Effect of temperature on development rate and fecundity of apterous Aphis gossypii Glover (Hom., Aphididae) reared on Gossypium hirsutum L.

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Serdar Satar
Cukurova University

Nedim Uygun
Cukurova University

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Effect of temperature on development rate and fecundity of apterous *Aphis gossypii* Glover (Hom., Aphididae) reared on *Gossypium hirsutum* L.

U. Kersting, S. Satar and N. Uygun
Department of Plant Protection, University of Çukurova, Turkey

Abstract: The developmental time, survival and reproduction of the cotton aphid, *Aphis gossypii* Glover (Hom., Aphididae), were evaluated on detached cotton leaves at five constant and two alternating temperatures (15, 20, 25, 30, 35, 25/30, and 30/35°C). The developmental periods of the immature stages ranged from 12.0 days at 15°C to 4.5 days at 30°C. A constant temperature of 35°C was lethal to the immature stages of *A. gossypii*. The lower developmental threshold for the cotton aphid was estimated at 6.2°C and it required 108.9 degree-days for a first instar to become adult. The average longevity of adult females was reduced from 39.7 days at 15°C to 12.6 days at 30/35°C. The average reproduction rate per female was 51.5 at 25/30°C and 20.9 at 30/35°C. Mean generation time of the population ranged from 10.4 days at 30°C to 24.5 days at 15°C. The largest per capita growth rate ($r_m = 0.413$) occurred at 30°C, the smallest at 15°C ($r_m = 0.177$). It was evident that temperatures over 30°C prolonged development, increased the mortality of the immature stages, shortened adult longevity, and reduced fecundity. The optimal range of temperature for population growth of *A. gossypii* on cotton was 25/30–30°C.

1 Introduction

Aphis gossypii Glover (Hom., Aphididae) is a cosmopolitan, polyphagous species widely distributed in tropical, subtropical and temperate regions. The cotton aphid is present in all cotton-growing areas of the world and in temperate zones is principally a pest of vegetables and ornamentals in field and greenhouses (Leclant and Deguine, 1994). *Aphis gossypii* causes direct damage, resulting from the search for food, that may induce plant deformation and indirect damage caused either by honeydew or by transmission viruses. This aphid is the vector of some 60 virus diseases in a very large range of plants (Eastop, 1983).

Aphis gossypii has long been considered as a minor pest on cotton, but now appears to cause serious problems in many production areas (Roy and Behura, 1983; Michel and Prudent, 1985; Ullah and Paul, 1985; Broza, 1986; Nan et al., 1987; Hardee and O'Brien, 1990; Bagwell et al., 1991; Deguine, 1992). In the eastern Mediterranean region, a most important cotton-growing area of Turkey, *A. gossypii* was known as an early and mid-season pest of cotton, gaining significant importance during periods with cooler temperatures (Özgür et al., 1988). However, in recent years the cotton aphid has emerged as one of the main problems even during the warm season in August (Mart et al., 1997). In addition to the appearance of insecticide resistance and the elimination of beneficial insects, changes in nutritional and bioclimatic factors are suggested to result in conditions more favourable to *A. gossypii,* which may account for the increasing pressure on cotton (King and Phillips, 1989; Slosser et al., 1989).

Data on temperature-dependent development and fecundity of the cotton aphid reported in the literature signify important differences with regard to host plant and geographical region (Isely, 1946; Komazaki, 1982; Liu and Perng, 1987; Akey and Butler, 1989; Aldyhim and Khalil, 1993; Kocourek et al., 1994; van Steenis and El-Khawass, 1995). Thus, the developmental and fecundity data for *A. gossypii* on one crop and from one region should be used with caution if applied to different crops and regions (Akey and Butler, 1989).

The present study was designed to provide data on the developmental rate and fecundity of *A. gossypii* at different constant and alternating temperatures that might be used for the development of control models of cotton pests in the east Mediterranean region of Turkey.

2 Materials and methods

2.1 Experimental design

Aphis gossypii were obtained from cotton fields near Adana in the east Mediterranean region of Turkey and colonized on *Gossypium hirsutum* L., cultivar Çukurova 1518 at 26 ± 2°C, 65 ± 10% relative humidity and 16 h of artificial light of approximately 10 000 Lux in a climatic room. The aphids had been reared in laboratory for about 1 year before individuals were used in the experiments.

Randomly selected apterous females from the stock culture were transferred onto excised cotton leaf discs placed upside down on wet cotton wool in Petri dishes (both 5 cm in diameter). Offspring born within 24 h were confined individually on cotton leaf discs in Petri dishes. All replications in which the nymphs died within 24 h after transfer were omitted. The cotton wool in the Petri dishes was wetted daily and every 3–

5 days the aphids were transferred to new cotton leaf discs. The leaves used in the experiments were obtained from greenhouse-grown cotton plants (Çukurova 1518) that were between 4 and 6 weeks of age.

The experiments were conducted at five constant temperatures ranging from 15 to 35 ± 1°C in 5°C increments and at two alternating temperatures of 25/30 ± 1°C and 30/35 ± 1°C with an abrupt transition after 12 h, 60 ± 5% relative humidity and 16 h of artificial light (5000 Lux) in temperature cabinets. The immature stages and adults were observed daily at all temperature regimes and their survival recorded. The exuviae were used to determine moulting time; new born larvae were removed after counting.

2.2 Data analysis

Differences in developmental time, longevity, and reproduction were tested by analysis of variance (ANOVA). If significant differences were detected, multiple comparisons were made using Tukey's HSD multiple range test (P = 0.05). A linear technique was employed to compute the lower development threshold of the nymphs stage by using growth rate data as the dependent variable and temperature treatments as the independent variable. The mean of the alternating temperatures (27.5°C for 25/30°C and 32.5°C for 30/35°C) was used in the regression analysis. The lower developmental threshold was determined as the x-intercept of the linear equation and the degree-day requirements were determined as the value of the inverse of the linear equation slope.

Population growth rates were calculated from the equation of Lotka (BIRCH, 1948):

$$1 = \Sigma\, e^{-r \times x} l_x \times m_x \tag{1}$$

in which: x is the age in days (including immature stages), r is the intrinsic rate of increase, l_x is the age-specific survival (including immature mortality) and m_x is the age-specific number of female offspring.

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

$$r_j = n \times r_{\text{all}} - (n-1) \times r_i \tag{2}$$

The mean values of $(n-1)$ jackknife pseudo-values for each treatment were subjected to analysis of variance. Tukey's HSD multiple range test was used to compare mean growth rates at different temperatures (P = 0.01). Because low probability levels were used, there was no concern over the inflation of experiment-wise error rates (JONES, 1984). Each of the above mentioned analysis were conducted using Statgraphics software package (STATISTICAL GRAPHIC CORPORATION, 1988).

3 Results

The developmental time of *A. gossypii* significantly decreased with increasing constant temperatures ranging from 4.5 days at 30°C to 12.0 days at 15°C ($F = 45.8$; P = 0.05) (table 1). Only small differences were observed between both of the alternating temperatures, the developmental times being similar to the 25°C treatment. A considerably higher mortality during developmental time occurred at 15 and 30/35°C, while at 30°C all nymphs survived. The constant temperature of 35°C was lethal to the early nymphal stages of the cotton aphid (table 1).

A linear regression analysis was applied to the developmental points within the 15–30°C range. Development >30°C (30/35°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 ($r_{(T)}$) of *A. gossypii* increased linearly with increasing temperature ($r_{(T)} = 0.00918 \times T - 0.05652$; $R^2 = 0.9965$; $F = 848.5$; P = 0.001) (fig. 1). The theoretical development threshold was estimated as 6.2°C. It required 108.9 degree-days for a first instar to become adult based on the developmental threshold for overall immature stages. Longevity was significant longer at 15°C ($F = 30.4$; P = 0.05) than at any other temperature regime tested (table 1, fig. 2). The highest mean fecundity per reproduction day occurred at 30 and 25/30°C and the lowest at 15 and 20°C ($F = 22.6$; P = 0.05) (table 1).

The survival rates of *A. gossypii* adults sharply decreased immediately after the peak of nymph production at higher temperatures, while a relatively long post-reproductive period was observed at 15°C and 20°C (fig. 2). The highest age-specific number of nymphs per female per day (m_x) ranged between 2.5 at 15°C and 4.9 at 30°C. Only 2.9 nymphs/day were produced as the maximum number in the 30/35°C treatment. Increasing temperatures resulted in shorter generation times (T_o) of *A. gossypii* with 24.5 days at 15°C and 10.4 days at 30°C (table 2). The net reproductive rate (R_o) was highest

Table 1. *Developmental time, longevity, mortality and fecundity rate of* Aphis gossypii *on excised cotton leaf discs at seven temperature regimes*

Temperature (°C)	n	Developmental time (days) (mean ± SEM)	Total nymphal mortality rate (%)	Longevity (days) (mean ± SEM)	Offspring per reproduction day (mean ± SEM)
15 ± 1	37	12.0 ± 0.18 d	15.6	39.7 ± 3.11 d	1.8 ± 0.07 a
20 ± 1	42	8.1 ± 0.20 c	8.7	19.5 ± 1.88 bc	2.0 ± 0.11 ab
25 ± 1	44	5.7 ± 0.09 b	4.3	23.1 ± 1.34 bc	2.3 ± 0.11 b
30 ± 1	41	4.5 ± 0.09 a	0.0	16.8 ± 0.83 ab	3.1 ± 0.16 c
35 ± 1	62	–	100.0		
25/30 ± 1	41	5.2 ± 0.16 b	6.8	25.2 ± 1.15 c	3.1 ± 0.20 c
30/35 ± 1	39	5.5 ± 0.15 b	17.0	12.6 ± 0.59 a	2.3 ± 0.11 b

Means in columns followed by the same letter are not significantly different by Tukey's HSD multiple range test (P = 0.05).

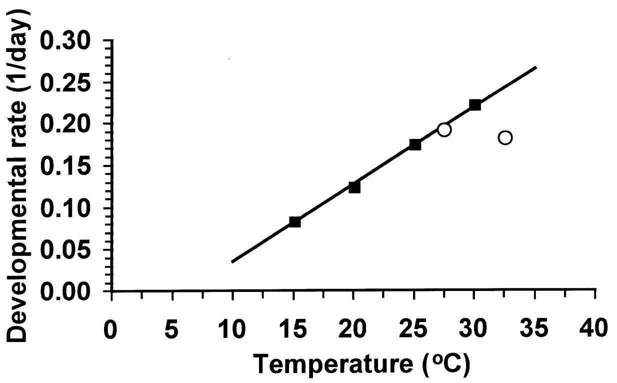

Fig. 1. *Developmental rate (r) of* Aphis gossypii *at four constant (black squares) and two alternating (open circle) temperatures. Line is the linear regression analysis of developmental rate and temperature within the range of 15–30°C. The mean of the alternating temperatures (27.5°C for 25/30°C and 32.5 for 30/35°C) was used to compute the regression analysis*

at 25/30°C (51.5 aphids/aphid) and lowest at 30/35°C with as less as 20.9 aphids/aphid. The populations of *A. gossypii* kept at warmer temperatures showed higher per capita rates of population growth, although the intrinsic rate of increase at 30°C (0.413 aphids/aphid per day) was statistically not different from that at the fluctuating temperature of 25/30°C (0.384 aphids/aphid per day) ($F = 83.5$; $P = 0.001$). The 30/35°C treatment resulted in a sharp reduction of the per capita growth rate of the cotton aphid ($r_m = 0.298$ aphids/aphid per day), which was not significantly different from that at 25°C.

4 Discussion

Although insects are not subjected to constant or alternating temperatures in nature, controlled laboratory studies can provide a valuable insight into the population dynamics of aphids. The results reported here clearly show the effects of temperature on the developmental time, nymphal mortality rate, longevity and fecundity of *A. gossypii*.

The optimum temperature for development of the cotton aphid was 30°C and thus, slightly higher than the 28°C reported by Isely (1946) and the 27.5°C

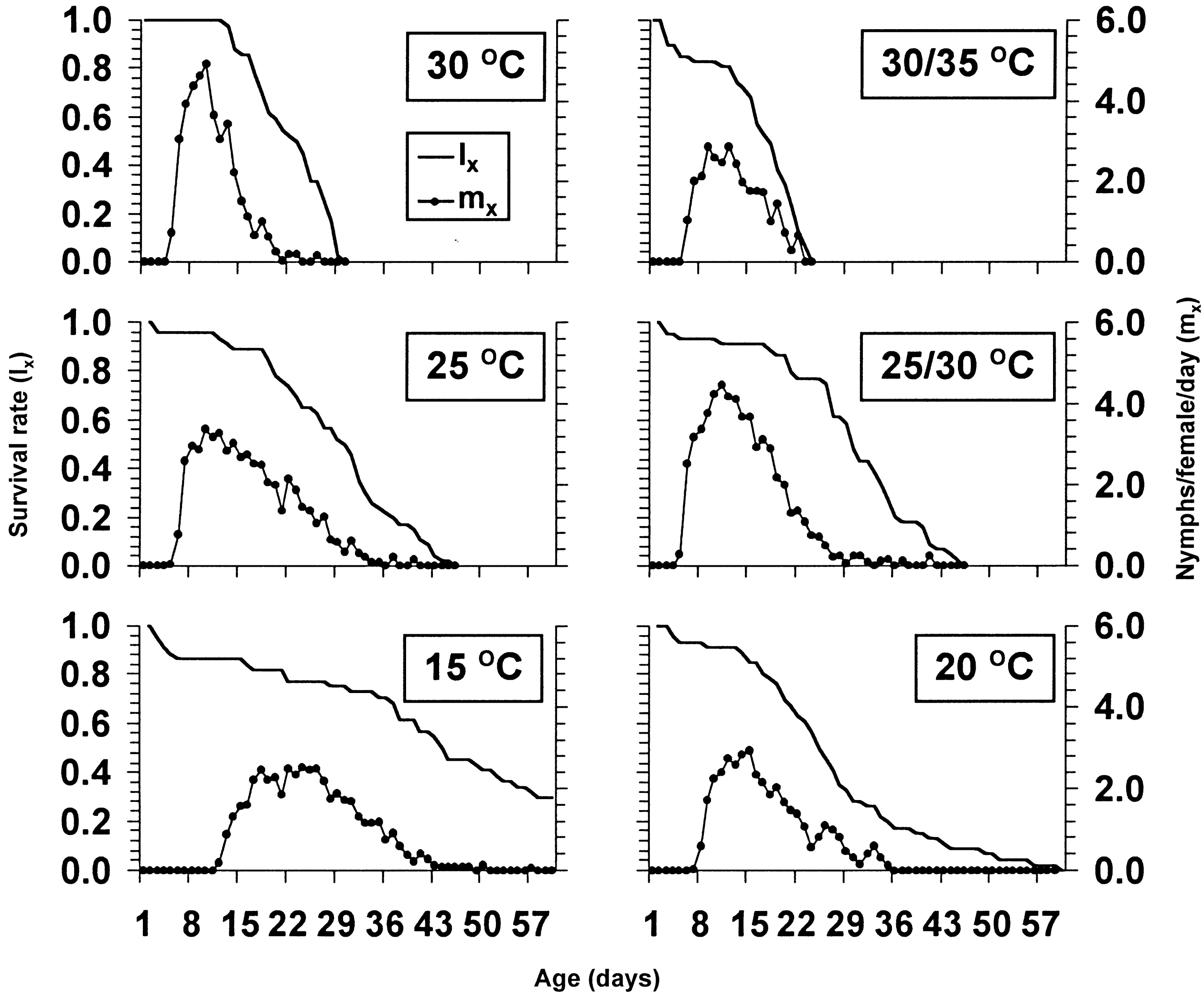

Fig. 2. *Age-specific survival rate (l_x) and age-specific fecundity (m_x) of* Aphis gossypii *on excised cotton leaf discs at six temperature regimes*

Table 2. *Generation time (T_o), net reproductive rate (R_o), and rate of population growth (r_m) of* Aphis gossypii *on excised cotton leaf discs at six temperature regimes*

Temperature (°C)	Generation time (T_o) (days)	Reproduction rate (R_o) (aphids/aphid)	Intrinsic rate of increase (r_m) (aphids/aphid per day)
15 ± 1	24.5	36.3	0.177 ± 0.0051 a
20 ± 1	15.8	29.2	0.253 ± 0.0102 b
25 ± 1	15.1	44.7	0.337 ± 0.0076 c
30 ± 1	10.4	37.9	0.413 ± 0.0086 d
25/30 ± 1	13.6	51.5	0.384 ± 0.0120 d
30/35 ± 1	11.7	20.9	0.298 ± 0.0112 c

Means in column followed by the same letter are not significantly different by Tukey's HSD multiple range test (P = 0.01).

mentioned by Akey and Butler (1989) on cotton, although it was essentially the same as the 29.7°C observed for *A. gossypii* on citrus (Komazaki, 1982). Insects reared at temperatures above the upper threshold develop more slowly than those reared under more favourable conditions (Curry et al., 1978; Stinner et al., 1984). This was also true for *A. gossypii* at 30/35°C, causing a significant increase in developmental time compared with that at 30°C. The theoretical development threshold of 6.2°C computed from the linear segment of the growth curve, was similar to the 6.4°C computed from data reported by Akey and Butler (1989), but quite different from the −0.4°C estimate for *A. gossypii* on citrus (Komazaki, 1982). The optimum temperature of 25/30°C for maximal production of nymphs per day in this study was close to that reported from Akey and Butler (1989) (27.5°C) on cotton and Liu and Perng (1987) (27°C) on bottle guard cucurbit, but quite different from the 19.8°C reported by Komazaki (1982) for a Japanese cotton aphid colony obtained from citrus.

The intrinsic rate of natural increase (r_m) is a good indicator of the temperature at which the growth of population is most favourable, because it reflects the overall effects of temperature on development, reproduction, and survival characteristics of a population. The population kept at 30°C had the highest r_m-value among all temperatures ($r_m = 0.413$ aphids/aphid per day), because of its faster development, higher survival of immature stages as well as the high daily rate of progeny. However, the capita growth rate at 30°C was statistically not different from that at 25/30°C ($r_m = 0.384$ aphids/aphid per day). The high r_m-value at this alternating temperature could be attributed to the considerably higher net reproduction rate per female ($R_o = 51.5$). In contrast, the population exposed to 15°C had a prolonged developmental time and a higher mortality rate at the immature stage, resulting in a much smaller intrinsic rate of increase. The capita growth rate of the *A. gossypii* on cotton was considerably smaller than those computed for the cotton aphid on cucumber and squash at comparable temperature regimes (Aldyhim and Khalil, 1992; Kocourek et al., 1994; van Steenis and El-Khawass, 1994). In contrast, Komazaki (1982) showed that the highest population growth rate ($r_m \approx 0.32$ aphids/aphid per day) of a citrus population of *A. gossypii* occurred at 19.8°C.

The short developmental time and the high reproduction rate of *A. gossypii* at warm temperatures indicates that the cotton aphid colony used in the present study has the potential to achieve high population densities rapidly during the warm cotton-growing season in August. These results are strongly supported by the recent findings of Atakan and Özgür (1997) who observed a generation time (from first nymph stage to first offspring) of only 5 days at average daily temperatures of 28–29°C in cotton fields in the east Mediterranean region. Therefore, a development–rate model can now be constructed using the data derived from this study.

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Authors' address: Dr ULRICH KERSTING (corresponding author), SERDAR SATAR and Professor Dr NEDIM UYGUN, Department of Plant Protection, Faculty of Agriculture, University of Çukurova, 01330 Adana, Turkey