Effect of Different Temperatures on the Life Table Parameters of *Rhyzobius Lophanthae* Blaisdell (Coleoptera: Coccinellidae)

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Abstract

The purple scale predator, *Rhyzobius lophanthae* Blaisdell (Coleoptera: Coccinellidae) is known as coccidophagous ladybird predator, and effective against scales' insects. The present study aimed to evaluate the optimum temperature for the species to be more efficient. In this study, the life table parameters of *R. lophanthae* were determined on different temperatures at 4, 16, 18, 20, 22, 24, 26, 28, 30 and 32 °C and 60% RH, by calculations using RmStat-3 software according to Euler-Lotka equation. The results showed that the intrinsic rates of increase (r_m) were 0.016, 0.022, 0.030, 0.052, 0.056, 0.068, 0.120, 0.142, 0.132, 0.021 females/females/day, respectively, while the net reproductive rates (R_0) were 7.082, 9.514, 11.960, 50.906, 54.150, 49.525, 56.883, 80.944, 31.149, 1.882 females/females/generation, respectively. The mean generation times (T_0) were 125.966, 104.602, 84.009, 75.742, 71.511, 57.568, 33.801, 30.866, 25.978, 30.759 days, respectively. Total productivity rates (GRR) were 34.865, 39.210, 48.216, 201.990, 209.469, 166.207, 177.779, 303.751, 105.751, 12.622 egg/female, respectively. The study concluded that 26-30 °C was the optimum temperature range for the efficient role of *R. lophanthae* under laboratory conditions. From the results, it is still needed to do more studies on the interactions of pests, predators with environmental conditions.

Introduction

Citrus trees production in Turkey has been affected by different insect pests including scale insects that have been increased recently. For controlling such pests, the intensive use of chemical pesticides has led to decrease the role of natural enemies; caused pesticides residues in the agricultural productions, environmental pollution and negative effects on human health. Producers of citrus have preferred to use various methods and reduce pest populations. Biological control is one of these methods and can be a promise way to control pests (Uygun & Karaca, 1998). The purple scale predator, *Rhyzobius lophanthae* Blaisdell (Coleoptera: Coccinellidae) is known as an important coccidophagous ladybird predator and very effective against soft scales insects and is frequently observed in citrus and other fruit orchards where scale insects are present (Branco et al., 2017). *R. lophanthae* is native to Australia and has distributed too many regions of the world as a biological control agent (Hodek & Honek, 1996). The predator has been reported on many countries, except Turkey as an important biocontrol agent of scale insects (Stathas et al., 2002; Mellado, 2011). As reported in many studies the development and efficacy of many predator and parasitoid insects are affected by temperature (Luhning et al., 2019; Gao et al., 2020; Kayahan & Karaca, 2020). The present study aimed to evaluate the effect of 10 different temperatures on the life table parameters of predator, *R. lophanthae* under laboratory conditions.

Materials And Methods

Culture of *Aspidiotus nerii* Bouché

Aspidiotus nerii was used as a prey in the present study. The culture of soft scale insect was obtained from the mass production at the laboratory from Biological Control Research and Application Center,

Faculty of Agriculture, Isparta University of Applied Sciences, Turkey. The *A. nerii* was continued reproductive in weekly periods of the study. *A. nerii* was reared on potato tubers (*Solanum tuberosum* L.). Infested potato tubers with *A. nerii* were placed on the clean potatoes for increasing the population culture of the pest to be used in experiments.

Culture of *Rhyzobius lophanthae*

Rhyzobius lophanthae samples were collected from citrus orchards in Adana Province located in Turkey. The predators were collected, using shaking method of the infested citrus branches. A laboratory colony of *R. lophanthae* was raised under incubator chamber at $25\pm1^{\circ}\text{C}$, $65\pm5\%$ RH with 16L: 8D light conditions at the Department of Plant Protection, Isparta University of Applied Sciences, Turkey. The predator individuals were used as a stock culture for experiments.

Experimental design

This study was carried out in incubators that set up on 10 different temperatures degrees (14, 16, 18, 20, 22, 24, 26, 28, 30 and 32°C), and 60% RH with a light period of (16L: 8D). Fresh 40 *R. lophanthae* adults (20 male, 20 female) newly emerged from pupae were collected. Then, all adults were placed on the potato tubers infested with *A. nerii* and left in a plastic container (9x9x5 cm dimensions). After rearing 20 pairs of the predator for 15 days on potatoes under the laboratory conditions, the eggs laid by the predator on potato tubers were collected by using a soft sable brush to avoid damaging the eggs. Each egg was placed on an infested potato tuber using a soft brush. Then, the larvae of *R. lophanthae*, were exposed to different temperatures until the adult stage. The experiment was continued with the pairs formed after the emergence of adult individuals from the pupae. For this purpose, female and male individuals were left on each potato infested with *A. nerii* depending on the temperature. After this process, daily checks of the replicates were made. Daily number of eggs deposited by female individuals was determined and the trials continued until the last predator died. Life tables' parameters of *R. lophanthae* at each temperature were recorded based on the data obtained. Replicates were examined daily under a stereomicroscope (Leica S6D) to record the predator life table parameters. Data obtained from the experiments were recorded to determine the development of age-related life tables for each temperature that used.

Statistical analyzes

Life table parameters of the predator were calculated by using RmStat-3 software (Özgökçe & Karaca, 2010) according to Euler-Lotka equation (Birch, 1948) and were evaluated separately. Tukey multiple comparison test was used for comparison of the periods with SPSS (ver. 17) at the significant difference $p<0.05$ level. To calculate the parameters, several equations were used which were:

Age-related survival rate (l_x), Fertility rate (m_x) (Birch, 1948);

Reproductive value (V_x) $V_x = \frac{\sum_{y=x}^{\infty} (e^{r_m \cdot y} \cdot l_y \cdot m_y)}{l_x \cdot e^{-r_m \cdot x}}$ (Imura, 1987);

Expected remaining life time (E_x) $E_x = \frac{\sum_{y=x}^{\infty} \frac{l_y + l_{y+1}}{2}}{l_x}$ (Southwood, 1978; Carey, 1993);

Stable age distribution (C_x) $C_x = \frac{l_x \cdot e^{-r_m \cdot x}}{\sum_{x=0}^{\infty} (l_x \cdot e^{-r_m \cdot x})}$ (Birch, 1948);

Net Production Rate (R_0) $R_0 = \sum l_x \cdot m_x$ (Birch, 1948);

Intrinsic Rate of Increase (r_m) $\sum e^{(-r_m \cdot x)} l_x \cdot m_x = 1$ (Birch, 1948);

Mean Generation Time (T_0) $T_0 = \frac{\ln R_0}{r_m}$ (Birch, 1948);

Total Productivity Rate (GRR) $GRR = \sum m_x$ (Birch, 1948);

Daily maximum reproductive value (λ) $\lambda = e^{r_m}$ (Birch, 1948);

Doubling time (T_2) $T_2 = \frac{\ln 2}{r_m}$ (Kairo and Murphy, 1995).

The pseudo-rmij values were calculated with according to the Jackknife method (Meyer et al., 1986; Özgökçe & Atlıhan, 2004) including the use of intrinsic rate of increase values that were calculated for these populations in comparison tests.

Results

Daily and total numbers of eggs of the predator *R. lophanthae* at different temperatures were significantly different according to Tukey multiple comparison tests, which were ($F_{DNE} = 73.62$; $DF = 9$; $P \leq 0.001$; $F_{TNE} = 18.75$; $DF = 9$; $P \leq 0.001$). Daily numbers of eggs increased with increasing the temperature degree until 28°C, afterwards, the numbers of eggs decreased. The lowest daily number of eggs was 0.70 ± 0.14 eggs, calculated at 14°C. While the highest daily number of eggs (11.17 ± 0.65 eggs) was recorded at 28°C. In other words, the lowest total numbers of eggs were 64.2 ± 12.1 and 30.9 ± 3.72 eggs, respectively, were determined at 14 and 32°C; while the highest total numbers of eggs (479.7 ± 54.6 eggs) were found at

28°C. Both of daily and total egg numbers were obtained at 28°C and were found statistically different from the number of eggs that recorded at other temperature degrees (Fig. 1).

At the end of the experiment, life table parameters of *R. lophanthae* were determined at 10 different temperature degrees. According to the statistical analyzes, Intrinsic Rate of Increase (r_m) were 0.016, 0.022, 0.030, 0.052, 0.056, 0.068, 0.120, 0.142, 0.132 and 0.021 females/female/day, respectively. The differences of pseudo-rmij values were determined according to Tukey multiple comparison test. The Net Reproductive Rate (R_0) were 7.082, 9.514, 11.960, 50.906, 54.150, 49.525, 56.883, 80.944, 31.149 and 1.882 females/female/generation, respectively. The lowest R_0 value (1.882) was calculated at 32°C, whereas the highest value of R_0 (80.944) was found at 28°C. Mean Generation Time (T_0) was calculated and the results recorded were 125.966, 104.602, 84.009, 75.742, 71.511, 57.568, 33.801, 30.866, 25.978 and 30.759 days, respectively (Table 1). The results of Total Productivity Rate (GRR) recording the highest value, was 303.751 eggs/female at 28°C. The shortest period of Doubling Time (T_2) was (4.869 days) and calculated at 28°C; while the longest period value was found (44.604 days) at 14°C. The lowest Daily Maximum Reproductive Value (λ) was (1.016 individual/female/day) at 14°C, while the highest value was 1.153 individual/female/day at 28°C (Table 1).

Table 1
Life table parameters of *Rhyzobius lophanthae* at different temperatures

	14°C	16°C	18°C	20°C	22°C
Intrinsic rate of increase, r_m	0.016 ± 0.000052 j	0.022 ± 0.000049 h	0.030 ± 0.000074 g	0.052 ± 0.000133 f	0.056 ± 0.000126 e
Pseudo- r_{mij}	0.0156 ± 0.00273 e	0.0219 ± 0.00258 de	0.0288 ± 0.00364 cde	0.0528 ± 0.00398 bcd	0.0563 ± 0.00402 bc
Net reproductive rate, R_0	7.082 ± 0.0436 i	9.514 ± 0.0481 h	11.960 ± 0.0682 g	50.906 ± 0.507 d	54.150 ± 0.477 c
Mean generation time, T_0	125.940 ± 0.0327 a	104.610 ± 0.0368 b	84.015 ± 0.0349 c	75.758 ± 0.0818 d	71.509 ± 0.0604 e
Total productivity rate, GRR	34.865 ± 0.126 i	39.210 ± 0.103 h	48.216 ± 0.137 g	201.780 ± 0.755 c	209.360 ± 0.514 b
Doubling time, T_2	44.648 ± 0.157 a	32.206 ± 0.0750 c	23.482 ± 0.0623 d	13.370 ± 0.0347 e	12.423 ± 0.0283 e

Different letters on the same parameters and same line show that there is a statistical difference according to Tukey, $p < 0.05$.

	14°C	16°C	18°C	20°C	22°C
Daily maximum reproductive value, λ	1.0157 ± 0.000052 j	1.0218 ± 0.000050 h	1.0300 ± 0.000077 g	1.0532 ± 0.000140 f	1.0574 ± 0.000133 e
N	54	54	50	31	51
	24°C	26°C	28°C	30°C	32°C
Intrinsic rate of increase, r_m	0.068 ± 0.000113 d	0.120 ± 0.000133 c	0.142 ± 0.000128 a	0.132 ± 0.000263 b	0.021 ± 0.000261 i
Pseudo- r_{mij}	0.0684 ± 0.00431 b	0.1209 ± 0.00652 a	0.1419 ± 0.00757 a	0.1336 ± 0.01050 a	0.0235 ± 0.01300 cde
Net reproductive rate, R_0	49.525 ± 0.313 e	56.883 ± 0.237 b	80.944 ± 0.313 a	31.149 ± 0.198 f	1.882 ± 0.0140 j
Mean generation time, T_0	57.570 ± 0.0354 f	33.805 ± 0.0087 g	30.862 ± 0.0112 h	25.978 ± 0.0089 i	30.775 ± 0.0138 h
Total productivity rate, GRR	166.180 ± 0.582 e	177.799 ± 0.138 d	303.751 ± 0.435 a	105.660 ± 0.254 f	12.622 ± 0.0420 j

Different letters on the same parameters and same line show that there is a statistical difference according to Tukey, $p < 0.05$.

	14°C	16°C	18°C	20°C	22°C
Doubling time, T_2	10.228	5.800	4.869	5.239	34.167
	±	±	±	±	±
	0.0173	0.0065	0.0044	0.0106	0.574
	f	g	h	gh	b
Daily maximum reproductive value, λ	1.0701	1.1270	1.1530	1.1415	1.0207
	±	±	±	±	±
	0.000121	0.000150	0.000148	0.000300	0.000265
	d	c	a	b	i
N	39	50	60	41	51
Different letters on the same parameters and same line show that there is a statistical difference according to Tukey, $p < 0.05$.					

The results of the values of Age-related survival rate (l_x), Fertility rate (m_x), Reproductive value (V_x), Stable age distribution (C_x) and Expected remaining life time (E_x) of *R. lophanthae* calculated at different temperature degrees indicated that fertility rate and reproductive values that obtained at 28°C were 5.63 ± 0.67 and 30.60 ± 3.05 , respectively, were determined at different temperature degrees according to the statistical analyzes ($F_{mx} = 41.01$; $DF = 9$; $P \leq 0.001$; $F_{Vx} = 34.32$; $DF = 9$; $P \leq 0.001$). Other values which were l_x , C_x and E_x of *R. lophanthae* were illustrated in Fig. 2.

Discussion

Stathas (2000) determined that the daily number of eggs ranged between 18 and 24 eggs when the predator *R. lophanthae* development was at 25°C and reported that the duration of the predator development from egg to adult was lower 24.82 days. Nar et al. (2009) studied the development of *R. lophanthae* at different temperatures (15, 20, 25, 30 and 35°C) for a daily number of eggs that was calculated as 2.0, 7.0, 13.6, 7.1 and 3.6 eggs, respectively. Şimşek et al. (2016) determined the development of *R. lophanthae* on 3 different preys (*Aspidiotus nerii*, *Chrysomphalus dictyospermi*, *Aonidiella aurantii*) and at 26°C. The daily number of eggs was 5.53, 5.16 and 2.75 eggs depending on the predator feeding on preys, respectively. When compared with the studies conducted, it is seen that the data we obtained are close.

Stathas et al. (2005) determined that the development of *R. lophanthae* at 25°C and recorded an increase in the intrinsic rate and found 0.122 females/female/day. Nar et al. (2009) found r_m values as 0.038, 0.091, 0.155, 0.127 and 0.103 females/female/day at different temperature degrees 15, 20, 25, 30 and 35°C, respectively. Şimşek et al. (2016) determined that r_m values on 3 different preys; *A. nerii*, *C.*

dictiospermi and *A. aurantii* at 26°C and the values were 0.120, 0.061 and 0.041 females/female/day, respectively. When the data obtained are examined, it is seen that the intrinsic rate of increase values obtained were close. It is thought that this is due to the fact that these studies were carried out at similar temperature values.

Stathas et al. (2005) found the net reproductive rate (R_0) of *R. lophanthae* at 25°C was 346.2 females/female/generation. Nar et al. (2009) indicated that the development of *R. lophanthae* at different temperature degrees (15, 20, 25, 30 and 35°C) were 82.5, 157.4, 217.8, 127.5 and 53.3 females/female/generation, respectively. Şimşek et al. (2016) determined that the development of *R. lophanthae* fed on different preys which were *A. nerii*, *C. dictiospermi* and *A. aurantii* at 26°C and R_0 values were found as 36.027, 12.520 and 6.600 females/female/generation, respectively. It was observed that the net reproductive power value obtained in our study was higher than Şimşek et al. (2016) and lower than the other two studies. This difference is thought to be due to the difference in the number of repetitions.

Nar et al. (2009) calculated mean generation times (T_0) of *R. lophanthae* at different temperatures 15, 20, 25, 30 and 35°C and recorded the value of T_0 115.8, 55.6, 34.7, 38.2 and 37.1 days, respectively. In a follow up study, Şimşek et al. (2016) reported that examined the development of *R. lophanthae* fed on three different preys at 26°C, calculated the value of T_0 and recorded 30.005, 41.151 and 45.826 days, respectively. When the data obtained are examined, it is seen that the mean generation times obtained were close. This similarity is thought to be due to the same temperature values.

Şimşek et al. (2016) were calculated the total productivity rate as 125.542, 65.111 and 41.369 eggs/female, respectively when the predator *R. lophanthae* fed on three different preys *A. nerii*, *C. dictiospermi*, *A. aurantii* at 26°C. It is seen that the value obtained in our study is higher than Şimşek et al. (2016). Stathas et al. (2005) were calculated the doubling time (T_2) of *R. lophanthae* to be 5.7 days at 25°C. Nar et al. (2009), in their study which were examined the development of *R. lophanthae* at different temperature degrees 15, 20, 25, 30 and 35°C, and calculated the T_2 as 18.19, 7.62, 4.47, 5.45 and 6.47 days, respectively. However Şimşek et al. (2016) were calculated T_2 of *R. lophanthae* fed on different preys *A. nerii*, *C. dictiospermi*, *A. aurantii* at 26°C and their results were 5.803, 11.286 and 16.832 days, respectively. According to the data obtained, the doubling time was determined similar with Stathas et al. (2005) and Şimşek et al. (2016), while this value was determined by Nar et al. (2009) was observed to be lower. This difference between the values is thought to be due to the number of repetitions.

Stathas et al. (2005) mentioned in their study, the determination of *R. lophanthae* the development at 25°C, which were calculated the daily maximum reproductive value (1.13 individual/female/day). Nar et al. (2009) calculated daily maximum reproductive value at different temperature degrees 15, 20, 25, 30 and 35°C and recorded 1.038, 1.095, 1.167, 1.135 and 1.113 individual/female/day, respectively, while Şimşek et al. (2016) found this value of *R. lophanthae* that fed on three different preys *A. nerii*, *C. dictiospermi*, *A. aurantii* at 26°C were 1.127, 1.063 and 1.042 individual/female/day, respectively. When the results obtained were compared with these studies, it was observed that the values were close.

Conclusions

The present study was carried out to select the optimum temperature for mass production of *R. lophanthae* as an efficient predator of citrus scale insect pests. Results demonstrated that the best development degree and maximum fecundity of the predator was at 28°C.

Declarations

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Figures

Figure 1

Figure 1

Daily and total numbers of eggs of *Rhyzobius lophanthae* at different temperatures. Different letters on different columns show that there is a statistical difference according to Tukey, $p < 0.05$ ($F_{DNE} = 73.62$; $DF = 9$; $P \leq 0.001$; $F_{TNE} = 18.75$; $DF = 9$; $P \leq 0.001$) (DNE: Daily number of eggs; TNE: Total number of eggs; DF : Degree of Freedom; SE : Standart Error)

Figure 2

Figure 2

Age-related survival rate (l_x), Fertility rate (m_x), Reproductive value (V_x), Stable age distribution (C_x), Expected remaining life time (E_x), (From top to bottom). Different letters on different columns show that there is a statistical difference according to Tukey, $p < 0.05$ ($F_{l_x} = 1.17$; $DF = 9$; $P = 0.309$; $F_{m_x} = 41.01$; $DF = 9$; $P \leq 0.001$; $F_{V_x} = 34.32$; $DF = 9$; $P \leq 0.001$; $F_{C_x} = 21.61$; $DF = 9$; $P \leq 0.001$; $F_{E_x} = 40.49$; $DF = 9$; $P \leq 0.001$)