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The effect of temperature on development and fecundity of *Scymnus levaillanti*

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Abstract. Development and fecundity of *Scymnus levaillanti* (Mulsant) were recorded at five constant temperatures ranging from 15 to 35 ± 1 °C in 5 °C increments, 60 ± 5% RH and 16 h of artificial light (5000 Lux). Developmental time (egg to adult) of *S. levaillanti* significantly decreased with increasing temperatures, ranging from 63.9 days at 15 °C to 11.1 days at 35 °C. Development from egg to adult required 305.2 DD above a developmental threshold estimated as 11.7 °C. Oviposition periods lasted 86.5, 76.1, 47.2, and 31.5 days at 20, 25, 30 and 35 °C, respectively. No eggs were deposited at 15 °C. Higher temperatures resulted in shorter generation times (T_O) and in decreased net reproductive rates (R_O) of the coccinellid. *S. levaillanti* kept at 30 °C produced 0.151 females/female/day, the highest per capita rate of population growth (r_m). The 'functional response' of larvae and adults of *S. levaillanti* matches well that described by Holling (1959) as Type 2. Daily number of eggs deposited by females increased to a plateau with increasing prey density. Results obtained here provide information about the biology of *S. levaillanti*, and its feeding capacity indicates that it may act as an important control agent.

Key words: development, fecundity, functional response, reproductive numerical response, temperature, Coccinellidae, *Aphis gossypii*, *Scymnus levaillanti*

Introduction

The lady beetle, *Scymnus levaillanti* (Mulsant) (Coleoptera: Coccinellidae) is a widespread aphidophagous predator in Turkey, in particular in the eastern Mediterranean region (Uygun 1981; Zeren and Düzgüneş, 1983). *S. levaillanti* is considered an important natural enemy of *Aphis* spp. in citrus (Yumruktepe and Uygun, 1994) and *Aphis gossypii* Glover (Homoptera: Aphididae) in cotton (Ghawami and Özgür, 1992; Atakan and Özgür, 1994), capable of reducing significantly pest population levels.

Studies on *S. levaillanti* have primarily concentrated on taxonomic or faunistic aspects of this predator (Mader, 1955; Bielawski, 1963; Uygun, 1981). In spite of the wide distribution and apparent economic importance of *S. levaillanti*, very little is known about its biology, ecology, and efficacy. Such information is essential for improvement of IPM or biological control programs in citrus and cotton.

The presented studies were designed to study the effects of different temperatures on development and fecundity, as well as the functional and numerical response of *S. levaillanti* on *A. gossypii* under controlled laboratory conditions.

Materials and methods

Insect rearing

Scymnus levaillanti was obtained from citrus orchards near Adana in the eastern Mediterranean region of Turkey and reared on cotton plants (*Gossypium hirsitum* L.) with *A. gossypii* as prey at 25 ± 2 °C, 65 ± 5% RH and 16 h of artificial light of about 4000 Lux in a controlled environment room. Every week the cotton plants in the rearing cages were replaced with new plants infested with *A. gossypii*. The cotton aphid was separately cultured on 4–6 weeks old, potted cotton plants, cv. Çukurova 1518 under the same conditions as the predator.

Development and fecundity

To determine developmental time and fecundity of *S. levaillanti*, newly laid eggs were picked randomly from rearing cages and transferred to Petri dishes (3.5 cm in diameter). The hatched larvae were confined individually onto small leaf disks infested with *A. gossypii* in Petri dishes. Every day new ample food was provided. Duration and the mortality of different developmental stages were recorded by daily observations at all temperatures. After adult eclosion, one female and one male were transferred to new Petri dishes and mortality and number of eggs laid were recorded daily until all adults died. Sex ratio was determined after preparation of genitalia (according to Uygun, 1981) from the adults reared at all temperatures except 15 °C, at which females did not deposit any eggs. The insects were reared at five constant temperatures ranging from 15–35 ± 1 °C in 5 °C increments, 60 ± 5% RH and 16 h of artificial light (5000 Lux) in temperature cabinets.

Prey consumption and reproductive numerical response

The functional responses of larvae and adults of *S. levaillanti* were determined at prey densities of 4, 8, 16, 32 and 64 adult *A. gossypii* in Petri dishes (3.5 cm in diameter) at 25 ± 1 °C, 65 ± 5% RH and 16 h artificial light. A single *S. levaillanti* larva of each developmental stage, males and females, were separately released into the cells for 24 h and the number of prey consumed counted. Similarly the reproductive numerical response to different prey densities was studied during the whole oviposition period of *S. levaillanti*.

Data analysis

Differences in developmental time, longevity, and fecundity were tested by analysis of variance (ANOVA). If significant differences were detected, multiple comparisons were made using Duncan's Multiple Range Test (α = 0.05). A linear technique was employed to compute the lower development threshold of the egg stage and the developmental time (egg to adult) by using the growth rate data as dependent variable and temperature treatments as independent variable. The lower developmental threshold was determined as the x-intercept of the linear equation and the degree-day (DD) requirements were determined as the value of the inverse of the linear equation slope. Differences in sex ratio were tested by Chi-square test (p = 0.05). Population growth rates were calculated according to Andrewartha and Birch (1970):

$$1 = \sum e^{r*x} 1_x * m_x \quad (1)$$

in which: x = age in days, r = intrinsic rate of increase, l_x = age-specific survival, m_x = age-specific number of female offspring.

Each of the above mentioned analyses were conducted using Statgraphics software package (Statistical Graphics Corporation, 1988).

Results

Development and fecundity

The egg incubation period of *S. levaillanti* decreased significantly with increasing constant temperatures ranging from 17.1 days at 15 °C to 3.0 days at 35 °C (Table 1). There was no significant difference between 30 °C and 35 °C. A linear regression analysis was applied to the egg development points within a 15–35 °C temperature range. Developmental rates for the egg stage ($r_{[Te]}$) of *S. levaillanti* increased linearly with increasing temperature ($r_{[Te]}$. = $0.014 * T - 0.164$; $R^2 = 0.97$; $F = 83.8$; $p = 0.0028$) (Figure 1). The theoretical developmental threshold of the egg stage was estimated as 11.1 °C and 69.4 DD were required for hatching.

The post-embryonic developmental time (four larval stages plus the pupal stage) was shortest at 35 °C (8 days) and increased significantly to 47.1 days at 15 °C (Table 1). The duration of 4th instar larva and pupa was longer than each of the other instars individually, but the development time of the pupa was longer than the 4th instar larva. The total developmental time (egg to adult) ($r_{[Tt]}$) of *S. levaillanti* also decreased linearly with increasing temperature ($r_{[Tt]}$. = 0.0033 ∗ T – 0.0384; R^2 = 0.99; F = 360.9; p = 0.0003) (Figure 1). From the regression analysis, the developmental threshold was estimated as 11.7 °C. Based on the developmental threshold, complete development from egg to adult required 305.2 DD.

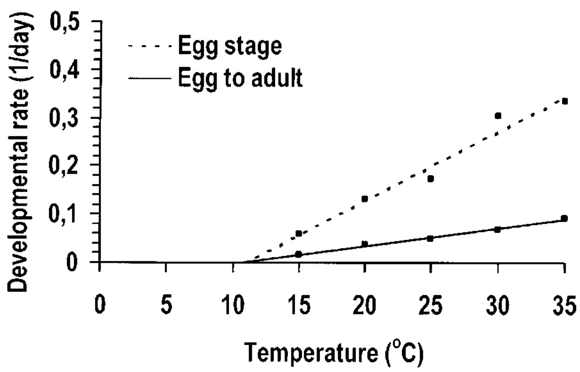

Figure 1. Developmental rate of eggs and total developmental rate (eggs to adult) of *Scymnus levaillanti*. Line represents the linear regression analysis of developmental rate and temperature within the range of 15–35 °C.

The mortality rate of the egg stage was 78%, 22%, 16%, 23% and 67% at 15, 20, 25, 30 and 35 °C respectively. In immature stages mortality occurred at only the first larval stage at all temperatures, and in the pupal stage at 15 °C and 35 °C. Total mortality (from egg to adult) was relatively low at 20 °C (27.2%), 25 °C (18.7%) and 30 °C (28.1%), but considerably high at 15 °C (81.7%) and 35 °C (71.4%).

The coccinellid deposited no eggs at 15 °C. Preoviposition, oviposition and postoviposition periods and the longevity of *S. levaillanti* were significantly longer at 20 °C than at the higher temperatures tested (Table 2). The highest oviposition rate was recorded at 30 °C (average 8.3 eggs per female per day), the lowest was 2.6 eggs per female per day at 35 °C. The overall fecundity was significantly lower at 35 °C (83.4 eggs/female) than at the other temperatures tested (Table 2). The sex ratio of the offspring in each treatment was close to 1:1 (51.1:48.9, 54.3:45.7, 58.1:41.9 and 56.6:43.4 at 20, 25, 30 and 35 °C respectively) according to chi-square test (p = 0.05). Survival rates of *S. levaillanti* adults decreased mainly at the end of the oviposition period at

Table 1. Mean duration of development of preadult stages in *Scymnus levaillanti* feeding on *Aphis gossypii* at five constant temperatures

Temperature		Duration of developmental stages (days) (mean ± SE)							
(°C)	n*	Egg stage	Stage 1	Stage 2	Stage 3	Stage 4	Pupa	Larva + Pupa	Egg to adult
15 ± 1	25	17.1 ± 0.80 a	5.9 ± 0.75 a	4.0 ± 0.31 a	4.6 ± 0.53 a	9.8 ± 0.87 a	22.6 ± 0.90 a	47.1 ± 2.07 a	63.9 ± 2.61 a
20 ± 1	28	7.6 ± 0.67 b	2.9 ± 0.34 b	2.0 ± 0.28 b	2.1 ± 0.20 b	3.8 ± 0.52 b	8.9 ± 0.70 b	19.6 ±1.13 b	27.3 ± 1.39 b
25 ± 1	29	5.8 ± 0.61 c	2.2 ± 0.47 c	1.6 ± 0.50 c	1.6 ± 0.56 c	3.0 ± 0.45 c	6.4 ± 0.50 c	14.9 ±1.20 c	20.6 ± 1.36 c
30 ± 1	28	3.3 ± 0.47 d	2.0 ± 0.20 c	1.0 ± 0.00 d	1.2 ± 0.37 d	2.5 ± 0.51 d	4.6 ± 0.50 d	11.2 ±0.47 d	14.7 ± 0.64 d
35 ± 1	26	3.0 ± 0.19 d	1.0 ± 0.00 d	1.0 ± 0.00 d	1.0 ± 0.00 d	1.1 ± 0.26 e	3.9 ± 0.20 e	8.0 ±0.21 e	11.1 ± 0.29 e

*Number of replicates represent the number that survived to adulthood.

Table 2. Mean fecundity and duration of preoviposition, oviposition, postoviposition periods, and longevity in *Scymnus levaillanti* feeding on *Aphis gossypii* at five constant temperatures

Temperature		Duration (days)			Longevity	No of eggs per female	
(°C)	n	Preoviposition mean ± SE	Oviposition mean ± SE	Postoviposition mean ± SE	(days) mean ± SE	per day mean ± SE	total mean ± SE
15 ± 1	18		No eggs l aid		174.6 ± 32.23 a		
20 ± 1	22	9.2 ± 0.89 a	86.5 ± 15.24 a	35.7 ± 4.80 a	133.2 ± 19.46 b	4.9 ± 1.16 c	428.2 ± 92.33 a
25 ± 1	26	6.3 ± 0.77 b	76.1 ± 8.28 b	25.3 ± 4.15 b	107.7 ± 21.29 c	5.9 ± 1.28 b	455.7 ± 87.72 a
30 ± 1	24	4.3 ± 0.56 c	47.2 ± 9.31 c	18.4 ± 1.56 c	69.9 ± 11.21 d	8.3 ± 2.22 a	393.1 ± 84.71 a
35 ± 1	21	4.1 ± 1.43 c	31.5 ± 12.68 d	11.3 ± 2.89 d	46.9 ± 12.63 e	2.6 ± 1.84 d	83.4 ± 51.09 b

Means in column followed by the same letter are not statistically different by Duncan test (p = 5%).

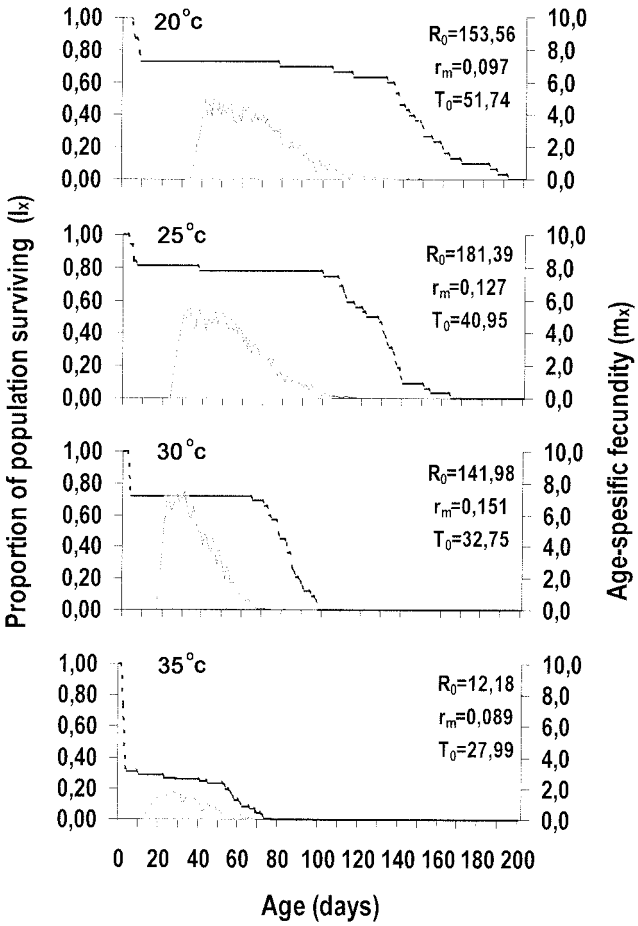

Figure 2. Survivorship curve (l_x) and age specific fecundity rate (m_x) of *Scymnus levaillanti* feeding on *Aphis gossypii* at four constant temperatures.

20, 25, and 30 °C. In contrast, a high mortality rate occurred at 35 °C before oviposition (Figure 2). Temperatures above 20 °C resulted in shorter generation times (T_O) and decreased net reproductive rates except at 25 °C, in which R_O was the highest. *S. levaillanti* kept at 30 °C showed the highest intrinsic rate of increase (r_m) with 0.151 females/female/day. 35 °C produced sharp reductions in the intrinsic rate of increase (r_m = 0.089 females/female/day) which was similar to that at 20 °C (r_m = 0.097 females/female/day) (Figure 2).

Prey consumption and numerical response

The consumption rate of larvae and adults of *S. levaillanti* increased with increasing prey densities up to 32 *A.gossypii*/day and then levelled off (Figure 3). Older larval stages and adults consumed more prey than younger stages, and females displayed a higher prey consumption than males at all five prey densities.

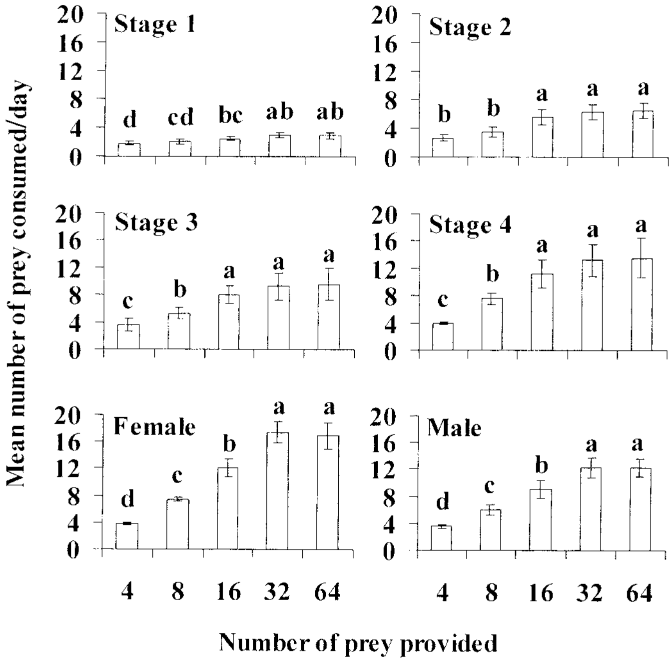

Figure 3. Prey consumption by larvae and adults of *Scymnus levaillanti* on increasing prey densities of *Aphis gossypii* adults.

Females offered 4 adult *A. gossypii* per day laid an average of 2.4 ± 0.48 eggs/day. This oviposition rate increased significantly to 5.8 ± 0.58 eggs/day at a prey density of 16 aphids per day, which was slightly higher than that at prey densities of 32 and 64 aphids per day. The total number of eggs laid per female increased significantly from 152.6 ± 37.38 eggs at a prey density of 4 aphids/day to 428.3 ± 81.35 eggs/day at a prey density of 32 aphids/day. However, there were no statistically significant differences among the prey densities of 16, 32, and 64 *A. gossypii*/day (Figure 4).

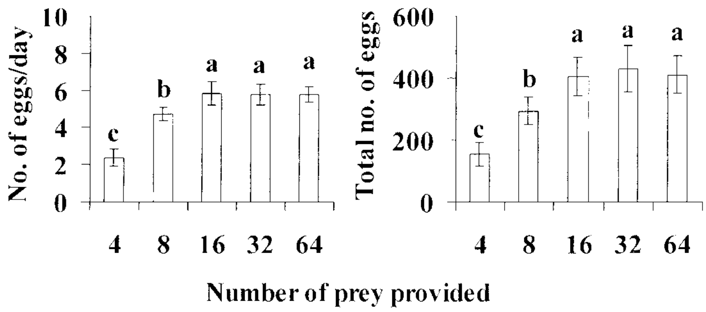

Figure 4. Numerical response of *Scymnus levaillanti* to increasing prey densities of *Aphis gossypii* adults.

Discussion

Very little information is available in the literature on developmental time, fecundity and responses to prey densities of *Scymnus* spp. and *S. levaillanti* in particular. Our results clearly show the effect of temperature on developmental time, mortality rate, longevity and fecundity of *S. levaillanti*. Controlled laboratory studies provide insights into the development and population dynamics of *S. levaillanti*, although insects are not subjected to constant temperature in nature. The related species *Scymnus* (*Pullus*) *hoffmanni* Weise (Coleoptera: Coccinellidae) displayed only a slightly longer developmental time (16.8 days at 25 °C) than *S. levaillanti* (14.9 days) (Kawauchi, 1983). In contrast, the same author reported a significantly lower net reproduction rate in *S. hoffmanni* of only 126.9 females/female compared with 181.4 females/female as observed in this study for *S. levaillanti* (Kawauchi, 1985).

The total number of eggs laid per female ranged between 393.1 and 455.7 at temperatures between 20 °C and 30 °C. These results are similar to those obtained by Gibson et al. (1992) for *Scymnus frontalis* (F.) (Coleoptera: Coccinellidae) with 413.6 eggs/female at 25 °C.

Furthermore, Tranfaglia and Viggiani (1973) reported that the longevity of *Scymnus includens* Kirsch. (Coleoptera: Coccinellidae) was 74 days, on average, at temperatures of 25–27 °C. Our results, and those reported in the literature, suggest that biological parameters within the genus *Scymnus* are quite similar for different species under similar temperature regimes.

Prey consumption of larvae and adults of *S. levaillanti* increased with increasing prey density. The maximum daily prey consumption by a female was 17 adult *A. gossypii* at a prey density of 32 aphids. A further increase in prey density to 64 aphids did not result in a higher prey consumption for any larval stage or for adults. The relevance of the laboratory experiments on prey consumption is, however, limited. *S. levaillanti* was confined with its prey in small Petri dishes, a condition that may, under high prey densities, result in an increased activity of the predator. Secondly, the time used by *S. levaillanti* in searching for food may reduce its prey consumption capacity under natural conditions. The results obtained should therefore be extrapolated with caution to field conditions. Nevertheless, the 'functional response' of larvae and adults of *S. levaillanti* matches well to that described by Holling (1959) as Type 2, which is also in agreement with several other studies on the prey consumption of coccinellid predators (Zhao and Holling 1986; Zou et al., 1986, Yiğit, 1989).

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