

Development, Fecundity and Prey Consumption of *Exochomus nigromaculatus* Feeding on *Hyalopterus pruni*

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Development, survival and reproduction of *Exochomus nigromaculatus* (Goeze) were studied in the laboratory at four constant temperatures from 20°C to 35±1°C in 5°C increments, 60±5% r.h. and 16 h of artificial light (5000 lux). Development time from egg to adult ranged from 22.4 days at 20°C to 10.6 days at 35°C, and required 278 degree-days above a threshold estimated to be 9.11°C. Survival was highest at 25°C and lowest at 35°C. Longevity of females declined significantly with increasing temperatures, ranging from 120.7 days at 20°C to 46.6 days at 35°C. Mean generation time became shorter with increasing temperatures. The intrinsic rate of increase of individuals kept at 30°C was significantly greater than that of individuals kept at the other temperatures tested. Fourth larval instars and adults of *E. nigromaculatus* displayed a Type II functional response to *Hyalopterus pruni* densities. Searching rate of fourth instar larvae and adults was similar, but handling time was shorter for female adults. Results obtained in this study showed that the optimal temperature for population growth of *E. nigromaculatus* was 30°C and this coccinellid predator may have potential as a biological control agent for *H. pruni* because of its feeding capacity.

KEY WORDS: *Exochomus nigromaculatus*; development; fecundity; prey consumption; *Hyalopterus pruni*; mealy plum aphid.

INTRODUCTION

Hyalopterus pruni (Geoffroy) (Homoptera: Aphididae), the mealy plum aphid, is a major pest of stone fruit trees, especially apricot and plum, in the Van region of eastern Turkey (2,20). A cosmopolitan species with worldwide distribution (3,4,5,10,18), it sucks plant sap, inducing plant deformation and producing copious amounts of honeydew. It has been reported also as a virus vector, specifically of plum pox virus (4,13). Chemical control measures applied against this pest may disrupt other biological control. Therefore, biological control or integrated management should be considered options for controlling this pest. There have been some studies indicating that natural enemies may be effective against *H. pruni*. For instance, integrated management experiments carried out with *Praon volucre* Haliday (Hymenoptera: Aphidiidae) against *H. pruni* in Czechoslovakia (18) and against *Aphidius transcaspicus* (Hymenoptera: Aphidiidae) in Georgia (USSR) (19) gave good results.

Coccinellids are well known all over the world as important natural enemies of aphids (7,8). In surveys carried out in the Van region, many natural enemies of *H. pruni* were found, among them the coccinellid predator *Exochomus nigromaculatus* (Goeze)

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(Coleoptera: Coccinellidae). This species has been considered an important natural enemy of *H. pruni* in stone fruit trees in Turkey (15) and has been observed to reduce populations of the pest significantly. In spite of the wide distribution and apparent economic importance of *E. nigromaculatus*, little is known of its biology, ecology, and efficacy as a biocontrol agent. The presented studies examined the effects of different temperatures on *E. nigromaculatus* development and fecundity and aspects of its functional response to *H. pruni*.

MATERIALS AND METHODS

Insect rearing *Exochomus nigromaculatus* was obtained from apricot orchards around Van in the eastern region of Turkey and reared on its secondary host plant, *Phragmites australis* (Cav.), with *H. pruni* as prey. The prey readily colonized on *P. australis*, a plant that is easily grown under laboratory conditions. Stock cultures of predator and prey were maintained at $25\pm 2^\circ\text{C}$, $65\pm 5\%$ r.h. and 16 h of artificial light of ~ 4000 lux in a controlled environment room.

Development and fecundity Development time and mortality of immature stages at different temperatures were studied by transferring newly laid eggs picked randomly from stock culture to petri dishes (110×15 mm). 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 small apricot leaf disks infested with *H. pruni* ($n=26-34$). Ample fresh food was provided daily. Development time and the mortality of different development stages were recorded by daily observations at all temperatures. After adult emergence, one female and one male were transferred to fresh petri dishes with prey; mortality and number of eggs laid were recorded daily until all adults died ($n=13-18$). Sex ratio was determined after preparation of genitalia from the adults reared at all temperatures. The experiments were conducted at four constant temperatures ranging from $20^\circ-35^\circ\pm 1^\circ\text{C}$ in 5°C increments, $60\pm 10\%$ r.h. and 16 h of artificial light (5000 lux) in temperature cabinets.

Prey consumption The predation rates of fourth instar larvae and adults of *E. nigromaculatus* were measured at prey densities of 5, 10, 20, 40, 80 and 160 *H. pruni* ($n=12-15$ per density) at $25\pm 1^\circ\text{C}$, $60\pm 10\%$ r.h. and 16 h artificial light. To conduct experiments, apricot leaves large enough to cover the whole petri dish arena were placed upside down on moist filter paper in petri dishes (110×15 mm). Only fourth and fifth instar nymphs of *H. pruni* were used to impede aphid reproduction during the experiment. To permit even dispersal of aphids throughout the dish, a single *E. nigromaculatus* fourth instar larva, adult female and male were separately released into the dishes 2 h after aphids were introduced; 24 h later the number of prey consumed was counted.

Statistical analyses Data on development time, longevity and fecundity were analyzed by one-way Anova followed by Duncan's Multiple Range Test ($P\leq 0.05$). The thermal threshold of the egg stage and the development time (egg to adult) were computed by employing a linear technique that uses growth rate (day^{-1}) data as the dependent variable and the temperature treatments as independent variables. The lower developmental threshold temperature was determined as the x-intercept of the linear equation and the degree-day (DD) requirements were determined as the inverse of the slope of the linear equation. Differences in sex ratio were analyzed by chi-square test ($P=0.05$).

Population growth rates at different temperatures were calculated by constructing life tables according to Andrewartha and Birch (1):

$$1 = \sum e^{-r \cdot x} l_x * m_x$$

To construct the life tables, age-specific survival rates (l_x) and number of female offspring (m_x) for each age interval (x) per day were used. From these data, net reproductive rate (R_0 = females/female/generation), intrinsic rate of increase (r_m = females/female/day) and mean generation time ($T_0 = \ln(R_0/r)$, in days) were calculated.

After r was computed for the original data (r_{all}), the differences in r_m - values were tested for significance by estimating the variance using the jackknife method, which facilitated calculation of the standard errors of r_m estimates (12,17). The jackknife pseudo-value r_j was calculated for n samples using the following equation:

$$r_j = n \times r_{all} - (n - 1) \times r_i$$

The mean values of $(n-1)$ jackknife pseudo-values for mean growth rate in each treatment were subjected to analysis of variance followed by Duncan's Multiple Range Test ($P \leq 0.01$).

The behavioral response of *E. nigromaculatus* to the various prey densities was expressed by fitting Holling's equation to the data (22):

$$N_\alpha = TP\alpha N / (1 + \alpha T_h N)$$

where N_α = the number of prey attacked, T = exposure time (24 h), P (number of predators) = 1, N = total prey density, α = searching rate of predator (attack rate), and T_h = handling time. Searching rate, handling time and their asymptotic standard errors were estimated from nonlinear regressions of disk equation. Confidence limits (95%) were used as an indicator of differences between searching rate as well as handling time of all three life stages. Each of the above mentioned analyses was conducted using SAS statistical software (16).

RESULTS

Development and fecundity Development times for eggs, larvae and pupae at the four constant temperatures are reported in Table 1. Linear regression analysis applied to the egg development times within the 20–35°C temperature range revealed that development rates for the egg stage ($r_{[T_e]}$) of *E. nigromaculatus* increased linearly with increasing temperature (Fig. 1). The thermal development threshold of the egg stage was estimated as 9.07°C and 69.9 DD were required for hatching. Total development rate ($r_{[T_t]}$) of *E. nigromaculatus* increased linearly with increasing temperature (Fig. 1). The theoretical development threshold was estimated to be 9.11°C. Based on the development threshold, completed development from egg to adult required 278 DD.

Overall mortality (egg to adult) ranged from 56.7% at 35° to 25.7% at 25°C. Mortality was 28.0% at 20° and 31.8% at 30°C. Most mortality occurred in the egg stage (24.0%, 20.0%, 27.3% and 51.6% at 20°, 25°, 30° and 35°C, respectively). Larval mortality occurred only in the first instar at all temperatures tested except 35°C, which resulted in some mortality in the second instar.

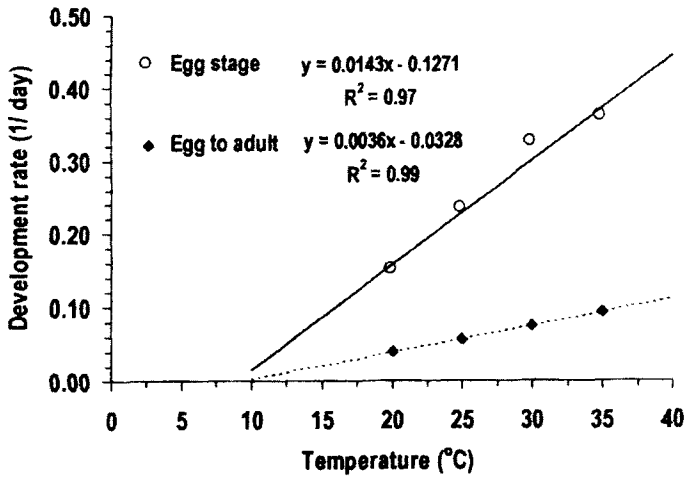


Fig. 1. Development rate of eggs ($r_{[Te]}$) and total development rate (eggs to adult) ($r_{[Tt]}$) of *Exochomus nigromaculatus*. Lines represent linear regressions of development rates on temperature within the range of 20–35°C.

TABLE 1. Mean (\pm S.E.) duration of egg and immature stages of *Exochomus nigromaculatus* feeding on *Hyalopterus pruni* at four constant temperatures

Temperature (°C)	n ²	Duration of development stages (days)						Total development time
		Egg	1st instar	2nd instar	3rd instar	4th instar	Pupa	
20 \pm 1	34	6.7 \pm 0.6a ^y	2.6 \pm 0.4a	2.4 \pm 0.3a	2.3 \pm 0.2a	3.8 \pm 0.4a	6.9 \pm 0.6a	24.8 \pm 1.1a
25 \pm 1	30	4.3 \pm 0.2b	2.1 \pm 0.3a	1.9 \pm 0.4a	1.8 \pm 0.8a	2.9 \pm 0.5a	4.7 \pm 0.5b	17.7 \pm 1.2b
30 \pm 1	26	3.1 \pm 0.4c	1.7 \pm 0.2b	1.2 \pm 0.2b	1.2 \pm 0.4b	2.1 \pm 0.5b	3.9 \pm 0.4c	13.3 \pm 0.6c
35 \pm 1	27	2.8 \pm 0.2c	1.0 \pm 0.0c	1.0 \pm 0.0c	1.0 \pm 0.0b	1.4 \pm 0.2c	3.3 \pm 0.2d	10.6 \pm 0.4d
F		73.71	17.63	21.26	8.41	19.74	52.46	119.75

²Number of replicates that survived to adulthood.

^yWithin columns, means followed by the same letter do not differ statistically (DMRT; $P \leq 0.05$).

The longest preoviposition period was 7.4 days at 20°C and the shortest was 3.6 days at 35°C. There was no significant difference in preoviposition period between 30° and 35°C. The length of the mean oviposition period decreased with increasing temperature, ranging from 88.9 days at 20° to 33.3 days at 35°C. The postoviposition period was the longest for individuals kept at 20°C. Adult longevity was significantly shorter at the higher

TABLE 2. Longevity and fecundity of *Exochomus nigromaculatus* feeding on *Hyalopterus pruni* at four constant temperatures (all data are means \pm S.E.)

Temperature (°C)	n	Duration (days)			Longevity (days)	Number of eggs per female	
		Preoviposition	Oviposition	Postoviposition		per day	total
20 \pm 1	18	7.4 \pm 0.8a ^z	88.9 \pm 9.2a	23.9 \pm 3.1a	120.7 \pm 11.3a	4.6 \pm 0.6b	388.6 \pm 36.4a
25 \pm 1	13	5.6 \pm 0.4b	75.3 \pm 6.9b	13.6 \pm 2.3b	94.4 \pm 8.8b	5.9 \pm 0.7b	428.5 \pm 44.8a
30 \pm 1	15	4.0 \pm 0.5c	49.3 \pm 9.3c	12.4 \pm 2.5b	65.9 \pm 6.2c	7.4 \pm 0.6a	348.7 \pm 47.9a
35 \pm 1	13	3.6 \pm 0.6c	33.3 \pm 6.8d	9.6 \pm 2.7b	46.6 \pm 7.6d	3.1 \pm 0.7c	98.6 \pm 25.2b
F		21.63	30.78	6.27	32.44	9.76	29.34

^zWithin columns, means followed by the same letter do not differ statistically (DMRT; $P \leq 0.05$).

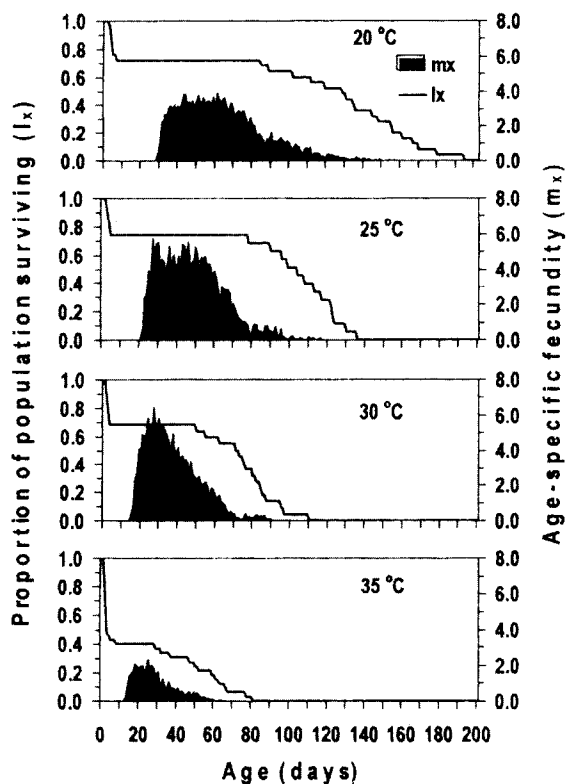


Fig. 2. Survivorship curve (l_x) and age-specific fecundity rate (m_x) of *Exochomus nigromaculatus* on *Hyalopterus pruni* at four constant temperatures.

TABLE 3. Net reproductive rate (R_0), intrinsic rate of increase (r_m) and generation time (T_0) of *Exochomus nigromaculatus* feeding on *Hyalopterus pruni* at four constant temperatures

Temperature (°C)	Net reproductive rate (females/female)	Intrinsic rate of increase ^z (females/female per day)	Generation time (days)
20±1	137.77	0.111±0.0012c	46.68
25±1	156.03	0.134±0.0009b	37.68
30±1	115.10	0.172±0.0014a	27.60
35±1	15.97	0.118±0.0012c	23.48
<i>F</i>		121.3	

^z Values followed by different letters differ significantly (DMRT; $P \leq 0.01$).

temperatures (Table 2). The daily rate of oviposition was highest at 30° and lowest at 35°C. The overall fecundity was significantly lower at 35°C than at the other temperatures tested (Table 2).

The offspring sex ratio of *E. nigromaculatus* in all treatments was not significantly different from 1:1 (54.4 : 45.6, 59.2 : 40.8, 57.6 : 42.4 and 48.6 : 51.4 at 20°, 25°, 30° and 35°C, respectively; chi-square, $P > 0.05$).

Mortality of *E. nigromaculatus* adults occurred mainly toward the end of the oviposition period at 20°, 25° and 30°C. On the other hand, a high mortality rate was recorded at 35°C

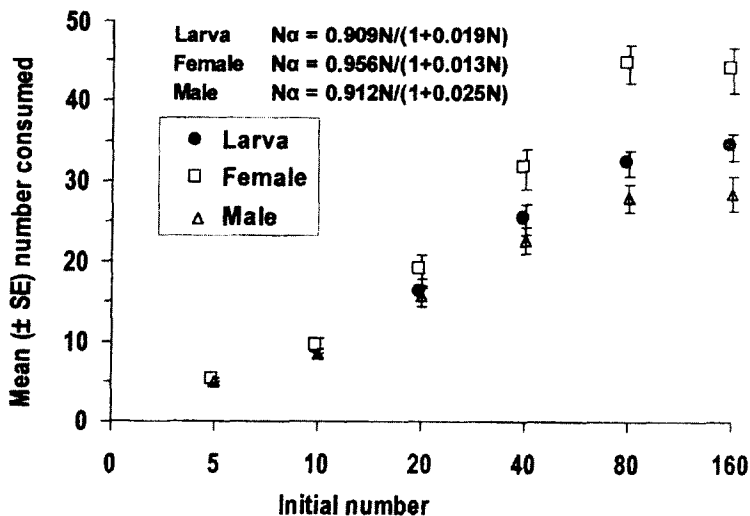


Fig. 3. Mean consumption (\pm S.E.) of *Hyalopterus pruni* nymphs per individual fourth instar larva, adult female and adult male of *Exochomus nigromaculatus* at different prey densities.

TABLE 4. Searching rate (α), handling time (T_h) and confidence limits in the Holling disk equation for *Exochomus nigromaculatus* feeding on *Hyalopterus pruni* nymphs

Stage	α (nymph/h) (asymptotic S.E.)	95% CL		T_h (h/nymph) (asymptotic S.E.)	95% CL	
		Lower	Upper		Lower	Upper
4th instar larva	0.045 (0.0017)	0.0412	0.0487	0.47 (0.018)	0.4303	0.5096
Adult female	0.043 (0.0042)	0.0337	0.0522	0.30 (0.044)	0.2031	0.3968
Adult male	0.045 (0.0051)	0.0332	0.0562	0.60 (0.054)	0.4811	0.7188

after the peak in reproduction (Fig. 2). The highest age-specific number of eggs per female per day (m_x) was observed at 30°C. Increasing temperature shortened the generation time (T_0) of *E. nigromaculatus* (Table 3). The net reproductive rate decreased with increasing temperature except at 25°C, at which the rate was the highest. The population of the predator showed the highest intrinsic rate of increase at 30°C. A constant temperature of either 20° or 35°C produced a sharp reduction in the intrinsic rate of increase.

Prey consumption Fourth instar larva and adults of *E. nigromaculatus* increased prey consumption with increasing prey densities up to 80 *H. pruni*/day and then levelled off (Fig. 3). Adult females consumed significantly more *H. pruni* nymphs than did adult males or fourth instar larvae at 40 and higher prey densities (Fig. 3). Handling time of adult females was significantly shorter than that of adult males and fourth instar larvae. On the other hand, searching rates of all three stages were fairly close to one another (Table 4).

DISCUSSION

Studies under controlled laboratory conditions may provide valuable insight into insect population dynamics, although temperatures are not constant in nature (21). The results obtained in this study clearly show the effect of temperature on development time, mortality, longevity and fecundity of *E. nigromaculatus*. The temperature of 30°C was the

optimum for development of *E. nigromaculatus* among those tested because it yielded a short development time in combination with a low mortality rate. Longevity of females became shorter with increasing temperature and there were significant differences among all temperatures tested. These findings are consistent with results of studies on other coccinellids (14,21).

While the net reproductive rate at 30° was lower than at 20° and 25°C, the intrinsic rate of increase, a good indicator of the combined effect of temperature on development, survival and reproduction, was significantly greater (Table 3). The greater rate of increase at 30°C was due to faster immature development time, greater survival to adulthood, higher daily number of progeny and earlier peak in reproduction. Generation time became shorter with increasing temperature, because the time required from egg hatch to first oviposition and peak oviposition was shorter at higher temperatures. Short development time and high fecundity indicate that the *E. nigromaculatus* population has the potential for rapid population growth at 30°C.

Consumption of *H. pruni* fourth instar larvae and adults of *E. nigromaculatus* increased with increasing prey densities up to 80. A further increase in prey density to 160 aphids did not result in higher prey consumption for the fourth larval stage and adults. The functional response of fourth instar larva and adults of *E. nigromaculatus* to *H. pruni* densities conforms well to that described by Holling (9) as Type II. Several other studies of prey consumption by coccinellids are in agreement with the results described here (6,21,23). Although the searching rate of all three life stages was similar, the handling time of females was shorter. This was due to the fact that adult females consumed more *H. pruni* nymphs than fourth instar larvae and adult males at 40 and greater prey densities. Because of higher consumption by adult females, any estimate of the voracity of *E. nigromaculatus* should consider the sex ratio and life stage. Adult females of another coccinellid, *Scymnus levaillanti*, were also reported to consume more prey than larvae and males (21). Consumption rates may be higher in the laboratory than in nature. Because *E. nigromaculatus* was confined with its prey in a small arena, search time was minimal. Activity levels of predators may increase in the laboratory, especially at high prey densities. For example, estimates of both searching rate and handling time of another coccinellid predator, *Propylaea quatuordecimpunctata*, on host plants were different from similar estimates obtained from petri dishes (11). Therefore, laboratory experiments on prey consumption provide relative, rather than absolute information and should not be extrapolated to natural conditions.

Based on the data obtained for reproduction and prey consumption, *E. nigromaculatus* possesses promise as a biological control agent to keep aphid populations at low levels. However, further field experiments are needed to draw firm conclusions about the effect of *E. nigromaculatus* on its prey populations.

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REFERENCES

1. Andrewartha, H.G. and Birch, L.C. (1970) The Distribution and Abundance of Animals. Univ. of Chicago Press, Chicago, IL, USA.

2. Atlihan, R., Denizhan, E. and Yaşar, B. (1999) Effects of different preys on development and fecundity of *Scymnus subvillosus* Goeze (Coleoptera: Coccinellidae). *Proc. IV Turkish National Congress of Biological Control* (Adana, Turkey), pp. 397-406 (Turkish, with English summary).
3. Blackman, R.L. and Eastop, V.F. (1984) *Aphids on the World's Crops: An Identification and Information Guide*. John Wiley & Sons, Chichester, UK.
4. Bodenheimer, F.S. and Swirski, E. (1957) *The Aphidoidea of the Middle East*. The Weizmann Science Press of Israel, Jerusalem, Israel.
5. Eastop, V.F. (1966) A taxonomic study of Australian Aphidoidea (Homoptera). *Austr. J. Zool.* 14:399-592.
6. Hazard, R.V. and Ferro, D.N. (1991) Feeding responses of adult *Coleomegilla maculata* (Coleoptera: Coccinellidae) to eggs of colorado potato beetle (Coleoptera: Chrysomelidae) and green peach aphids (Homoptera: Aphididae). *Environ. Entomol.* 20:644-651.
7. Hodek, I. (1973) *Biology of Coccinellidae*. Junk, the Hague, the Netherlands.
8. Hodek, I. and Ruzicka, Z. (1979) Photoperiodic response in relation to diapause in *Coccinella septempunctata* L. (Coleoptera). *Acta Entomol. Bohemoslov.* 4:209-218.
9. Holling, C.S. (1959) The components of predation as revealed by a study of small mammal-predation on European pine sawfly. *Can. Entomol.* 91:293-320.
10. Mackauer, M. and Starý, P. (1967) Hym. Ichneumonidae World Aphidiidae. in: Delucchi, V. and Remaudière, G. [Eds.] *Index of Entomophagous Insects*. Le François, Paris, France.
11. Messina, F.J. and Hanks, J.B. (1998) Host plant alters the shape of the functional response of an aphid predator (Coleoptera: Coccinellidae). *Environ. Entomol.* 27:1196-1202.
12. Meyer, J.S., Ingersoll, C.G., McDonald, L.L. and Boyce, M.S. (1986) Estimating uncertainty in population growth rates: jackknife vs. bootstrap techniques. *Ecology* 67:1156-1166.
13. Minoiu, N. (1973) The vectors transmitting plum pox virus (Prunus virus 7 Christ.) to plum. *Anal. Inst. Cercet. Prot. Plant* 9:49-56.
14. Naranjo, S.E., Robertha, L.G. and Walgenbach, D.D. (1990) Development, survival and reproduction of *Scymnus frontalis* (Col.:Coccinellidae), an imported predator of Russian wheat aphid, at four fluctuating temperatures. *Ann. Entomol. Soc. Am.* 83:527-531.
15. Öncüer, C. (1991) *A Catalogue of the Parasites and Predators of Insect Pests of Turkey*. Publ. no. 505, Agriculture Faculty, Ege University, Izmir, Turkey (Turkish, with English summary).
16. SAS Institute. (1998) *User's Manual, version 7.0*. SAS Institute, Cary, NC, USA.
17. Sokal, R.R. and Rohlf, F.J. (1981) *Biometry*. 2nd ed. Freeman, New York, NY.
18. Starý, P. (1965) Integrated control of the mealy plum aphid *Hyalopterus pruni* (Geoffroy) in Czechoslovakia (Hom. Aphididae). *Ann. Soc. Entomol. Fr.* 1:177-180.
19. Starý, P. (1965) Aphidiid parasites of aphids in the USSR (Hym.: Aphidiidae). *Sb. Faun. Pr. Entomol. Oddeleni Národního Mus. Praha* 1(1):187-223.
20. Toros, S., Yaşar, B., Özgökçe, M.S. and Kasap, I. (1996) Studies on determination of Aphidoidea species in Van province. *Proc. IV Turkish National Entomological Congress* (Ankara, Turkey), pp. 549-556 (Turkish, with English summary).
21. Uygun, N. and Atlihan, R. (2000) The effect of temperature on development and fecundity of *Scymnus levaillanti*. *BioControl* 45:453-462.
22. Williams, F.M. and Juliano, S.A. (1985) Further difficulties in the analysis of functional-response experiments and a resolution. *Can. Entomol.* 117:631-640.
23. Yiğit, A. (1989) Studies on the interaction between hawthorn spider mite, *Tetranychus viennensis* Zacher (Acarina: Tetranychidae) injurious on apple trees and its predator *Stethorus punctillum* Weise (Coleoptera: Coccinellidae). Publ. no. 62, Food, Agriculture and Animal Husbandry Ministry, Republic of Turkey, Ankara, Turkey (Turkish, with English summary).