information that we have found during the course of elucidating the silkworm and mulberry interaction.

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Occurrence of a *Ranunculus* Leaf-Mining Fly, *Phytomyza ranunculi* and Its Eulophid Parasitoids from Fall to Summer in the Low Land¹

Tuyosi SUGIMOTO, Issei YASUDA, Michiko ONO and Shigeru MATSUNAGA

*Entomological Laboratory,
Faculty of Agriculture, Kinki University,
Higashi-Osaka 577, Japan*

(Received July 21, 1981)

Eulophid parasitoids, *Chrysocharis pentheus* (WALKER) and *Diglyphus pusztenensis* (ERDÖS and NOVICKY), are important mortality agencies for larvae of the ranunculus leaf-miner, *Phytomyza ranunculi* SCHRANK, in Japan. A comparison between the seasonal shifts of generations of the host and these parasitoids is essential to understand the effect of the parasitoids upon the host population in the field. In the low land of western Japan, the host is not found in any stage in summer, but appears in early October and increases rapidly in number until early May (KURODA, 1959). Neither host nor these parasitoids appears to have diapause in winter. Thus, the seasonal shift of their generations from fall to the following summer in the low land is determined by their thermal requirements for non-diapause development. A comparison of the seasonal shifts of generations of the host and parasitoids based upon their thermal requirements, as estimated by BLUNCK's (1914) model with the thermal threshold of development(t) and the thermal constant(k), will be dealt with in this paper.

Most experiments were conducted by releasing

female adults of the fly or these parasitoids separately, under a 24 hr light condition, into a transparent plastic cylinder with a gauze cover (20 cm high, 10.5 cm wide); the leaves (fresh ones for flies or those infested with host larvae for parasitoids) were also put into the cylinder in a water bottle.

To determine the effect of the temperature upon the host development, the potted plants, *Ranunculus glaber* MAKINO, were kept at various fixed temperatures after exposure to host oviposition for one day at 20°C. On the other hand, 3rd-instar hosts mining the leaves, after exposure to parasitoid attack for a day, were kept at various fixed temperatures to learn the effect of temperature upon parasitoid development. The period of development of the fly before pupation was shorter than the pupal period, and the time of 2nd- and 3rd-instar larvae (susceptible to parasitoid attack) was less than 20% of the total development period (Table 1). All pupae died at between 28 and 30°C and 3rd-instar larvae at 32°C. Table 1 shows the thermal threshold(t) and thermal constant(k) at various development stages of the fly, using data for 10 to 25°C. The fly had its lowest threshold in the pupal stage though the thermal constant was large. Table 2 indicates that the pupal period of *C. pentheus* was about 50% of its total development period and that of *D. pusztenensis* less than 40%. The latter species developed a little faster at the temperatures examined because its pupa with a thermal constant less than half of the former's had a thermal threshold higher by 4°C, in spite of their almost similar thermal requirement before pupation. The thermal thresholds of these parasitoids were higher than those of the host; this fact was also found in other parasitoid species

¹ Appl. Ent. Zool. **17** (1) : 139-143 (1982)

Table 1. Effect of temperature upon development and longevity(days) of the ranunculus leaf-mining fly, *P. ranunculi*

Temperature (°C)	Egg	Larval instar			Pupa	Total development period	Longevity of adult females
		1	2	3			
10	12.9±0.9	4.8±1.0	5.9±0.8	8.4±0.8	35.2±0.5	67.0±0.0	
15	4.2±0.6	2.1±0.6	2.5±0.7	3.4±0.6	17.9±0.6	30.2±0.9	24.0±5.8
20	4.0±0.8	1.8±0.3	1.3±0.4	2.2±0.4	14.9±1.1	24.2±2.1	24.0±2.7
25	2.5±0.5	1.2±0.4	1.0±0.0	2.3±0.4	11.2±0.8	18.3±0.9	17.2±1.7
28		1.0±0.0	1.1±0.3	2.4±0.6	died		11.1±1.4
30		1.0±0.0	1.0±0.0	2.4±0.5	died		
32		1.3±0.4	1.5±0.5	died			
t	5.4		4.2		2.1	3.4	
k	73.0		64.9		256.4	392.8	

t and k; Thermal threshold and thermal constant, calculated using data for temperatures from 10 to 25°C, respectively.

Table 2. Effect of temperature upon development and longevity(days) of eulophid parasitoids, *C. pentheus* and *D. pusztensis*

Tem- perature (°C)	<i>C. pentheus</i>				
	Egg	Larva	Pupa	Total develop- ment period	Longevity of adult females
15	8.2±1.1	11.3±0.3	15.1±1.4	34.5±2.7	11.3±3.5
20	5.0±0.5	6.1±0.6	12.3±0.7	23.4±1.3	19.1±3.0
23					
25	4.1±0.8	3.9±1.0	8.0±1.5	16.0±1.5	
28					9.6±2.2
30	3.8±0.4	2.2±0.4	6.0±0.6	12.0±0.6	
32	3.0±0.0	2.4±0.9	6.4±0.9	11.6±0.9	
35	2.9±0.3	11.6±2.5	5.0±2.8	18.5±5.0	
t	8.6		5.2	7.6	
k	128.2		161.3	273.7	

Tem- perature (°C)	<i>D. pusztensis</i>				
	Egg	Larva	Pupa	Total develop- ment period	Longevity of adult females
15	7.5±1.5	9.8±1.9	13.2±1.5	31.0±4.5	13.4±2.8
20	4.8±0.8	5.4±1.8	6.5±1.0	16.2±2.2	32.6±3.8
23	3.7±1.2	4.0±1.2	4.0±0.8	12.0±1.4	
25					10.0±2.7
28					
30	4.2±0.4	1.8±1.4	3.3±1.5	9.3±1.3	6.8±1.6
32	3.2±0.4	1.5±0.8	2.8±0.7	7.2±0.6	
35	3.3±0.5	died			
t	8.2		9.6	9.2	
k	119.0		63.3	174.4	

t and k; Thermal threshold and thermal constant calculated using data for temperatures except 35°C, respectively.

which emerge later than their hosts (CAMPBELL *et al.*, 1974; CAMPBELL and MACKAUER, 1975).

To learn the effect of temperature upon the length of the preoviposition period of adult females, and also the period from their emergence to their final oviposition besides upon their longevity, newly emerged female flies grown at 20°C were kept separately at different temperatures in a plastic cylinder containing fresh leaves. These leaves were changed every day and were treated in a saturated solution of Scarlet red (Sudan

IV) in 70% ethanol (SUGIMOTO, 1976) to confirm whether or not eggs had been deposited. To determine the similar effect on parasitoids, each emerged female grown at 25°C was allowed to attack hosts at different temperatures in the plastic cylinder containing leaves infested with 10 to 15 3rd-instar larvae. These leaves, changed daily for those with fresh hosts, were kept until the pupation of the parasitoids at 25°C to determine whether or not individual hosts were parasitized. The optimal temperature zone for lon-

Fig. 1. Effects of temperature (T) upon lengths of preoviposition period of adult females (D_1) and period from their emergence until their final oviposition (D_2). T_e ; Thermal range for oviposition (°C). Solid and broken lines show the theoretical relationship of D_1 and D_2 to T expected from equations shown in graphs but the dotted line for *D. pusztenis* was obtained by extrapolation.

Table 3. Effect of low temperatures upon oviposition by the host, *P. ranunculi*, and host attack by eulophid parasitoids, *C. pentheus* and *D. pusztenis*

Temperature (°C)	<i>P. ranunculi</i>	<i>C. pentheus</i>		<i>D. pusztenis</i>	
	No. eggs laid /day/female	No. hosts killed /day/female ^a	No. hosts parasitized /day/female	No. hosts killed /day/female ^a	No. hosts parasitized /day/female
15		2.2±2.8	1.0±0.5	4.1±3.6	1.0±1.8
14		1.4±1.7	0.6±0.9	1.8±1.7	1.0±1.4
13		0.2±0.4	0.1±0.3	0.3±0.8	0
12		0	0	0	0
11		0	0	0	0
10	7.5±5.6				
8	4.3±3.3				
7	2.8±3.3				
6	0.7±1.2				
5	0				

^a Adult females kill hosts by both parasitization and host-feeding (SUGIMOTO, 1977).

gevity of adult hosts seems to lie between 15 and 20°C (Table 1) and that for both parasitoid species around 20°C (Table 2). The preoviposition period (D_1) and the period from adult emergence to their final oviposition (D_2 : including the former period) in these three species could be expressed well by the 2nd- or 3rd-order function of temperature (Fig. 1). The difference between D_1 and D_2 predicted for each temperature from the respective curves shows the period available for oviposition at that temperature. The thermal range available for oviposition can therefore be estimated as the range between two intersecting points of these two kinds of curves. This research obtained these two points by solving the simultaneous equations shown in Fig. 1, for *T*. Though the 3rd-order function fitted best at intermediate temperatures to the observed trend of D_1 for *D. pusztenis*, it predicts an unreasonable increase at high temperatures. This paper conveniently expresses the upper limit of

the thermal range for this species by the intersecting point obtained by extrapolation of the curve D_1 and the modified part of the other curve (the dotted line in Fig. 1, right). The upper thermal limit of these three species was similar but the lower limit of the fly was far lower (5.2 °C) than those of the parasitoids (14.4°C in both species). These estimates of the lower limit were well confirmed by an experiment carried out in a manner similar to those above, using 3- to 10-day-old females grown at 25°C (Table 3). The thermal range of the fly was similar to that of a closely related species, *Phytomyza horticola* (SASAKAWA, 1953).

Fig. 2(top) shows the observed seasonal fluctuation of the host population per plant of *R. glaber*, in Higashi-Osaka from late October 1972 to early June 1973. At each census 100 leaflets from 20 randomly selected plants were sampled. Almost all of the dead hosts found in the census had been attacked by parasitoids. The host popu-

Fig. 2. Seasonal fluctuation of the host population, *P. ranunculi*, in Higashi-Osaka(top) and, estimated seasonal shifts (bottom) of generations (I, II,) of the host(P-), *C. pentheus*(C-) and *D. pusztenis*(D-). Ov; Oviposition by initial adult population in the fall.

lation increased rapidly after March and was exposed to heavy parasitoid attack from late April. To estimate the seasonal shift of generations of the host and two parasitoid species, a simulation (Fig. 2, bottom) was conducted using daily mean temperatures recorded by the Osaka District Meteorological Observatories. Assumptions for the simulation are as follows: (1) The thermal thresholds and thermal constants shown in Tables 1 and 2, and the relations of adult periods to temperature shown in Fig. 1 are applicable to field populations throughout the season. (2) The fly becomes ready to lay eggs on October 1, while both parasitoid species start to attack hosts as soon as those hatched from eggs laid on October 1 have reached the 2nd instar. (3) Insects in a given development stage accomplish that stage on the day when the sum of the effective temperature (the difference between the air temperature and the thermal threshold) which is accumulated day to day after reaching the stage, exceeds for the first time the thermal constant for the stage. (4) Adult females complete their preoviposition period (and the period from their emergence until their final oviposition) on the day when the length of the period, which has increased day by day since their simulated emergence, exceeds for the first time the duration estimated by substituting the daily mean temperature in the above period, for T from the function D_1 (and D_2) shown in Fig. 1. Each belt shown in Fig. 2(bottom) represents the seasons when hosts and parasitoids in each generation occur in the field, and also when hosts and parasitoids in different stages appear within each generation. Fig. 2 shows that the long oviposition period of the fly leads to the occurrence of adults throughout almost all seasons, but the impossibility of oviposition below 14.4°C by the parasitoids (Fig. 1) results in a synchronous emergence of adults the next spring (C-II, D-II). There were five generations or more of both the host and

parasitoids between the fall and summer. Most of the increased host larvae in spring would have originated from eggs laid by flies belonging to the overwintering generation (P-II). The host mortality observed in the fall might be ascribed to the adult parasitoids in the first generation in the low land (C-I, D-I) and that in April to those in the overwintering generation (C-II, D-II). Adults of *D. pusztensis* in the overwintering generation (D-II), though emerging earlier in the spring, would have brought about a low parasitism because they would have been short-lived on account of low temperatures (Fig. 1). These inferences would also be explainable for the observed seasonal change of parasitism by these two species on the closely related host, *P. horticola*, appearing in the field in the same season. (TAKADA and KAMIJO, 1979).

The authors wish to express their thanks to Messrs. A. SAITO, T. KAWAGUCHI and T. NAKAJIMA for their kind help in the course of this experiment and also to Dr. Y. SAKURATANI for reading this manuscript.

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