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Thermal Constants for Development of the Cereal Aphid, *Rhopalosiphum padi* (Homoptera: Aphididae) and its Parasitoid *Aphidius matricariae* (Hymenoptera: Aphidiidae)

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ABSTRACT

The relationship between thermal units' requirements and developmental rate was studied for the cereal aphid, *Rhopalosiphum padi* L. on wheat and barley and its parasitoid, *Aphidius matricariae* Hal. Three constant temperatures of 13, 20, 26±1°C were selected to estimate the aphid thermal developmental requirements and thresholds of five developmental stages (*i.e.*, four nymphal instars, and time to adult) on wheat and barley. Also, for seven developmental stages of the parasitoid (*i.e.*, egg, three larval instars, pre-pupa, pupa, and time to adult). The thermal unit requirements for the time to adult were estimated as 96.15 and 86.2 degree- days for *R. padi* on wheat and barley, respectively, (with no significant difference between them) and 208.33 degree-days for *A. matricariae*. The developmental thresholds for the time to adult were estimated as 4.4 and 5°C for *R. padi* on wheat and barley, respectively, and 5.7°C for *A. matricariae*.

Key Words: Thermal requirements, *Rhopalosiphum padi*, *Aphidius matricariae*, wheat, barley.

INTRODUCTION

The rate of development of poikilothermic animals including insects is temperature dependent. The relationship between temperature and rate of development in insects is linear over most of the range of temperatures to which they are exposed. Exceptions to this occur near high temperatures that prove deleterious or lethal to the insects, and near the developmental threshold (t) of the insect. The developmental threshold is defined as that temperature below which no measurable development occurs. The amount of heat required to complete development from egg to adult (k) is considered a thermal constant. The parameters (t) and (k) can be estimated by least squares regression analysis of the effect of temperature on the rate of development (Andrewartha and Birch, 1954).

Knowledge for the temperature requirements (t and k) of insects can be useful in at least two ways. First, the temperature requirements of insects can be used for predicting their seasonal occurrence and fluctuations on a physiological time-scale (Ali-Niazee, 1976; Sevacherian *et al.*, 1977 a,b and Harcourt, 1981). Second, knowledge of the temperature requirements (t and k) together with knowledge of the diapause capabilities of insects are useful in forecasting the potential distribution and abundance of insect species (Messenger, 1970, 1971, and Flint, 1980). Thus, temperature related studies could be useful when attempting to make predictions concerning the dynamics and distribution of insect populations.

In case of biological control, the thermal requirements, *i.e.*, (t) and (k) of natural enemies are one among many attributes (*e.g.* fecundity, searching capacity, host preferences, ...etc.) that acting in concert with environmental factors will influence the outcome of attempts at biological control of a host. The thermal requirements of a natural enemy may determine its success, or failure, in the biological control of a given host population. In the case of aphid pests, an early appearance of parasitoids in the field will facilitate the build-up of high parasitoid: aphid ratios early in the season, which may contribute to decelerating the initial growth rates of aphid populations (Wratten and Powell, 1991).

Present study is concerned with determining the thermal requirements for different developmental stages of *Rhopalosiphum padi* L. (Homoptera: Aphididae),(the most common cereal aphid species on wheat in Egypt, EL-Heneidy, 1994), and its abundant parasitoid, *Aphidius matricariae* Haliday (Hymenoptera: Aphidiidae), which is widely distributed in almost all the Mediterranean countries (Stary, 1976), under laboratory conditions.

MATERIALS AND METHODS

Biological Studies

Detailed rearing conditions and methods for the laboratory cultures of both the host and parasitoid were described by Adly (2002). Both the aphid species and its parasitoid were collected from wheat fields. Developmental times of *R. padi* on two host plants; wheat and barley, and the parasitoid species *A. matricariae* on *R. padi* were measured at three constant temperatures (13, 20, 26 ±1°C), photoperiod 16:8 L:D and 50-70% R.H.

Aphid Development

Newly deposited nymphs from the aphid apterous viviparous females (adults) (50 individuals /replicate and treatment n =50) were used as start for biological studies. Each individual of the first nymphal instar of *R. padi* was placed on one- week old wheat or barley seedling in a small pot and kept in small cage. Cages were placed in controlled environmental chambers at each of the respective temperature regimes. Individual nymphs were observed daily to record the developmental durations for each nymphal instar (through molting and removing the caste skin regularly), and time to adult.

Parasitoid Development

One hundred nymphs *R. padi*, (almost 2*nd* and 3*rd* nymphal instars), were placed on wheat seedlings cultivated in small pots and kept in cages (30 individuals/ replicate and treatment n =30). In each cage, aphids were exposed to 10 mated parasitoid females for one hour. Afterwards, parasitoid females were removed, then the cages were placed inside incubators at the selected temperatures to determine the duration of different parasitoid stages (egg, larval instars, pre-pupa and pupa). To determine the parasitoid developmental stage, parasitized aphids were dissected daily by a very fine needle, in a drop of Ringer's solution using a stereomicroscope.

Thermal Requirements

The lower developmental thresholds (t) of the aphid and the parasitoid, the thermal constant (k) and their respective standard errors were estimated by linear regression analysis of the developmental rates on temperature (Campbell *et al.,* 1974). When the rate of development at each temperature is plotted against the temperature, over a range of average temperatures, this relationship approaches a straight line (Andrewartha and Birch, 1954). This relationship can be described by a linear regression equation of the formula: $y = a + bx$, where (y) is the rate of development 1/D, (D being the time in days required for the competition of a particular developmental stage at the temperature (x), in degrees centigrade); and (a) and (b) are constants, which are computed using the least-sum-of-squares method for the fitting of the regression line. The lower threshold for development, (t), is equal to (-a/b). It can be estimated from the regression equation by solving for (x) when (y) = 0. The thermal units required for the time to adult, (k), which is required for the computation of a physiological time – scale (Hughes, 1963), is given by the reciprocal of the slope (b) of the regression line.

All data of the biological experiments on the aphid and the parasitoid were statistically analyzed using (ANOVA) in Statistical Block of Social Science Program SAS (Statistical Analysis System).

RESULTS AND DISCUSSION

Rhopalosiphum padi **L.**

Developmental rates of different nymphal instars and total time to adult of *R. padi* on wheat and barley are presented in Table (1). In general, the developmental rates of different nymphal instars and time to adult were influenced by the temperature to which they were exposed. As temperature increased, developmental times for respective instars were shorter, and developmental rates were faster. (Table 1 and Fig. 1).

Regression equations indicated that there was a correlation between temperature and developmental rates of different nymphal instars and the total time to adult on wheat and barley. Out of these equations, lower developmental threshold (t), and thermal requirement (k) are presented in Table (2). The lower developmental threshold (t) of *R. padi* for the first, second, third, and fourth nymphal instars, and the time to adult were estimated as 4.2, 4.7, 3.9, 4.6, and 4.4°C on wheat, and 4.6, 5.1, 4.6, 5.6, and 5°C on barley, respectively. The thermal requirements for correspondent parameters were 25.58, 21.69, 25.84, 22.99, and 96.15 on wheat, and 22.42, 22.88, 22.22, 18.62, and 86.2 degree- days on barley. Statistical analysis showed that there was no significant difference between the thermal requirements of *R. padi* on wheat and barley.

These results indicated that the estimated (t) values on the two host plants; wheat and barley, were nearly equal. This result agreed with the findings of Campbell *et al.* (1974) who suggested that (t) values do not vary with the host species. On the contrary, these results disagreed with those of Villanueva and Strong (1964), who estimated the lower developmental threshold for *R. padi* as 8°C, Kuroli (1984) who found that the average of thermal constant of *R. padi* was 187.6 day-degrees above a threshold of 3.3°C, and Yang *et al.* (1994) who estimated the development zero for *R. padi* on wheat as 1.55-3.48°C and effective accumulated heat units as 288.6 day-degrees.

Aphidius matricariae **Hal.**

Developmental rates for different instars (*i.e.,*egg, larval instars, pre-pupa, and pupa) and total times to adult of the parasitoid *A. matricariae* on *R. padi* are presented in Table (3). In general, the developmental rates of respective stages of *A. matricariae* were influenced by the temperature to which they were exposed. Developmental times were shorter, and developmental rates were faster, as temperature increased. (Table 3 and Fig. 1).

Regression equations indicated that there was a correlation between temperature and developmental rates for the parasitoid *A. matricariae* for different stages and total time to adult on *R. padi*. Out of these equations, lower developmental threshold (t), and thermal requirement (k) are presented in Table (4). The lower developmental threshold (t) of the parasitoid *A. matricariae* for egg, first, second, and third larval instars, pre-pupa, pupa, and the time to adult were 7.9, 5.9, 5.8, 5.8, 5.9, 3.8, and 5.7°C, respectively. The thermal units requirements for correspondent stages were 26.95, 33.9, 20.08, 31.25, 18.94, 81.97, and 208.33 degree-days.

The (k) value of the parasitoid was higher than those of its host, *R. padi.* The thermal requirements of this parasitoid were estimated as 208.33 degree-days, while those for *R. padi* were 96.15, and 86.2 degree-days on wheat and barley, respectively.

The temperature threshold (t) for the time to the adult stage in the parasitoid was 5.7°C, while the thresholds for the time to adult in the aphid were 4.4, and 5°C on wheat and barley, respectively.

The present results agreed with those of Campbell *et al.* (1974) who suggested that temperature requirements of parasitoids were higher than of their host and have a two fold effect on the host-parasitoid complex: one, ensuring that, in a temperature climate, parasitoid do not appear before its hosts early in the season, and other, that a continued minimum host supply is available throughout the season. This hypothesis can be tested. For example, one would expect that because of differences in the threshold values, the primary parasitoids might appear together with or shortly after the fundatrix generation of the aphid in the season.

Obtained results indicated that the developmental threshold (t) estimated for *A. matricariae* was slightly lower than that reported by other authors. Scopes and Biggerstaff (1977), and Rabasse and Shalaby (1980) reported (t) values as 7.9, and 6°C, respectively. On the contrary, the present data were relatively higher than that

Table (1): Mean duration and developmental rate (1/D) of different nymphal instars of *Rhopalosiphum padi* on wheat and barley at three constant temperatures, 50-70% R.H. and 16:8 L:D.

Nymphal instrs	Duration (mean ± S.D)						Developmental rate					
	13°C		20°C		26°C		14°C		20°C		26°C	
	Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley	Wheat	Barley
First	3.16±0.37	3.17±0.38	1.48±0.51	1.23±0.42	1.22±0.42	1.13±0.35	0.3165	0.3155	0.6757	0.813	0.8197	0.885
Second	3.19±0.39	3.12±0.33	1.17±0.38	1.43±0.50	1.11±0.31	1.13±0.35	0.3135	0.3205	0.8547	0.6993	0.9009	0.885
Third	3.22±0.41	3.22±0.42	1.39±0.49	1.20±0.41	1.24±0.44	1.13±0.35	0.3106	0.3106	0.7194	0.8333	0.8065	0.885
Fourth	3.26±0.44	3.17±0.38	1.26±0.44	1.05±0.22	1.16±0.37	1.00±0.00	0.3067	0.3155	0.7957	0.9524	0.8621	1.000
Time to Ault	12.81±0.85	12.68±0.82	5.30±0.76	4.90±0.59	4.73±0.45	4.40±0.50	0.0781	0.0789	0.1887	0.2041	0.2114	0.2273

Table (2): Thermal constants (k), developmental thresholds (t), and regression equations of *Rhopalosephum padi* on wheat and barley.

Host plant	Nymphal instars	Regression equation ($y = a + bx$)	Coefficient of determination (r^2)	Developmental threshold (t) (°C)	Thermal constant (k) (degree-days)
Wheat	First	$Y = -0.1642 + 0.0391\,x$	0.961	4.2	25.58
	Second	$Y = -0.2164 + 0.0461\,x$	0.842	4.7	21.69
	Third	$Y = -0.1490 + 0.0387\,x$	0.905	3.9	25.84
	Fourth	$Y = -0.2005 + 0.0435\,x$	0.872	4.6	22.99
	Time to adult	$Y = -0.0454 + 0.0104\,x$	0.902	4.4	96.15
Barley	First	$Y = -0.2052 + 0.0446\,x$	0.874	4.6	22.42
	Second	$Y = -0.2248 + 0.0437\,x$	0.977	5.1	22.88
	Third	$Y = -0.2092 + 0.0450\,x$	0.850	4.6	22.22
	Fourth	$Y = -0.3004 + 0.0537\,x$	0.836	5.6	18.62
	Time to adult	$Y = -0.0580 + 0.0116\,x$	0.893	5.0	86.20

Table (3): Mean duration and developmental rate (1/D) of different immature stages of *Aphidius matricariae* parasitizing *Rhoplaosephum padi* at constant constant temperatures, 50-70% R.H. and 16:8 L:D.

Temperature	Duration (maen ± S.D)			Developmental rate		
	13°C	20°C	26°C	13°C	20°C	26°C
Egg	4.43±0.50	2.70±0.47	1.40± 0.50	0.2257	0.3704	0.7143
First larval instar	4.40±0.50	2.70±0.47	1.63±0.50	0.2273	0.3704	0.6135
Second larval instar	2.83±0.38	1.40±0.50	1.10±0.21	0.3534	0.7143	1.0000
Third larval instar	3.63±0.50	2.77±0.43	1.43±0.50	0.2755	0.3610	0.6993
Pre-pupa	3.10±0.31	1.17±0.38	1.00±0.00	0.3226	0.8547	1.0000
Pupa	8.33±0.48	5.50±0.51	3.57±0.50	0.1200	0.1818	0.2801
Time to adult	26.73±0.45	16.23±0.43	10.03±0.18	0.0374	0.0616	0.0997

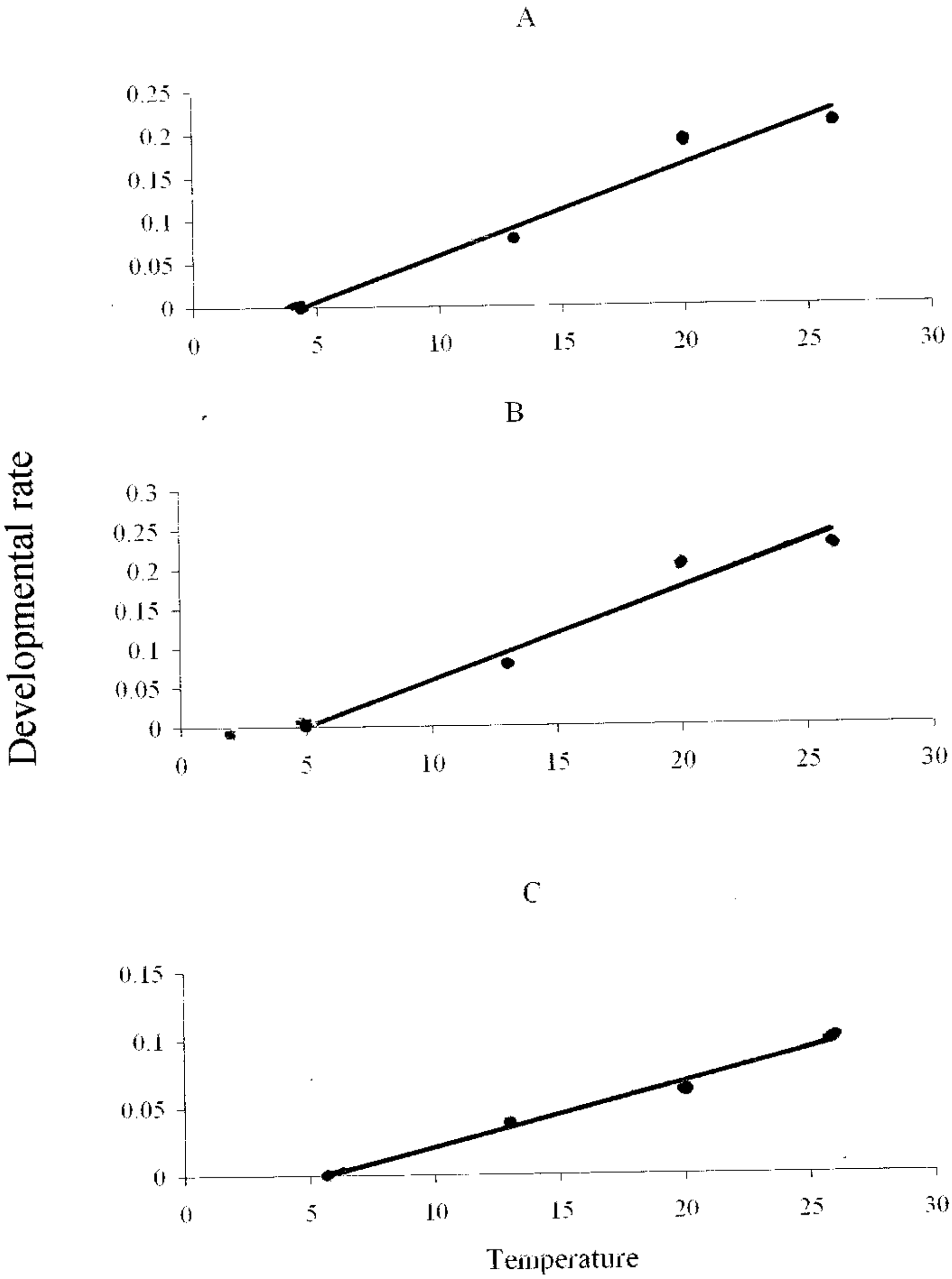

Fig.(1): Regression lines of developmenal rates of *Rhopalosiphum padi* and the parasitoid species *Aphidius matricariae* for total developmental periods to adult.

A- R. padi on wheat

B- R. padi on barley

C- A. matricariae

Table (4): Thermal constants (k), developmental thresholds (t) and regression equations for *Aphidius matricariae* parasitizing *Rhopalosephum padi.*

Stages	Regression equation (y = a + bx)	Coefficient of determination (r^2)	Developmental threshold (t) (°C)	Thermal constant (k) (degree-days)
Egg	y = -0.2931a + 0.0371x	0.926	7.9	26.95
First larval instar	y = -0.1756a + 0.0295x	0.963	5.9	33.90
Second larval instar	y = -0.2900a + 0.0498x	0.984	5.8	20.08
Third larval instar	y = -0.1848a + 0.0320x	0.865	5.8	31.25
Pre-pupa	y = -0.3120a + 0.0528x	0.927	5.9	18.94
Pupa	y = -0.0463a + 0.0122x	0.970	3.8	81.97
Time to adult	y = -0.0273a + 0.0048x	0.971	5.7	208.33

reported by Miller and Gerth (1994), who reported (t) value of 4.5°C for *A. matricariae* on *Myzus persicae* as host. The thermal requirement (k) values reported by those authors were lower than the present, except that of Miller and Gerth (1994), who reported (k) value of 273 degree-days. The discrepancies among the present results and other references for the estimated (t) and (k) values may be due to the differences among the parasitoid populations from different geographical areas (local climatic) as suggested by Gonzalez *et al.* (1979).

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