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ISSN 2146-0035 ***Orijinal araştırma* (*Original article*)**

The effects of various temperatures on development and fecundity of *Scymnus subvillosus* (Goeze) (Coleoptera: Coccinellidae) feeding on *Aphis gossypii* Glover (Hemiptera: Aphididae)[1]

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Farklı sıcaklıkların *Aphis gossypii* Glover (Hemiptera: Aphididae) üzerinde beslenen *Scymnus subvillosus* (Geoeze) (Coleoptera: Coccinellidae)'un gelişimi ve üreme gücüne etkileri

Özet: Bu çalışmada, *Aphis gossypii* Glover (Hemiptera: Aphididae) ile beslenen *Scymnus subvillosus* (Goeze) (Coleoptera: Coccinellidae)'un gelişme, canlı kalma oranı ve üremesi beş farklı sabit (15, 20, 25, 30, 35 °C) ve bir değişken sıcaklık (25-35 °C), % 60 ± 10 orantılı nem ve 16 saat aydınlatma koşullarına sahip iklim dolaplarında yürütülmüştür. Yumurtadan ergine gelişme süresi sıcaklığın artmasıyla birlikte önemli ölçüde kısalmış olup, 14.2 gün (30 °C) ile 31.0 gün (20 °C)' arasında değişmiştir. Avcının gelişmesi 15 ve 35 °C sıcaklıklarda tamamlanamamıştır. Ovipozisyon periyodu 20, 25, 30 ve 25-35 °C' de sırasıyla 67.9, 48.6, 42.5 ve 40.3 gün sürmüştür. En yüksek günlük ve toplam yumurta sayısı değerleri 30 °C' de (11.8 dişi/gün ve 499.5 dişi/ömür) elde edilmiştir. Net üreme gücü ve kalıtsal üreme yeteneği değerleri 30 °C' de (R_0 = 109.51, r_m= 0.155 gün^{-1}) en yüksek, 20 °C' de (R_0= 64.77 ve r_m= 0.058 gün^{-1}) ise en düşük olarak bulunmuştur. Ortalama döl süresi (T_0) sıcaklıktaki artışla birlikte kısalmış ve 39.99 gün (30 °C) ile 90.62 gün (20 °C) arasında değişmiştir. *S. subvillosus'* un yumurtadan ergine gelişme eşiği sıcaklığının 10.26 °C, bir dölünü tamamlaması için gerekli etkili sıcaklıklar toplamının 286 gün-derece olduğu ve Adana (Türkiye)'da yılda 9.92 döl verebileceği hesaplanmıştır.

Anahtar sözcükler: *Scymnus subvillosus*, sıcaklık, gelişme süresi, yaşam çizelgesi

Abstract: In this study, the development survival, and fecundity of *Scymnus subvillosus* (Goeze) (Coleoptera: Coccinellidae) were determined at five constant temperatures (15, 20, 25, 30 and 35 ±1 °C) and one alternate temperature (25/35±1 °C), 60 ± 10% RH and a photoperiod of 16:8 h (L:D), (5,000 lux) in the climate chamber. Development time from egg to adult of *S. subvillosus* significantly decreased, varying from 14.2 days at 30 °C to 31.0 days at 20 °C. Development was not completed at 15 and 35 °C. The oviposition period lasted 67.9, 48.6, 42.5 and 40.3 days at 20, 25, 30 and 25/35 °C, respectively. The highest total fecundity and daily oviposition rate per female were obtained at 30°C as 499.5 eggs/♀ and 11.8 eggs/day, respectively. The highest intrinsic rate of increase (r_m= 0.155 d^{-1}) and net reproduction rate (R_0= 109.51) values were determined at 30 °C and they were the lowest at 20 °C (r_m= 0.058 d^{-1} and R_0= 64.77). The mean generation time (T_0) was the shortest at 30°C (T_0= 39.99 d) and was the longest at 20 °C (90.62 d). Development from

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egg to adult required 286 DD (degree-days) above a base of 10.26 °C, estimated as developmental threshold, and predator can produce 9.92 generations per year in Adana, Turkey.

Key words: *Scymnus subvillosus*, temperature, development time, life table

Introduction

Aphids are widespread and important pest of many agricultural crops in the Eastern Mediterranean region of Turkey (Uygun et al. 2001). Members of this family can cause serious damages on many plants by directly feeding on phloem sap or by indirectly secreting excessive sugar in honeydew form. Aphididae are also known as transmitting important viral diseases to many crops (Bodenheimer & Swirski 1957; Satar et al. 1999). Biological control is a promising alternative method to prevent negative effects of chemical control on environment and economy. Uygun et al. (2001) determined more than 50 predators and parasitoids on aphids in the Eastern Mediterranean Region of Turkey. One of the most important natural enemy of aphids is *Scymnus subvillosus* (Goeze) (Coleoptera: Coccinellidae), which was determined on 27 aphid species (Uygun et al. 2001).

Most of the studies on *S. subvillosus* reported in literature primarily concentrated on taxonomic or faunistic aspects of this predator (Uygun 1981; Zeren 1989; Uygun et al. 2001; Uygun et al. 2004). However, little is known about important demographic characteristics of *S. subvillosus* such as effect of different temperatures on development and fecundity. Understanding these biological parameters of predators is of primary importance for the development of successful biological control strategies. In this study, the effects of different temperature regimes on development, survival and and fecundity of *S. subvillosus* were determined.

Material and methods

Insect rearing

Aphis gossypii Glover (Hemiptera: Aphididae) used as prey for rearing *Scymnus subvillosus* stock culture and was produced on cotton plant.

The initial population of *S. subvillosus* was collected from *Hibiscus* sp. infested by *A. gossypii*. They were reared in cylindrical plexiglas cages on cotton plants populated by excessive amounts of *A. gossypii*. Sponge pieces were placed in cages for the purpose of egg-laying. The stock cultures of *S. subvillosus* and *A. gossypii* were maintained at 25 °C with 60 ± 10 % RH under daily artificial light (16L:8D) in controlled environment.

Laboratory experiment

The experiments were conducted in growth chambers at five constant temperatures (15, 20, 25, 30, 35±1 ºC) and an alternate temperature (25/35±1 ºC), 60 ± 10 % RH and a photoperiod of 16:8 L:D h for constant temperatures and 12:12 L:D h for alternate temperature. Same aged adult individuals were collected from the rearing cages and placed into plexiglas cages including ample prey in incubator at 25 ºC. Eggs of *S. subvillosus* laid within a 24-h period were transferred to petri dishes (5 cm diameter). Hatching time and mortality of eggs were determined by daily observations at all temperatures tested. The hatched larvae were confined individually in Petri dishes on excised cotton leaves infested with *A. gossypii*. Ample fresh food was provided daily. Developmental time and the mortality of different developmental stages were recorded by daily observations at all temperatures. After adult emergence, one female and one male were transferred to new Petri dishes with prey and sponge piece. Survival and fecundity data were recorded daily until all adults die. The male/female ratio of emerged adults was determined according to Uygun (1981). Furthermore, adult weight and length x width of *S. subvillosus* were also determined by using precision balance (mg, $.10^{-4}$) and ocular micrometer, respectively.

Data analysis

Life table statistics

Data on developmental time, longevity and fecundity were analysed by one-way ANOVA followed by Duncan's Multiple Range Test ($P \leq 0.05$). using SPSS 13 program.

Life tables were prepared separately for each temperature regime. Data from daily observations were used to estimate life table statistics according to the method of Birch (1970) and Southwood (1978):

$$\Sigma\, e^{-r*x}\, l_x * m_x = 1 \qquad (1)$$

where: l_x = age specific survival rate, m_x = number of female offspring, (♀/♀/day), e = natural log base, r_m = intrinsic rate of increase, x = age of females in days.

After "r_m, was calculated for the original data (r_{all}), differences in r_m values were tested for significance by estimating variances through the jack-knife method (Meyer et al. 1986). The jack-knife pseudo-value (r_j) was calculated for 'n' samples using the following equation:

$$r_j = n \text{ x } r_m - (n-1) \text{ x } r_i \qquad (2)$$

R_0 is a parameter defining the total number of female offspring of female. The method estimating R_0 with the information of the life table is the sum of reproduction expectation

$$(\sum l_x.m_x) \qquad (3)$$

for each age group. The mean period elapsed from birth of parents to birth of offspring (T_0) was estimated according to Laing (1968) with $T_o = \ln R_0 / r_m$ (4).

Developmental threshold, thermal constant and theoretical number of generations of *Scymnus subvillosus*

Developmental threshold of immature stages of *S. subvillosus* and the thermal constant were calculated by using their development times at 20, 25, 30 ºC constant and 25/35 ºC alternate temperatures. Linear regression (y = a + bx (x: temperature; y: developmental rate)) was used to describe the relationship between developmental rate (1/development time) of each immature stage and overall development and temperature throughout the entire range. The point of interception of this line with the x-axis approximates the lower threshold temperature (Campbell et al. 1974). The thermal constant (the sum of effective temperature) equals 1/b of the temperature-developmental rate equation (Karman 1971). Theoretical number of generation was calculated using experimental data and the meteorological data of the year 2006 provided by State Meteorology Office in Adana, after calculation of thermal constant and lower threshold temperature.

Results and discussion

Effect of different temperatures on development period and mortality rate of *Scymnus subvillosus*

Larvae of *S. subvillosus* were not able to complete their development at 15 and eggs didn't enclose 35 ºC. Concerning to other temperature regimes, 4th larval stage was found as longest larval stage; on the other hand pupal stage was longer than larval stages. Duration of developmental time of egg, larval stages, pupa and total immature (egg to adult) shortened with increasing temperature. The longest and shortest total development periods were determined at 20 and 30 ºC, respectively (Table 1) (P_{egg} =0.00, df_{egg}=4, 529, F_{egg}=3384.782; P_{L1}= 0.00, df_{L1}=4, 426, F_{L1}=329.812; P_{L2}=0.00, df_{L2}=4, 419, F_{L2}=224.248; P_{L3}=0.00, df_{L3}=3, 414, F_{L3}=93.522; P_{L4} = 0.00, df_{L4}=3, 411, F_{L4}=149.238; P_{P}=0.00, df_{P}=3, 345, F_{P}=399.841; P_{Topgel} = 0.00, df_{Topgel} =3, 346, F_{Topgel} =639.245). Parallel results were reported by Kawauchi (1985), Naranjo et al. (1990), Emami et al. (1998), Uygun & Atlıhan (2000), Lu & Montgomery (2001), Jafari et al. (2002), Omkar & Pervez (2004), Yarpuzlu & Uygun (2010), Katsarou (2005), Atlıhan & Chi (2008), Jalali et al. (2009) for other coccinellid predators.

The highest total mortality from egg to adult was determined at 15 and 35 ºC, while the lowest one was found at an alternate temperature of 25/35±1 ºC. The egg stage suffered the highest mortality rate, followed by the pupal and first larval stage (Table 2). Atlıhan & Chi (2008) reported that preadult mortality rate were 41.3, 37.5, 43. and 78% at 20, 25, 30 and 35°C for *S. subvillosus* feeding with *Hyalepterus pruni* (Geoffroy) (Hemiptera: Aphididae). They found lower mortality rate for all temperature than our study, probably because of different prey.

Effect of different temperatures on preoviposition, oviposition, postoviposition periods, number of laid eggs, adult longevity of *Scymnus subvillosus*

Duration of preoviposition, oviposition and postoviposition shortened with increasing temperature. Preoviposition and oviposition periods were the longest at 20 ºC and the shortest at 30 ºC and 25/35 ºC. There was a significant difference in the preoviposition and oviposition periods, while no significant differences were observed among postoviposition periods (Table 3) (P_{Pre}=0.000, df_{pre}=3, 69, F_{pre}=61.770; P_{ovi}=0.132, df_{ovi}=3, 69, F_{ovi}=1.933; P_{post}=0.178, df_{post}=3, 69, F_{post}=1.685). Longevity for both female and male individuals were reduced with increasing temperature.

Table 1. Mean duruation of immature stages of *Scymnus subvillosus* feeding on *Aphis gossypii* at different temperatures (day, mean ± SE).

Temperature °C	n	Egg	Larva 1	Larva 2	Larva 3	Larva 4	Pupa	Egg to adult
15 ± 1	83	13.9 ± 0.16 e	9.3 ± 1.33 d	9.0 ± 0.00 c	No development			
20 ± 1	96	6.5 ± 0.06 d	2.6 ± 0.06 c	2.3 ± 0.08 b	2.4 ± 0.16 c	4.2 ± 0.16 d	12.5 ± 0.24 c	31.0 ± 0.62 d
25 ± 1	146	4.0 ± 0.03 c	1.6 ± 0.04 b	1.3 ± 0.04 a	1.6 ± 0.05 b	2.7 ± 0.06 c	8.0 ± 0.09 b	19.1 ± 0.11 c
30 ± 1	140	2.9 ± 0.05 a	1.0 ± 0.03 a	1.1 ± 0.03 a	1.2 ± 0.05 a	2.0 ± 0.05 a	6.1 ± 0.10 a	14.2 ± 0.10 a
25/35 ± 1	72	3.2 ± 0.04 b	1.2 ± 0.06 a	1.2 ± 0.05 a	1.1 ± 0.04 a	2.4 ± 0.07 b	6.5 ± 0.13 a	15.6 ± 0.14 b
35 ± 1					No egg eclosion			

Means within column followed by the same letter are not statistically different by Duncan test (p=0.05)

Table 2. Immature stage mortality of *Scymnus subvillosus* on *Aphis gossypii* at different temperatures with 60±10 R.H. (%)

Temperature (°C)	n	Egg	n_2	Larva 1	Larva 2	Larva 3	Larva 4	Pupa	Total (%)
15 ± 1	657	76.56	83	96.30	33.30	100.00			100.00
20 ± 1	549	40.44	96	9.35	2.30	2.35	1.20	8.35	68.44
25 ± 1	241	58.92	146	3.40	0.00	1.40	0.70	15.20	78.82
30 ± 1	331	48.04	140	2.80	1.40	0.00	0.00	23.00	71.08
25/35 ± 1	194	54.12	72	5.80	2.30	0.00	0.80	11.90	66.02
35 ± 1	600	100.00							100.00

The longest female longevity was determined at 20 ºC, while the shortest one was at 30 and 25/35 ºC.

No statistically significant differences for both female and male longevity were found among the temperatures of 25, 30 ºC and 25/35 ºC, while the longevity at these three temperature regimes was significantly shorter than that of obtained at 20 ^{o}C ($P_{♀}$ = 0.153, $df_{♀}$=3, 58, $F_{♀}$=3.731; $P_{♂}$=0.153, $df_{♂}$=3, 58, $F_{♂}$=1.826). Uygun and Atlıhan (2000) reported that *S. levaillantii* had the longest adult longevity at 15 °C and the shortest one at 35 °C. Although *S. levaillantii* could reach adult stage at 15 °C unlike our species, it could not lay eggs at this temperature. On average, times from oviposition to the onset of reproduction of *S. frontalis* were 100.2, 62.1, 29.7, and 24.9 day at mean temperatures of 15, 18.7, 26.2, and 30°C, respectively. It shows the ovipositing period decreased with increasing temperature, same trend was observed in this study.

Average female longevity of *S. subvillosus* shortened with increasing temperature, but in contrast, the number of daily and total eggs laid increased. The highest number of eggs laid per day and total number of eggs laid by female were at 30 ºC, while the lowest ones were determined at 20 ºC. ($P_{♀/day}$=0.00, $df_{♀/day}$=3, 69, $F_{♀/day}$=11.236; $P_{♀/longevity}$= 0.072, $df_{♀/longevity}$=3, 69, $F_{♀/longevity}$=2.439).). Tawfik et al. (1974) also reported the similar finding at 30 ºC for *S. interruptus* Goeze.

Effect of different temperatures on sex ratio and size of *Scymnus subvillosus*

In this study, sex ratio was found similar at all temperatures ranging between 1/0.8 and 1.1/1.3. Similar results were obtained with other coccinellid species like *S. interruptus, S. levaillaniti, Propylea dissecta* (Mulsant), *Adalia bipunctata* (L.) (Tawfik et al. 1974; Uygun & Atlıhan 2000; Omkar & Pervez 2004; Jalali et al. 2009).

The weight and size of coccinellid adults varied with species, sex and feeding. Females were more variable than males in body size. Females of some species were heavier and larger than males, and species can be classified on a basis of difference in the weight and size of the sexes (Smith 1966). In this study, both female and male weight weren't influenced by different temperatures. While length x width of female of *S. subvillosus* varied and there were statistical differences between constant temperatures and alternate temperature on the other hand, there was difference between 25 and 25/35 ºC for male size (Table 4).($P_{femalesize}$ = 0.014, $df_{femalesize}$=3, 126, $F_{femalesize}$=3.667; $P_{femaleweight}$=0.187, $df_{femaleweight}$=3, 126, $F_{femaleweight}$=1.626; $P_{malesize}$=0.17, $df_{malesize}$=3, 118, $F_{malesize}$=3.517; $P_{maleweight}$=0.643, $df_{maleweight}$=3, 118 $F_{maleweight}$=0.560). Naranjo (1990) determined that both females and males of *S. frontalis* were heavier at 18.7 and 26.2 °C than at 15 and 30 °C. A linear relationship between weight and temperature was not observed in our study and that of Naranjo (1990).

Table 3. Preoviposition, oviposition, postoviposition periods, number of the total laid eggs and adult longevity (day) of *Scymnus subvillosus* on *Aphis gossypii* at different temperatures with 60±10 R.H. (%), (day, mean ± SE*).

Temperature °C	n	Preoviposition period	Oviposition period	Postoviposition period	Female Longevity	Male Longevity	No. of eggs (♀/day)	Number of eggs (♀/longevity)
20 ± 1	17	14.0 ± 0.81 c	67.9 ± 13.36 b	50.8 ± 17.47	132.1 ± 23.56 b	119.1 ± 26.15 b	3.0 ± 0.47 a	250.8 ± 55.95 a
25 ± 1	19	6.4 ± 0.48 b	48.6 ± 5.83 ab	41.0 ± 10.20	96.1 ± 12.40 ab	94.4 ± 16.26 ab	7.5 ± 0.92 b	404.6 ± 70.26 ab
30 ± 1	19	4.2 ± 0.47 a	42.5 ± 6.19 ab	23.6 ± 8.54	70.4 ± 12.68 a	56.9 ± 11.46 a	11.8 ± 1.33 c	499.5 ± 74.78 b
25/35 ± 1	20	5.6 ± 0.37 ab	40.3 ± 8.97 a	20.0 ± 5.84	65.9 ± 12.30 a	83.1 ± 13.71 ab	9.9 ± 1.40 bc	348.4 ± 58.83 ab

Means within column followed by the same letter are not statistically different by Duncan test (p=0.05)

Table 4. Effects of temperature on adult weight (mg), length x width (mm) of female and male *Scymnus subvillosus* individuals feeding on *Aphis gossypii* (mean ± SE*).

Temperature	Female			Male		
°C	n	Index of body size	Weight (mg)	n	Index of body size	Weight (mg)
20 ± 1	27	5.1 ± 0.24 b	0.6 ± 0.02	25	4.2 ± 0.20 ab	0.5 ± 0.03
25 ± 1	36	5.3 ± 0.18 b	0.6 ± 0.06	41	5.2 ± 0.19 b	0.6 ± 0.02
30 ± 1	27	5.2 ± 0.17 b	0.6 ± 0.05	20	4.8 ± 0.18 ab	0.6 ± 0.03
25/35 ± 1	40	4.5 ± 0.16 a	0.6 ± 0.06	36	4.2 ± 0.22 a	0.6 ± 0.02

Means within column followed by the same letter are not statistically different by Duncan test (p=0.05)

Yarpuzlu & Uygun (2010) reported that males and females of *Cheilomenes propinqua* (Mulsant) had their highest weight at 25 °C. In contrast to our study, statistical differences was determined for weight of *C. propinqua.* Katsarou (2005) observed that the maximal weight of *Hippodamia convergens* Guérin-Méneville was at temperatures of 17 and 20 °C. The author also indicated that the body weight of adults of *H. convergens* was significantly related to their body size index (length x width).

Life table of *Scymnus subvillosus* at different temperatures

The mortality rate generally tends to be higher in immature stages, especially in early stages, approximately 50% of the individuals died in the immature stages at all temperatures (Figure 1). Mortality of adults considerably increased after the mid-oviposition stage. The longest adult longevity at different temperatures were found as 315, 244, 206 and 176 days at 20, 25, 30 °C and 25/35 °C, respectively. Female individuals began to lay eggs after 40, 26, 18 and 21 days at 20, 25, 30°C and 25/35 °C, respectively. Oviposition periods lasted 151, 83, 72, and 126 days at 20, 25, 30 and 25/35 °C, respectively. The peak of age specific fecundity rate (m_x) was the highest and occured earlier at 30 and 25/30 ^oC. The highest net reproduction rate (R_0) was observed at 30°C, while the lowest one at 20 °C.

The lowest intrinsic rate of increase (r_m) was determined at 20 ^oC, being statistically significant lower than at any other temperature tested. The highest intrinsic rate of increase was observed at 30 ^oC, but being not significant different from that at the alternate temperature of 25/30 ^oC, according to jack-knife method (P_{rm}=0.000. df_{rm}=3, 168; F_{rm}=28.662) (Figure 1).

The intrinsic rate of increase (r_m) is a good indicator of the combined effect of temperature on development, survival and reproduction (Atlıhan & Chi, 2008). The greater r_m at 30 ^oC was due to faster immature developmental time, higher daily rate of progeny and earlier peak in reproduction. The generation time (T_0) decreased with increasing temperature from 90.62 days at 20 ^oC to 39.99 day at 30 ^oC (Figure 1). It was due to the fact that time required from egg hatch to first oviposition and peak oviposition was shorter at higher temperatures. Similarly, *S. levaillantii* preying on *A. gossypii* (Uygun & Atlıhan 2000) and *S. subvillosus* on *H. pruni* (Atlıhan & Chi 2008) were reported the highest r_m and lowest T_0 values at 30 °C. While r_m value of our study is similar with these two studies, T_0 values are longer. It is likely that this difference might be due to different prey and different predator.

Developmental threshold, thermal constant and theoretical generation number of *Scymnus subvillosus*

Development time of immature stages of *S. subvillosus* produced a best linear fit with a "$R_{(Top)}$" of 0.9706 at the temperatures ranging from 20°C to 30°C and 25/35 °C (Figure 2, Table 5). Development rate of *S. subvillosus* was diminished by increasing temperature.

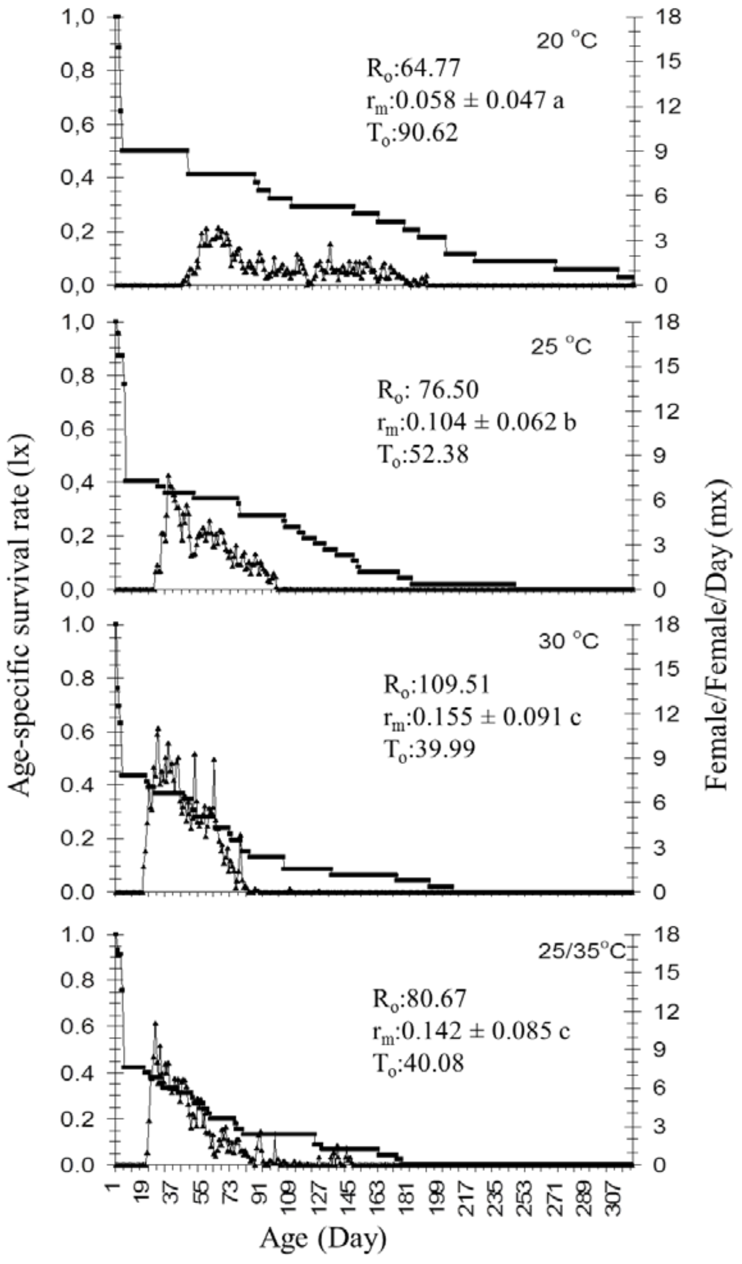

Figure 1. Age-specific survival rate (lx) and age-specific fecundity rate (mx), lower net reproductive rate (R_o), the intrinsic rate of increase (r_m) (Jackknife Estimate (mean±SE)) and the generation time (T_o) of *Scymnus subvillosus* at different temperatures.

The developmental threshold (C) of *S. subvillosus* was calculated as 11.5°C and the thermal summation of the total preadult stage was 286 DD. According to the data obtained from the meteorology station of Adana State Meteorology Office, the theoretical generation number was estimated as 9.92/per year for Adana. The annual generation number for *S. levaillantii* collected in same region (Mediterranean region) of Turkey was reported as 8 (Uygun & Atlıhan 2000). Species difference may be reason for discrepancy

The lower development threshold for development and the thermal constant are useful indicators for the potential distribution and abundance of an insect (Messenger 1970). The developmental threshold and thermal constant value of *S. subvillosus* were similar those of other Scymnus species (*Symnus frontalis;* 11.7 °C, 312.2 DD, *S. hofmanii;* 10.1°C, 223.4 DD, *S. levaillantii;* 11.7°C, 305.2 DD, *S. syriacus;* 11.3 °C, 323.7 DD (Naranjo et al., 1990, Kawauchi, 1985; Uygun & Atlıhan, 2000; Emami et al. 1998). On the other hand, Atlıhan & Chi (2008) found developmental threshold of *S. subvillosus* as 7.1. It is different than our result and it might be due to difference of ecological properties of regions where *S. subvillosus* individuals collected. We collected individuals of the predator in Mediterranean region where has mild winters, and they collected individuals in Van region where has a harsh and long winter condition, so the species might be develop adaptation to this condition.

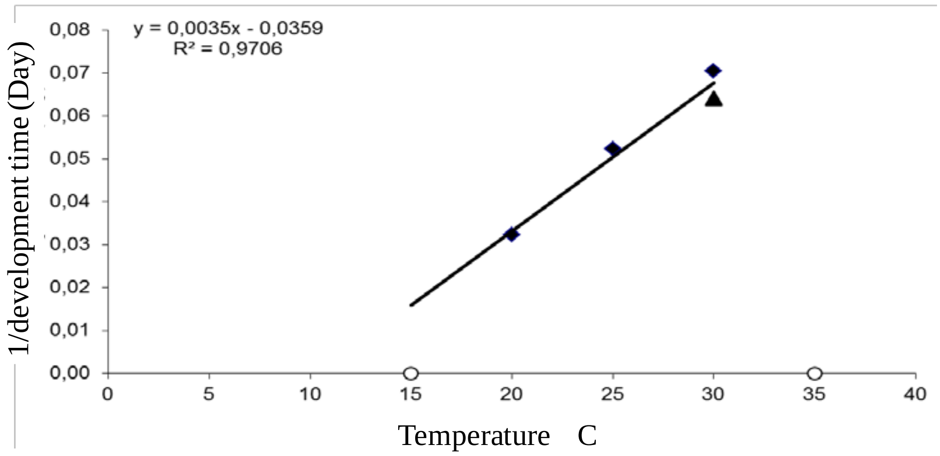

Figure 2. Relationship between development rate of *Scymnus subvillosus* and temperature (alternate temperature (25/35 °C) ▲; development not completed at 15 and 35 °C -○-).

The Regression coefficient (r) values obtained by regression equations of eggs, larvae and pupa stages of *S. subvillosus* were found close to 1, and correlation was very strong between temperatures and life stages. Result of 15 °C was added to calculation regression coefficient of egg, first and second larval stages. The developmental threshold obtained for egg, second and third larval stages were close to each other, and it was the lowest for forth larval stage (Table 5).

Developmental thresholds of immature stages of *S. subvillosus* varied between larval stages (Table 5). Similarly, Naranjo et al. (1990) determined variation between larval stages for *S. frontalis* (10.1 °C for the first larval stage, 13.0 °C for the fourth larval stage). Developmental thresholds of the egg and the larval stages of *S. subvillosus* were reported as 7.4 and 4.1 °C, respectively (Atlıhan & Chi 2008).

Temperature is one of the most important factors regulating seasonal development and affecting the rate of insect development. Studies on developmental requirements of beneficial species contribute to the efficiency of mass-rearing and they increase our ability to use beneficial species in pest management by providing a quantitative basis for predicting their development and activities (Obrycki & Tauber 1981). Our findings on some temperatures depending demographic characteristics of *S. subvillosus* may prove useful in implementing biological control and IPM programs of aphids on various agricultural crops.

Table 5. Development threshold and sum of effective temperatures of *Scymnus subvillosus*

Stage	Development threshold (°C)	Sum of effective temperature (degree-days)	Regression equation	R^2
Egg	10.88	58.14	y = 0.0172x – 0.1872	0.9887
Larva 1	13.01	18.65	y = 0.0536x – 0.6973	0.9715
Larva 2	11.75	20.04	y = 0.0499x – 0.5863	0.9532
Larva 3	11.05	21.83	y = 0.0458x – 0.5062	0.9788
Larva 4	8.62	46.29	y = 0.0216x – 0.1863	0.8935
Pupa	9.45	128.20	y = 0.0078x – 0.0737	0.9827
Total Developmental Time	10.26	285.71	y = 0.0035x – 0.0359	0.9706

Data gathered on thermal requirements and reproduction rates of *S. subvillosus* showed their high potential as biological control agent of *A. gossypii*. However, further studies on numerical and functional responses, foraging behavior, the effects of humidity on adult life and larval development and studies of different prey preference will contribute to a more efficient use of *S. subvillosus*. On the other hand, most populations are influenced by a variety of changing biotic and abiotic factors in natural environments. Therefore, further field experiments are also needed to draw firm conclusions.

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