupal stage	Total development	Longevity of males
15	30	7.8±0.14 d	14.2±0.65 b	22.5±1.93 b	26.5±1.17 c	71.0±1.97 c	8.3±0.47 c
20	13	8.1±0.26 d	13.4±0.78 b	11.9±0.85 a	11.9±0.94 b	45.3±1.74 b	4.5±0.63 b
25	7	4.7±0.28 c	8.1±0.14 a	5.6±0.20 a	7.8±0.34 ab	26.3±0.28 a	4.7±0.47 b
25/30	20	2.7±0.10 a	7.8±0.41 a	6.3±0.28 a	7.8±0.28 ab	24.6±0.44 a	1.8±0.18 a
30	10	3.6±0.22 b	9.7±1.01 a	9.2±2.20 a	6.4±0.42 a	28.9±3.20 a	2.7±0.30 ab
35	50	No development					

* Means (± SE) sharing same letter within same column are not significantly different from each other (Tukey's HSD multiple range test at $P < 0.05$) ($F_{egg} = 197.920$, df = 4,80, P = 0.000; $F_{Nymph\_1} = 19.651$, df = 4,80, P = 0.000; $F_{Nymph\_2} = 20.619$, df = 4,80, P = 0.000; $F_{Pupa} = 85.577$, df = 4,80, P = 0.000; $F_{Total\_development} = 132.743$, df = 4,80, P = 0.000; $F_{Longevity} = 37.897$, df = 4,80, P = 0.000).

The shortest egg stage was calculated as 2.7 d at 25/30°C, followed by 30, 25, 20 and 15°C, respectively (Table 1). For males, the shortest egg stage was observed at 25/30°C with 2.7 d, and the longest egg stage was 8.1 d, obtained at 20°C (Table 2). Arai (1996) suggested that hatching time of *P. citri* males in egg stage were 4 d at 25°C, 3.2 d at 27°C and 4 d at 27.5°C. According to the results of this study, the hatching time initially decreased with increasing temperature, and then increased again. These results were similar to the results in this present study (Table 2).

The first nymph stage lasted 7.9 d at 25°C for females, and 8.1 d for males. The duration of this stage decreased with increasing temperature up to 25°C, and then increased again at 30°C (Tables 1 & 2). The longest duration for the second nymph stage was obtained at 15°C with 25.7 and 22.5d for females and males, respectively, and the shortest duration for this stage was seen at 25°C with 6.4 and 5.6 d for females and males, respectively (Tables 1 & 2). For last period of immature stages, the third nymph stage for *P. citri* females completed in 7.0 d at 25°C, and the pupal stage for *P. citri* males lasted 7.8 d at 25°C (Table 1 & 2). Similarly, research in Brazil (Cecília et al., 2009) determined that the development time of the first instar nymphs of *P. citri* females fed on coffee plant was 7.8 d at 25°C and 70% RH. Also, that study found that the duration of the third nymph stage of *P. citri* females fed on coffee plant under the same conditions was 7.02 d (Cecília et al., 2009).

Polat et al. (2007) studied on the development of *P. citri* fed on four different ornamental plants *Schefflera arbicola* (Hayata) Kanehira, *Kalanchoe blossfeldiana* Poelln., *Nerium oleander* L. and *Syngonium podophyllum* Schott, and found that the first nymph stage of *P. citri* females fed on those ornamental plants were 7.90, 6.74, 6.66 and 5.61 d at 28°C, respectively. Also, Polat et al. (2007) reported that the durations of the first instar nymphs of *P. citri* males fed on those ornamental plants were 7.55, 6.78, 6.60 and 5.55 d at 28°C, respectively. The results of the present study showed similarities with the results obtained for the first instar nymphs of *P. citri* females fed on *S. arbicola* by Polat et al. (2007). However, the results obtained by Polat et al. (2007) on the development of *P. citri* fed on other ornamental plants were different from the results of this present study. Based on this, it is reasonable to conclude that the development of this pest depends on host plant species and temperature.

The durations of preoviposition, oviposition, and postoviposition periods decreased with increasing temperature especially between 15 and 25°C (Table 3). The longest longevity for *P. citri* females was determined as 80.4 d at 15°C, and the shortest longevity was 29.5 d at 30°C (Table 3) and the longest longevity for *P. citri* male was the same as for females, but shortest longevity for male was at 25/30°C instead of 30°C (Table 2). However, the results for total fecundity followed a different trend. The highest total fecundity was observed as 149.7 eggs/female at 25/30°C, followed by 144.9 eggs/female at 20°C, 112.7 eggs/female at 25°C, 104.1 eggs/female at 15°C and 60.72 eggs/female at 30°C. A study of Francis et al. (2012) on the biology of the passion vine mealybug, *Planococcus minor* (Maskell, 1897) (Hemiptera: Pseudococcidae) demonstrated that females laid no eggs at 15°C but laid 269.8 eggs/female at 20°C, 205.6 eggs/female at 25°C, and 187.9 eggs/female at 29°C, under 60±10% RH and 24 h light.

A study conducted on host plants, geographical distribution, natural enemies and the biology of *P. citri* in Egypt by Ahmed and Abd-Rabou (2010) demonstrated that the mean daily fecundity of this pest on citrus was 136.1 eggs/female/day at 18°C, and 65-75% RH. Also, a study conducted by Kim et al. (2008) on the effect of temperature on the development and fecundity of *Pseudococcus cryptus* Hempel, 1918 on zucchini determined the mean daily fecundity of *P. cryptus* as 111 eggs/female/day at 25°C. In addition, Kim et al. (2008) stated that the preoviposition period and longevity of *P. cryptus* females on zucchini at 32°C were 12.5 and 31.3 d, respectively. The results have a similarity with the results obtained on the preoviposition period at 30°C in the present study. In addition, the longevity of *P. cryptus* was determined as 35.3, 27.3, 20.7 and 17.0 d at 16, 20, 24 and 28°C, respectively by Kim et al. (2008), unlike the results of this present study. This was thought to be due to host plant and species differences. Also, it is reasonable to conclude that fecundity and longevity of *P. citri* females were affected by temperature (Table 3).

Table 3. Development durations (d) of mature biological stages and the total fecundity (Eggs/female/day) of *Planococcus citri* females on grapefruit leaves under different temperature regimes (mean ± SE)*

Temperature (°C)	n	Preoviposition period	Oviposition period	Postoviposition period	Longevity of females	Total fecundity
15	16	32.0±1.87 b	40.9±3.92 c	7.5±1.82 b	80.4±4.84 c	104.1±23.89 a
20	15	17.5±2.26 a	21.7±1.85 b	3.7±1.35 ab	41.4±2.53 b	144.9±28.39 a
25	23	13.3±0.59 a	15.4±1.09 ab	2.8±0.45 a	30.7±1.11 a	112.7±15.81 a
25/30	30	13.1±0.91 a	15.7±0.81 ab	3.1±0.43 a	31.9±1.16 ab	149.7±15.45 a
30	11	13.3±1.87 a	13.4±1.06 a	3.1±0.62 a	29.5±2.31 a	60.7±17.47 a
35	50	No development				

* Means (± SE) sharing same letter within same column are not significantly different from each other (Tukey's HSD multiple range test at $P < 0.05$) ($F_{Preoviposition} = 31.569$, df = 4,90, $P = 0.000$; $F_{Oviposition} = 33.650$, df = 4,90, $P = 0.000$; $F_{Postoviposition} = 4.073$, df = 4,90, $P = 0.005$; $F_{Longevity} = 74.832$, df = 4,90, $P = 0.000$; $F_{Number\ of\ eggs} = 2.646$, df = 4,90, $P = 0.039$).

As shown in Table 4, the highest hatching rate of *P. citri* eggs on grapefruit leaves was obtained at 25/30°C with 100%, and the lowest one was 76.3% at 20°C. However, no hatching was observed at 35°C.

Mortality in immature stage ranged from 8.8 to 42.2% under different temperature regimes and while the most death was in the third nymph stage among immature stages, the least death ratio was calculated in pupal stage. Also, the mean amount of death in immature stage was higher than that in the preoviposition period. The highest mortality was at 30°C with 42.2% in immature stage and at 15°C with 27.3% in the preoviposition period (Table 4). A study on the effect of temperature on biological parameters of *P. citri* by Goldasteh et al. (2009) found that the lowest mortality on *Solenostemon scutellarioides* (L.) R.Br. was in the first and second nymph stages at 25°C.

Table 4. Hatching rate of eggs and mortality rates in different biological stages of *Planococcus citri* on grapefruit leaves under different temperature regimes

Temperature (°C)	Hatching rate		Mortality rate (%)							Sex ratio
	n		n	First nymph stage	Second nymph stage	Third nymph stage	Pupal stage	Mortality in immature stage	Mortality in preoviposition period	♂:♀
15	104	85.9	63	3.2	8.2	11.11	6.2	17.5	27.3	1:0.5
20	118	76.3	42	2.4	14.6	15.80	0.0	23.8	15.8	1:1.2
25	105	99.1	41	2.4	2.5	12.50	0.0	14.6	17.9	1:3.0
25/30	100	100.0	57	0.0	1.8	8.60	4.8	8.8	6.2	1: 1.5
30	106	92.5	45	20.0	13.9	19.20	0.0	42.2	26.7	1: 1.1
35	600	No development and hatching								

Life table parameters of *P. citri* on grapefruit leaves under different temperature regimes are given in Table 5. While the highest intrinsic rate was obtained at 25/30°C with 0.108 females/female/day, the least one at 15°C with 0.036 females/female/day (Table 5).

Table 5. Life table parameters of *Planococcus citri* on grapefruit leaves under different temperature regimes

Temperature (°C)	n	Intrinsic rate of increase, r_m [1]	Net reproductive rate, R_o [2]	Mean generation time, T_o	Gross reproduction rate, *GRR*	Theoretical population-doubling time, T_2	Finite rate of increase, λ
15	24	0.036±0.002 c	52.17±2.185	115.2	75.7	22.4	1.031
20	21	0.059±0.004 b	67.09±3.193	74.5	117.9	12.4	1.057
25	31	0.100±0.005 a	80.69±2.359	45.6	132.9	6.9	1.105
25/30	35	0.108±0.003 a	82.28±1.935	42.7	133.0	5.0	1.123
30	20	0.064±0.008 b	22.69±1.696	53.8	44.8	13.7	1.052
35	50	No development					

[1] Means (± SE) of the intrinsic rate of increase sharing same letters within same row do not differ significantly from each other (Tukey's HSD multiple range test at $P < 0.05$; $F_{Intrinsic\_rate} = 44.583$, df = 4,126, $P = 0.000$). [2]The net productive rate and SE were assed bootstrap technique (5000 times).

The net reproductive rate ranged from 22.69 to 82.28 females/female/offspring and the highest one was seen at 25/30°C. The longest mean generation time was observed at 15°C with 115.210 d (Table 5). Moreover, the age-specific survival rates (lx) and fecundities (mx) of *P. citri* females on grapefruit leaves under different temperature regimes are shown Figure 1.

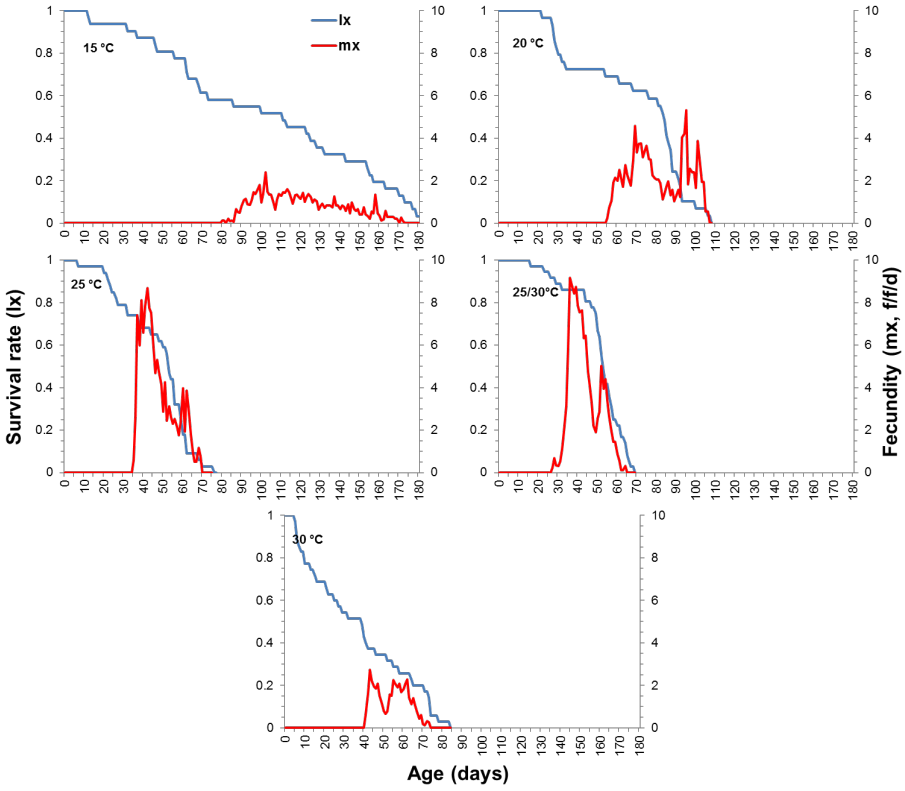

Figure 1. Age-specific survival rates (l_x) and fecundities (m_x) of *Planococcus citri* females on grapefruit leaves under different temperature regimes.

A linear regression analysis was applied to the developmental points within the 15 to 27.5°C range. Development at 30°C was outside the linear segment of the growth curve and therefore excluded from the linear regression. Within the chosen temperature range the developmental rates of *P. citri* increased linearly with increasing temperature. Development rates of *P. citri* at the different temperature regimes were modeled by linear regression line (y = a ± bx) (Figure 2). According to the results of the regression model fitted separately for the data obtained from males and females of *P. citri*, the development rate equation of females was found as Develop. rate = 0.0024*Temp.-0.0231 (R^2 = 0.95; P ≤ 0.05) for egg to adult stage and Develop. rate = 0.0015*Temp.-0.0128 (R^2 = 0.97; P ≤ 0.05) for egg to egg stage. For male *P. citri*, the formula of the development rate equation was Develop. rate = 0.002*Temp.-0.0191 (R^2 = 0.99; P ≤ 0.05) in egg to adult stage. Based on these equations, the development thresholds and thermal constants were calculated as shown in Table 6.

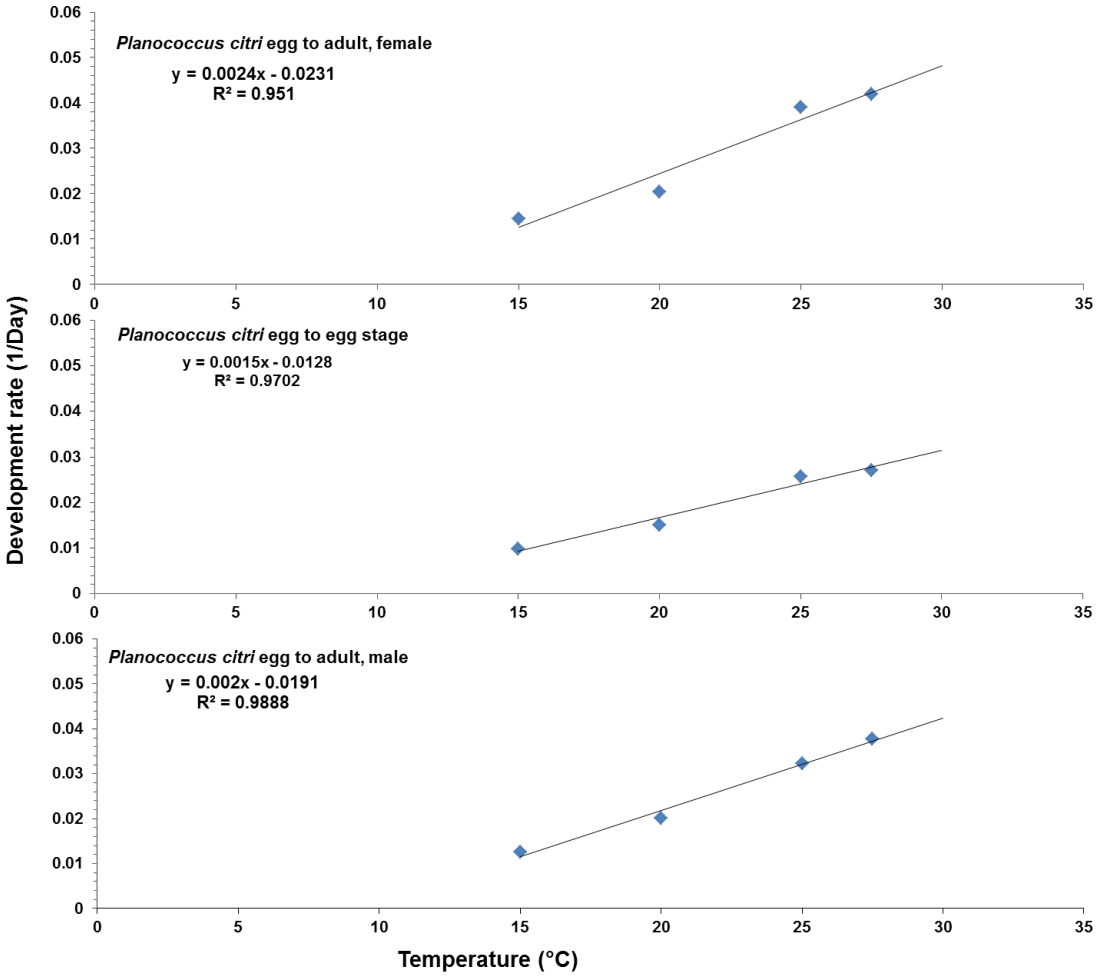

Figure 2. Temperature-dependent development rate of *Planococcus citri* at three constant and one alternating temperature (27.5°C for 25/30°C) on grapefruit leaves. Line is the linear regression analysis of developmental rate and temperature within the range of 15 to 27.5°C

Table 6. Regression equations and parameters of development rates of *Planococcus citri* on grapefruit leaves under different temperature regimes

Equations and parameters	Female from egg to adult stage	Female from egg to egg stage	Male from egg to adult stage
Equation	y = 0.0024x - 0.0231	y = 0.0015x - 0.0128	y=0.002x - 0.0191
Development threshold (-a/b) (°C)	9.63	8.53	9.55
Thermal constants (1/b) (°C.Day)	416.67	666.67	500.00
R^2	0.95	0.97	0.99

Asiedu et al. (2014) determined that total developmental time, female longevity and mean egg number laid by female of *P. citri* were 24.4 to 37.0 d, 32.9 to 38.1 d and 257 to 497 eggs/female, respectively. Francis et al. (2012) studied on the biological characteristics of the passion vine mealybug, *P. minor* at five constant temperatures (15, 20, 25, 29 and 35 °C) and 60±10% RH under constant light, and found that there was no development at 15 and 35°C. Also, male of *P. minor* completed their development from egg to adult in 51.5, 32.8 and 27.5 d under 20, 25 and 29°C, respectively. For females, the development from egg to adult lasted 48.8, 30.8 and 26.9 d at 20, 25 and 29°C, respectively.

The data analysis conducted at the end of the study showed that the optimum development temperature for *P. citri* was 25/30°C and the results showed that the pest can complete the most successfully its life cycle at 25/30°C. The last point should be noted as this temperature has a significant role on planning of control programs against this pest. When viewed from this aspect, the period in which the average temperature in the microclimate of the tree, especially grapefruit that has fruit settle inside the tree canopy, is 25/30°C in Adana Province is between July and September, and the most effective period for this insect in terms of reproductive and abundance is September. However, insecticide application conducted against this pest in this period may create significant residue problems for fruit in marketing and consumption. Herewith, the application of insecticides with low side effects against overwintering individuals on citrus trees, and before neonate crawlers settled under calyx of citrus fruit in end of spring will reduce the reproductive capacity and enable an increase in the success of biological control. In addition, such an approach will be a more environmentally-friendly in terms of IPM.

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