

# Effect of Temperature on the Life History Traits of *Aphis gossypii* Glover (Homoptera: Aphididae) on Bottle Gourd, *Lagineria Siceraria* (Molina) Standl. (Cucurbitaceae)

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**Abstract**—Life history traits of *Aphis gossypii* Glover (Homoptera: Aphididae) were estimated at five constant temperatures (10, 15, 20, 25 and 30 ± 0.5 °C) inside Growth Chambers on a cucurbit vegetable, *Lagineria siceraria*. (Molina) Standl. Within each instar the development was fastest at 30 °C, with a pre-larviposition period of only one day. Estimates of the lower developmental threshold ( $tL$ ), and predicted developmental time in degree days ( $D^\circ$ ), ranged from 25.61  $D^\circ$  (for IV instar nymphs) to 132.90  $D^\circ$  (for I to IV instar nymphs). *A. gossypii* survived longer at 10 °C (27.2±2.2 SD days) followed by at 15 °C (24.3±0.2 SD days), 20 °C (18.2±1.0 SD days), 25 °C (12.2±0.6 SD days) and 30 °C (12.4±0.9 SD days). Fecundity was highest at 25 °C on sorghum (32.5 nymphs/female). *A. gossypii* achieved its maximum intrinsic rate of increase ( $r_m = 0.322 d^{-1}$ ) at 25 °C. Differences in  $r_m$  values were caused primarily by differences in pattern of fecundity of *A. gossypii* and its survival. The variation in  $r_m$  was also reflected in other life-table parameters. Doubling time (DT) was inversely proportional to temperatures. Generation time (GT) is shortest at 25 °C.

**Index Terms**—*Aphis gossypii*, temperature, life history traits, Aphididae

## I. INTRODUCTION

The aphid, *Aphis gossypii* Glover (Homoptera: Aphididae) is a polyphagous pest infesting various crops throughout the world. The development, survivorship, and reproduction of the aphid are strongly influenced by temperature and quality of food. The effect of variations in food quality (food plant species/varieties) on *A. gossypii* has already been described [1], [2].

Among the ecological factors influencing aphid in fields, temperature exerts important and limiting effects on their biology, distribution and abundance by (a) reducing their survival, (b) retarding development and/or (c) suppressing reproduction [3]-[7]. The understanding of the effect of temperature on the biology of aphids can also be utilised for predicting their seasonal occurrence and fluctuation on a physiological time scale. The

rapidity of physiological development and rate of reproduction of the aphid increase as the temperature increases to an upper limit. At extreme low and high temperatures, developmental rate and reproduction rate of the aphids are reduced. The developmental rate for different stages of *A. gossypii* was reported to increase linearly as temperature increased within the range of 15 to 30 °C [8]. Both food quality and temperature play a distinct role in this aphid population increase. The life-table of *A. gossypii* was studied at five constant temperatures (10, 15, 20, 25, and 30 °C) and on three food plants (*Psidium guajava* Linn., *Bidens pilosa* Linn. and *Ageratum houstonianum* Mill.) [9] and it was observed that the temperature and food plants are highly interactive. The objective of this study was to generate comprehensive life history traits across a temperature range (10-30 °C) in a standard rearing environment in the laboratory.

## II. MATERIALS AND METHODS

### A. Experimental Design

Experiments were carried out on excised leaf disk of bottle gourd, *Lagineria siceraria* var. PBOG 1. The life cycle traits such as development times, age-specific survival rates and longevity, age-specific and net fecundity rates, intrinsic rate of increase and other life-table statistics were determined in B.O.D. chambers, at five constant temperatures 10, 15, 20, 25 and 30 ± 0.5 °C, at a L12:D12 photoperiod, light intensity 5000 lux, and 80 ± 5 % R.H.

The *A. gossypii* were obtained from the bottle gourd growing in field laboratory in the university campus. The aphids were reared on bottle gourd seedlings for about 5 generations before adult females were transferred from the stock culture to the leaves of experimental plants and allowed to larviposit. The test aphids were randomly selected from the new-born nymphs, and were put into a Petri dish having a leaf disk of the host plant kept on moist filter paper inside it. Three replicates of 10 individuals were performed at each temperature and the characteristics of the apterous virginoparous females were noted.

**B. Thermal Requirement for Development**

Temperature controls the developmental rate of aphids like other insects. Insects require a certain amount of heat to develop from one point in their life cycles to another. This measure of accumulated heat is known as physiological time. Theoretically, physiological time provides a common reference for the development of organisms. The amount of heat required to complete a given organism's development does not vary-the combination of temperature (between thresholds) and time will always be the same. Physiological time is often expressed and approximated in units called degree-days ( $\mathcal{D}$ ). The lower developmental threshold ( $tL$ ) for an organism is the temperature below which development stops. The lower threshold is determined by the organism's physiology. It is independent of the method used to calculate degree-days [10].

The thermal requirements for nymphal instars ( $N_1$  to  $N_4$ ), pre-reproductive period (the time from adult eclosion to onset of reproduction), total pre-imaginal development (the time from birth to adult eclosion), and total pre-reproductive development (the time from birth to onset of reproduction) were determined. The aphids were observed every 24 hour at 15-25 °C and every 12 hour at 30 °C.

For each temperature, rates of developments ( $RD$ : day<sup>-1</sup>) were calculated as reciprocals of the total pre-imaginal ( $RD_{pi}$ ) and total pre-reproductive ( $RD_{pr}$ ) development. The relationships between  $RD$  and temperature ( $T$ ) were described by a linear function:

$$RD = a + b.T$$

where  $a$  and  $b$  are parameters of the linear regression [3]. From this, the lower development thresholds ( $tL$ ) was estimated as:

$$tL = - a/b$$

and the sums of effective temperatures, i.e. number of day-degrees ( $\mathcal{D}$ ) above  $tL$  necessary for completion of development was estimated as:

$$\mathcal{D} = 1/b.$$

**C. Life Table Characteristics**

Adults were observed daily at all temperatures and their age specific survivorship ( $l_x$ ) and age specific fecundity ( $m_x$ ) were recorded. Newborn larvae were counted and removed. From this data, the length of the reproductive period (in days), total fecundity as total mean number of progeny per female, longevity (in days) were estimated.

The value of net fecundity rate ( $R_o$ ) was calculated as expected lifetime production of female progeny for a newborn female as:

$$R_o = \sum l_x.m_x$$

Intrinsic rate of increase ( $r_m$ ) was calculated by iterating the following equation:

$$\sum l_x.m_x \exp(-r_m.x) = 1$$

In addition, following other life-table parameters such as generation time ( $GT$ ) as mean life-span to the median of  $R_o$  (in days), infinite rate of increase ( $\lambda_m$ ), weekly multiplication rate ( $r_w$ ) and doubling time ( $DT$ ) of the population were calculated by using the value of  $r_m$  as:

$$GT = \ln R_o/r_m, \lambda_m = \exp(r_m), r_w = (\lambda_m)^7, DT = \ln 2/r_m$$

TABLE I. THE MEAN DEVELOPMENT TIME FOR PRE-IMAGINAL STAGES, ADULT PRE-REPRODUCTIVE PERIOD, AND TOTAL PRE-IMAGINAL AND PRE-REPRODUCTIVE PERIOD, REPRODUCTIVE PERIOD, MEAN LONGEVITY OF *APHIS GOSSYPYII* REARED ON EXCISED LEAF DISK OF *LIGINARIA SICERARIA* VAR. PBOG 1 AT VARIOUS CONSTANT TEMPERATURES

Particulars	Temperature °C					Regression equation	r-value	
	10	15	20	25	30			
Development time (days)	I instar	4.7±0.32	3.4±0.25	3.1±0.25	1.8±0.20	1.4±0.15	Y=6.13-0.16X	0.981*
	II instar	5.2±0.64	3.6±0.21	2.6±0.25	1.7±0.10	1.4±0.15	Y=6.68-0.19X	0.967*
	III instar	5.6±0.15	2.9±0.08	2.3±0.23	1.3±0.18	1.3±0.20	Y=6.81-0.21X	0.913*
	IV instar	6.2±0.26	3.8±0.36	2.2±0.26	1.2±0.12	1.2±0.15	Y=7.98-0.25X	0.942*
Total pre-imaginal development (days)	21.7±1.33	13.7±0.23	10.2±0.45	6.1±0.53	5.3±0.32	Y=27.60-0.81x	0.957*	
Pre-reproductive period (days)	3.5±0.25	2.6±0.40	1.6±0.10	1.2±0.12	1.0±0.06	Y=4.55-0.13X	0.961*	
Total pre-reproductive period (days)	25.3±1.38	16.3±0.18	11.8±0.51	7.3±0.45	6.4±0.29	Y=32.14-0.94X	0.959*	
Post- reproductive period (days)	1.30±0.10	1.57±0.30	1.50±0.00	1.07±0.15	0.97±0.32	Y=2.28-0.04X	0.954*	
Reproductive period (days)	22.3±1.96	20.1±0.30	15.1±1.05	9.9±0.30	10.4±0.59	Y=31.66-0.85X	0.986*	
Mean longevity (days)	27.2±2.2	24.3±0.2	18.2±1.0	12.2±0.6	12.4±0.9	Y=37.15-1.02X	0.989*	

**III. RESULTS**

**A. Development Times and Reproductive Periods**

Development times are given in Table I. From 10 to 30 °C, the nymphs on average took 26.8% in  $N_1$  (I instar), 26.1% in  $N_2$  (II instar), 23.2% in  $N_3$  (III instar) and 23.9% in  $N_4$  (IV instar) of the total pre-imaginal period. The

adults started to reproduce on the second (at 20-30 °C) to third (at 15 °C) or fourth (at 10 °C) day after eclosion. The relationships between the rate of total pre-imaginal ( $RD_{pi}$ ) and total pre-reproductive ( $RD_{pr}$ ) development and temperature were linearly correlated on the range of temperatures from 10 to 30 °C (Table I).  $RD_{pr}$  was almost four times on 10 °C (25.3±1.38 SD days) than on 30 °C

(6.4±0.29 SD days). The reproductive period also varied with temperature (Table I). The female gave birth up to 22.3 days at 10 °C while only about 10 days at 25 and 30 °C. The lower development threshold (*tL*) was estimated as 4.84 °C and day-degrees above *tL* necessary for completion of development was 132.9 °C. These parameters for each stage are also shown in the Table II.

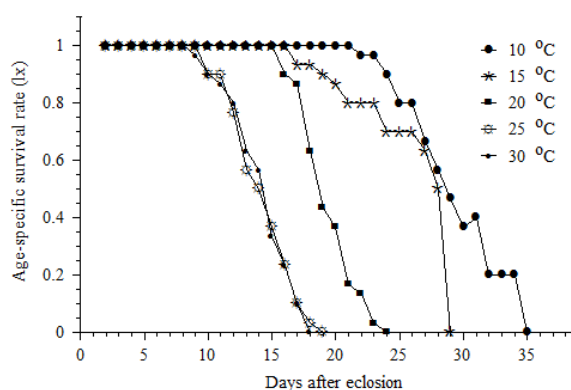


Figure 1. Effect of temperature on the age-specific survival rate of *Aphis gossypii*.

TABLE II. TEMPERATURE THRESHOLD (*tL*) AND THE DAY-DEGREES (*D*) REQUIRED FOR THE DEVELOPMENT OF THE DIFFERENT STAGES OF *APHIS GOSSYPYI* REARED ON EXCISED LEAF DISK OF *LAGINARIA SICERARIA* VAR. PBOG 1 AT VARIOUS CONSTANT TEMPERATURES WITH THE RESPECTIVE COEFFICIENT OF DETERMINATION (*R*<sup>2</sup>)

Particulars	Developmental stages of <i>Aphis gossypii</i>				
	I	II	III	IV	I-IV
Intercept (a)	-0.0758	-0.097	-0.1447	-0.269	-0.036
Slope (b)	0.025	0.026	0.032	0.039	0.0075
<i>tL</i>	3.09	3.70	4.52	6.89	4.84
<i>D</i>	40.78	38.14	31.25	25.61	132.9
<i>R</i> <sup>2</sup>	0.922	0.984	0.935	0.942	0.964

**B. Age-Specific Survival Rate and Longevity**

Figures on longevity are summarized in Table I. At 10 and 15 °C the aphids lived longer than at 20, 25 and 30 °C. The data shown in Fig. 1 demonstrated that the first

female on average died on day 22, 17, 16, 11 and 9; and last female died on day 35, 29, 24, 19 and 18 reared at 10, 15, 20, 25 and 30 °C, respectively. It implies that the life-span of the female was about half at 30 °C than at 10 °C. The relationship between longevity (*L*) and temperature (*T*) was linear ( $L = 37.15 - 1.02 T$ ,  $r = -0.989$ ,  $P < 0.01$ , Table I).

**C. Age-Specific Net Fecundity Rate (*m<sub>x</sub>*) and Net Fecundity Rate (*R<sub>0</sub>*)**

Figures on the fecundity rates are summarised in Table III. The maximum rate of reproduction was only 0.55±0.02 SD nymph per day at 10 °C compared with 2.30±0.22 SD at 25 °C and 2.11±0.32 SD at 30 °C. The age-specific net fecundity rates (*m<sub>x</sub>*) (average number of daughters yielded) of *A. gossypii* at 5 constant temperatures are shown in Fig. 2.

The *m<sub>x</sub>* is highly influenced by variations in temperature. It reached a maximum value on day 3 and 4 at 25 and 30 °C, respectively and decreased sharply thereafter. At 10 °C the values of *m<sub>x</sub>* was almost same between most of the larviposition days (Fig. 2).

Mean total fecundity (*R<sub>0</sub>*) ranged from 15.5 nymphs per female at 10 °C to 32.5 nymphs at 25 °C (Table III). The net fecundity rate increased linearly with temperature range 10-25 °C ( $R_0 = 5.3 - 1.1 T$ ,  $r = 0.99$ ,  $P < 0.01$ ).

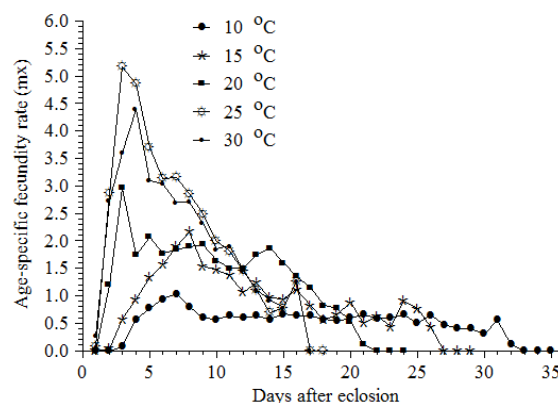


Figure 2. Effect of temperature on the age-specific fecundity rate of *Aphis gossypii*.

TABLE III. THE LIFE-TABLE PARAMETERS OF *APHIS GOSSYPYI* REARED ON EXCISED LEAF DISK OF *LAGINARIA SICERARIA* VAR. PBOG 1 AT VARIOUS CONSTANT TEMPERATURES. VALUES ARE EXPRESSED AS MEAN±SD

Particulars	Temperature °C					Regression equation (between first four temperature regime)	r-value
	10	15	20	25	30		
Mean <i>m<sub>x</sub></i> per day	0.55 ±0.02	0.92 ±0.03	1.40 ±0.05	2.30 ±0.22	2.11 ±0.32	$Y = -0.713 + 0.11 X$	0.978*
Net fecundity rate ( <i>R<sub>0</sub></i> )	15.50 ±0.92	23.27 ±0.90	28.23 ±1.19	32.50 ±1.39	29.50 ±1.61	$Y = 5.289 + 1.12 X$	0.990*
Intrinsic rate of increase ( <i>r<sub>m</sub></i> )	0.0834 ±0.0017	0.1373 ±0.0026	0.2057 ±0.0097	0.3226 ±0.0047	0.3079 ±0.0065	$Y = -0.088 + 0.016 X$	0.983*
Infinite rate of increase ( <i>λ<sub>w</sub></i> )	1.09 ±0.002	1.15 ±0.003	1.23 ±0.012	1.38 ±0.006	1.36 ±0.009	$Y = -0.713 + 0.11 X$	0.978*
Weekly multiplication rate ( <i>r<sub>w</sub></i> )	1.79 ±0.022	2.61 ±0.048	4.23 ±0.286	9.57 ±0.312	8.64 ±0.398	$Y = -4.186 + 0.50 X$	0.921*
Doubling time (Days) (DT)	8.31 ±0.172	5.05 ±0.097	3.37 ±0.161	2.15 ±0.031	2.25 ±0.047	$Y = 11.78 - 0.40 X$	-0.974*
Generation time (GT) (days)	32.85 ±1.34	22.92 ±0.21	16.26 ±0.74	10.79 ±0.28	10.99 ±0.09	$Y = 46.199 - 1.46 X$	-0.990*

#### D. Intrinsic Rate of Increase ( $r_m$ ) and Other Life-Table Parameters

Parameters related to population growth are shown in Table III. The parameter  $r_m$  increased linearly from 0.0834 to 0.3226 on a per day scale ( $r_m = -0.0878 + 0.0157 T$ ;  $r = 0.983$ ,  $P < 0.01$ ). Consequently, when the aphid age distribution is stable and in an unlimited environment one can use  $r_m$  to predict the population development of *A. gossypii* on bottle gourd var. PBOG 1 using the model:

$$N_t = N_o \cdot \exp(r_m T)$$

where  $N_t$  is the predicted aphid density at time  $t$ ,  $N_o$  is the initial population density,  $r_m$  is the intrinsic rate of increase in day-degrees, and  $T$  is time expressed in day-degrees above  $tL$ .

The variation in  $r_m$  was also reflected in the variations of other life-table statistics that utilise  $r_m$  in their calculation, viz., the finite rate of increase ( $\lambda_m$ ) and weekly multiplication rates ( $r_w$ ), doubling time of the population ( $DT$ ) and generation time ( $GT$ ).  $DT$  was 3.69 times higher at 10°C than at 25°C. Since  $l_x$ ,  $m_x$  and  $r_m$  were temperature dependent,  $GT$  also varied significantly with temperature variation (Table III). Higher temperature always reduced  $GT$  which was about one-third at 25-30°C (10.8-11.0 days) than at 10°C (32.9 days). A linear regression yielded significant correlation coefficient between  $GT$  and temperature ( $GT = 46.20 - 1.46 T$ ,  $r = -0.990$ ,  $P < 0.01$ , Table III).

#### IV. DISCUSSION

The  $tL$  and  $\mathcal{D}$  obtained for the pre-imaginal development of *A. gossypii* highly varied through different studies (Table IV) and should not be compared as the design of experiments and conditions are highly variable through studies.

TABLE IV. ESTIMATES OF LOWER THRESHOLD TEMPERATURE ( $tL$ ) IN °C, THERMAL CONSTANT IN DEGREE DAYS ( $\mathcal{D}$ ) AND LONGEVITY OF *APHIS GOSSYPYII* REARED AT DIFFERENT FOOD PLANTS

Food plants	$tL$	$\mathcal{D}$	References
<i>Citrus unshiu</i>	-0.4	181.8	Komazaki, 1982
<i>Cucumis melo</i>	3.5	113.6	Narai and Murai, 1991
	5.8	113.6	Kocourek <i>et al.</i> , 1994
	6.9	96.3	Adam, 1998
	4.8	105.6	Wyatt and Brown, 1977
<i>Cucumis sativus</i>	6.9	90.1	Kocourek <i>et al.</i> , 1994
	6.19	97.1	Zamani <i>et al.</i> , 2006
<i>Gossypium hirsutum</i>	6.2	108.9	Kersting <i>et al.</i> , 1999
	7.9	168.8	Xia <i>et al.</i> , 1999
	7.9	98.0	Akey and Butler, 1989
<i>Lilium longiflorum</i>	5.9	106.6	Liu <i>et al.</i> , 2000

That the maximum longevity was recorded at low temperature is unusual, and differs from that observed in another population of *A. gossypii* reared on other cucurbits [11]. It survived more than 1 month at 15°C on

cotton [8] and citrus [12]. This trait may enable some females to survive over winter in unheated greenhouses. On the other hand, the maximum  $r_m$  is typical for aphid species with a high reproductive potential developing on an optimal host plant [9], [13]-[20].

The high optimal temperatures for development, fecundity and growth for *A. gossypii* suggest a subtropical origin of the population. The minimum pre-reproductive period was achieved at 30°C compared with 29.7°C on citrus [12], 28°C on cotton [21], and 27°C on bottle gourd cucurbit [22]. Maximum  $R_o$  values were also attained at 30°C compared with maximum at 25°C [23], 20°C [21] and 19.8°C [12] for other population of *A. gossypii* and on other host plants. In contrast, on cucumbers, a striking difference was found in population growth with their population having a higher  $R_o$  at 18 than at 24°C [11]. Probably for the first time we record an interesting phenomenon, the intrinsic rate of increase ( $r_m$ ) expressed in day-degrees is nearly constant over a range of temperature.

The parameter  $r_m$  is inversely proportional to generation time and directly to the logarithm of  $R_o$ , which is not affected by the time scale because it is calculated on per generation basis. Therefore, when  $m_x$  and  $l_x$  are expressed in terms of days, increase in  $r_m$  with increasing temperature can be attributed both to an increase in  $R_o$  and decline in generation time. Generation time decreased due to a reduction in the pre-reproductive and a larger reduction in the reproductive period (Table III). However, on a day-degree scale the increase in  $R_o$  was compensated by an increase in temperature, and  $r_m$  declined with increase in temperature. Generation time decreased with increase in temperature because both the pre-reproductive and reproductive periods (Table I) decreased.

According to these results, *A. gossypii* populations in the north-eastern U.P. are well adapted to temperatures between 20 and 30°C, showing a high capita growth rate within this temperature range. Temperatures below or above this range result in drastically reduced population growth, and temperatures over 30°C are lethal to nymphs of the aphids.

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