



Research Article

Temperature based differences in biological parameters of some potential species/strains of *Trichogramma*

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ABSTRACT: The effect of temperature on different *Trichogramma* spp. is an aspect to be understood for planning mass production strategies and further field releases. The key biological parameters of seven different spp./strains of trichogrammatids (viz. *Trichogramma japonicum* Ashmead, *T. cordubensis* Vargas and Carbello, *T. achaeae* Nagaraja and Nagarkatti, four strains of *T. chilonis* Ishii i.e. lab strain, Nilgiris strain, Kodaikanal strain and a strain acclimatized to constant 15°C) were investigated at five constant temperatures (16, 21, 26, 31 and 36±1°C with 60-70% RH and L: D-12:12). The different test temperatures had a significant impact on the biological parameters of the different species/strains. Based on longevity, parasitism and fecundity attributes, the best temperature to propagate these trichogrammatids was found to be 26°C. Considering the higher parasitism rates and the ability to parasitize and remain fecund at varied temperatures, *T. chilonis* Nilgiris strain proved to be the best. From the linear model of regression analysis, the upper temperature thresholds ranged from 35 to 46.37°C and the lower temperature thresholds were recorded to range between 9 and 12°C, with *T. cordubensis* appearing to be least temperature sensitive.

KEY WORDS: Biology, effect of temperature, *Trichogramma*

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INTRODUCTION

Trichogrammatids are utilized as potential bio-control agents in integrated management of lepidopteran pests of various crops (Chailleux *et al.*, 2013; Corrigan and Laing, 1994; El-Arnaouty *et al.*, 2014). Their ability to provide 100% parasitism in favourable conditions and their amenability to rearing have made them one of the most widely used bio-control agents. Inundative releases of *Trichogramma* species have proved to be effective against several pests, especially where the natural enemy development is not disrupted by chemical pesticides (Briere *et al.*, 1999; Garcia *et al.*, 1995b). When released in the field, these parasitoids experience fluctuating abiotic conditions including temperature variations, which play a major role in determining their rate of development and survival (Foester and Foester, 2009; Pizzol *et al.*, 2010; Ratte, 1985). Different fitness attributes change based on how temperature communicates with different species/strains of natural enemies and also the host (Pizzol *et al.*, 2010; Reznik and Vaghina, 2006). In Asiatic countries, *Corecya cephalonica* (Stainton) (Lepidoptera: Pyralidae) is preferred as a factitious host as it can be reared by adopting a simple and easy production protocol.

The relationship between constant temperatures and development of insects is generally linear within the threshold limit of temperatures. It is important to identify the temperature range within which an insect parasitoid remains active as it can influence the outcome of its field release. Selection of the optimum temperature for rearing helps in standardization of production protocols for mass rearing of quality parasitoids leading to successful biological control. In India at least 28 species of Trichogrammatids are known to occur, out of which *Trichogramma chilonis* (Ishii) and *T. japonicum* (Ashmead) are highly efficient egg parasitoids that are used extensively for pest management in tomato, sugarcane, cotton and rice ecosystems, while *Trichogramma achaeae* Nagaraja and Nagarkatti has shown promising results against *Acanthodelta* (= *Achaeae*) *janata* (Linn.) (Noctuidae) on castor (Lalitha and Ballal, 2015; Lingappa and Hegde, 2001; Nagarkatti and Nagaraja, 1977; Singh *et al.*, 2001). *Trichogramma cordubensis* Vargas and Carbello is an exotic species, which is used world-wide to target *Autographa gamma* (L.), *Chrysodeixis chalcites* (Esper), *Phlogophora meticulosa* (L.), *Peridroma saucia* (Hübner), *Xestia c-nigrum* (L.) and *Noctua pronuba* (L.) (Garcia *et al.*, 1995b; Garcia *et al.*, 1995). In India, *T. chilonis* is rec-

ognised as the most promising indigenous species, which has a wider host range and high survival capacity. Hence, in the current study four strains of *T. chilonis* along with three other important species (*T. cordubensis*, *T. japonicum*, *T. achaeae*) were chosen to compare their responses to temperature variations and their fitness attributes which would enable us to select the best strain for future research on short and long term storage. The aim was also to study their thermal requirements, to identify the most suitable rearing temperature for each of the species/strains and to identify the superior spp./strain which is amenable to rearing. The performances of continuously lab reared populations at different rearing temperatures differed from those of field collected populations, which had undergone only few generations in the laboratory.

MATERIALS AND METHODS

Maintenance of *Trichogramma* spp

Pure cultures of *T. japonicum* (National Accession No: NBAIL-MP-Tr-65), *T. achaeae* (NBAIL-MP-Tr-06), *T. cordubensis* (NBAIL-MP-Tr-55) and four strains of *T. chilonis* viz. two high altitude strains, collected from Nilgiris (NBAIL-MP-Tr-23a) and Kodaikanal (NBAIL-MP-Tr-23b), lab strain (NBAIL-MP-Tr-13) and a low temperature tolerant strain / reared at 15°C (NBAIL-MP-Tr-25) are being reared continuously in the insectary of ICAR-NBAIR, Bangalore. An alternative laboratory host *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae) is used for rearing *Trichogramma* spp. Rearing of *C. cephalonica* was done by following protocol suggested by Lalitha and Ballal (2015). UV irradiated (30 W UV tube for 45 minutes at a distance of 2 feet) *Corcyra* eggs were glued on 'Tricho' cards (15 x 10 cm). These eggs are exposed to adult females of *Trichogramma* spp./strains in the ratio of 40:1 until mortality. For experimental purposes, cultures of each species/ strains were maintained in tubes at 25±1°C with 14h light and 65±10% RH.

Evaluation of biological parameters of *Trichogramma* spp. at different temperatures

Twenty five sets of hundred UV irradiated eggs of *Corcyra cephalonica* (for each spp./strain) were pasted on thick card pieces (2 x 1cm) and exposed to *T. chilonis* (all four strains), *T. achaeae*, *T. cordubensis* and *T. japonicum* adults separately in tubes (14 x 2.5 cm) in the ration of 1:40 (adult females: host eggs) at room temperature and the tubes plugged with cotton wool. After 24 hours, the parasitized egg cards were used for the experiment. The experiment was conducted in a temperature gradient chamber (NK system-TG-180 CCFL-5LE model) set at the test temperatures, viz., 16, 21, 26, 31, 36±1°C (with L: D = 12: 12, RH= 60± 10%). Parasitized cards were placed in glass vials

(with tight cotton plug) and kept on racks and each rack set at the constant test temperature (as indicated above). Five replications were maintained for each spp./strain at each temperature treatment. Once the adults started emerging, 10% honey solution was provided. Data was recorded on number of adults emerged, number of days from the date of parasitism to adult emergence (recorded as developmental duration) and longevity of the adults (male and female).

To check percent parasitism and fecundity an additional experiment was set up. Two mated females emerging from each of the treatments were transferred into separate vials with 10% honey solution (as streaks on the wall of the tube) as their diet. In a 1: 30 parasitoid host egg ratio, exposures were made for 24 hours in each tube and this was performed in five different replications and repeated every 24h throughout the effective parasitizing period (first three days after emergence). This was repeated for each spp./strain at the five test temperatures. From these exposed cards, percent parasitism was calculated based on the average of number of blackened eggs over the total number eggs provided each day. The average number of progeny produced per day by each female was calculated as mean daily fecundity while the total progeny produced by each female in their whole fecund life time was considered as mean life time fecundity.

These data were subjected to one way analysis of variance (ANOVA) a) with different temperature regimes as the main effects (factors) and the biological parameters (viz. development duration, longevity, mean daily fecundity, mean life-time fecundity and mean percent parasitism) as response variables b) set temperature, spp./strains were selected as main effect and biological parameters were selected as response variable followed by least significance difference test at 0.05 level of probability by using SPSS 16.0. When there large variations were observed between the different treatment values, the mean percentage values ($X+0.5$) were subjected to angular transformation and whole numbers to square root transformation ($\sqrt{X+0.5}$) in order to normalize the data.

Calculating threshold temperatures

The developmental rates of the different spp./strains as the dependent variables were used for regression analysis with temperature as the independent variable. Estimates of the respective lower development thresholds was calculated by the 'x' intercept method by setting regression equation to zero development per day (Arnold, 1959). Thermal constant (K), expressed in degree-days (DD), is the amount of heat units that each species requires to complete its lifecycle or part of it above and below the threshold temperature,

regardless of the temperature to which it is exposed (Urta *et al.*, 2005), mathematically being the reciprocal of the slope (b) of the regression line and was calculated as suggested by Morris and Fulton (Morris and Fulton, 1970). Linear degree day model was opted in this study as it has the advantage of simplicity and allows estimation of developmental threshold and the degree day requirements of the insect species (Briere *et al.*, 1999).

RESULTS AND DISCUSSION

Developmental duration

The highest developmental duration for all the spp./strains was recorded at 16°C. With increasing temperature, there was a gradual decrease in developmental duration. The minimum developmental duration was recorded at 36°C for *T. japonicum*, *T. achaeae* and *T. chilonis* Kodaikanal, while

for the other species/strains minimum developmental duration was recorded at both 31 and 36°C. Significantly higher development duration was recorded for *T. cordubensis* at all set test temperatures (Table 1).

Temperature thresholds

The relationship between developmental duration and temperature for the test spp./strains is depicted in Table 3. The calculated lower threshold (LT) temperatures ranged between 9.3 to 12°C and the upper threshold temperature ranged between 35 to 46.37°C with the minimum LT and maximum UT recorded in the case of *T. cordubensis*, *T. japonicum*, *T. achaeae*, *T. cordubensis*, *T. chilonis* lab, *T. chilonis* Nilgiris, *T. chilonis* 15°C and *T. chilonis* Kodaikanal needed 166.66, 200, 333, 166.66, 166.66, 142.85 and 166.66 DD, respectively to complete their development (Table 3).

Table 1. Effect of constant set test temperatures on the development duration, longevity and Mean Percent parasitism of *Trichogramma* spp./strains (L:D- 12:12, RH- 60-70%)

Biological Parameters (Mean ± SE)	Tm (±1°C)	<i>T. jap</i>	<i>T. ach</i>	<i>T. cor</i>	<i>T. ch lab</i>	<i>T. ch Nilgiris</i>	<i>T. ch 15°C</i>	<i>T. ch Kodai</i>	df	F	P	LSD at P ≤ 0.05	
Developmental duration (days)	16	25.2±0.2	29.4±0.2	30.6±0.2	17.4±0.2	30.8±0	27.4±0.2	29.8±0	6, 28	441.3	≤0.001	0.7	
	21	14.2±0.2	16.0±0	18.8±0.2	11.0±0	16.8±0	13.4±0.2	15.8±0	6, 28	203.5	≤0.001	0.5	
	26	9.2±0.2	10.4±0	10.4±0.2	8.0±0	10.0±0	9.4±0.2	8.8±0	6, 28	15.2	≤0.001	0.7	
	31	7.2±0.2	8.0±0	8.4±0	6.0±0	7.0±0	5.8±0.2	7.4±0	6, 28	21.4	≤0.001	0.6	
	36	6.0±0.2	7.0±0	8.2±0	6.0±0	6.5±0	5.4±0.2	6.6±0	6, 28	35.4	≤0.001	0.4	
	df	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20					
	F	673.9	3531	1771	1901	1835	1462	1976					
	P	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001					
LSD at P ≤ 0.05	0.5	0.46	0.67	0.32	0.7	0.7	0.65						
Longevity (days)	16	6.6±0.2	7.8±0.2	9.6±0	6.4±0.2	6.0±0	6.6±2.4	7.0±0	6, 28	37.2	≤0.001	0.6	
	21	5.0±0.2	6.4±0.2	7.8±0	5.0±0	9.0±0	5.2±0.2	6.0±0	6, 28	11.8	≤0.001	0.4	
	26	4.6±0.2	6.2±0.2	7.8±0	4.0±0	8.6±0	5.8±0.2	6.0±0	6, 28	59.0	≤0.001	0.5	
	31	3.6±0.2	6.2±0.2	3.4±0	3.6±0.2	4.0±0	4.2±0.2	3.4±0	6, 28	21.5	≤0.001	0.6	
	36	3.0±0.2	4.8±0.2	3.0±0	3.0±0.2	4.0±0	3.5±0.2	3.0±0	6, 28	34.4	≤0.001	0.3	
	df	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20					
	F	53.55	25.72	183	74.1	484	28.9	261					
	P	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001					
LSD at P ≤ 0.05	0.56	0.62	0.18	0.45	0.32	0.64	0.32						
Parasitism# (%)	16	53.0±0.2	0	34.4±1.5	37.3±3.2	47.2±1.9	39.4±1.8	44.0±3.5	6, 28	93.7	≤0.001	4.3	
	21	46.2±0.9	40.4±2.1	51.1±2.6	33.7±4.1	50.6±1.5	42.6±0.7	50.8±2.7	6, 28	5.7	≤0.001	4.6	
	26	52.2±0.9	58.4±1.6	56.4±3.4	52.6±1.2	53.6±2.3	55.2±1.2	48.2±3.3	6, 28	1.02	≤0.001	NS	
	31	47.0±1.3	64.8±1.4	34.4±2.4	35.5±1.6	58.6±1.5	54.4±1.7	48.8±2.2	6, 28	16.5	≤0.001	5.1	
	36	49.3±2.3	50.2±3.7	0	30.6±2.8	64.6±3.7	48.8±4.9	44.4±2.5	6, 28	86.1	≤0.001	5.0	
	df	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20					
	F	53.55	25.72	183	74.1	484	28.9	261					
	P	= 0.65	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	= 0.4					
LSD at P ≤ 0.05	NS	4.62	0.18	0.45	0.32	0.64	NS						

T. jap- *T. japonicum*, T. ach- *T. achaeae*, T. cor- *T. cordubensis*, T. ch lab - *T. chilonis* Laboratory strain, T. ch Nilgiris- *T. chilonis* Nilgiris strain, T. ch 15°C- *T. chilonis* maintained at 15°C, T. ch Kodai- *T. chilonis* Kodaikanal strain # Analysis based on angular transformed values, Formula used: average number of blackened eggs/total eggs provided X 100

Longevity

The highest longevity was recorded at 16°C for all the spp./strains except *T. chilonis* Nilgiris where significantly higher longevity of 9 days was recorded at 21°C. The lowest recorded longevity was at 36°C for all the spp./strains except *T. chilonis* Nilgiris and *T. chilonis* 15°C which recorded equally short longevity at 31 and 36°C. When the longevity of different spp./strains were compared at each test temperature, *T. cordubensis* emerged as significantly superior at 16°C, *T. chilonis* Nilgiris at 21 and 26°C and *T. achaeae* at 31 and 36°C (Table 1).

Mean percentage parasitism (M%P)

Temperature had no significant effect on mean percent parasitism of *T. japonicum* and *T. chilonis* Kodaikanal at-rain. In case of *T. achaeae* the highest parasitism was recorded at 26 and 31°C, for *T. cordubensis* at 21 and 26°C,

for *T. chilonis* lab population at 26°C, for *T. chilonis* Nilgiris 31 and 36°C and for *T. chilonis* 15°C from 26 to 36°C. When compared across the different spp./strains *T. chilonis* Nilgiris recorded higher parasitism at the test temperatures. However, parasitism rates of *T. japonicum* at 16°C, *T. cordubensis* and *T. chilonis* Kodaikanal at 31°C and *T. achaeae* at 31°C were statistically similar to those of *T. chilonis* Nilgiris at the same temperatures (Table 1).

Mean daily fecundity (MDF)

Temperature had no significant effect on MDF of *T. japonicum*, *T. chilonis* Nilgiris and *T. chilonis* Kodaikanal. Highest MDF for *T. achaeae* was recorded at 31°C, for *T. chilonis* lab at 26°C. *T. chilonis* 15°C and *T. cordubensis* showed equally good MDF at 26, 31°C and 21, 26°C, respectively. While comparing different spp./strains, *T. chilonis* Nilgiris recorded high MDF at all the test temperatures,

Table 2. Effect of constant set test temperatures on the mean daily fecundity, mean life-time fecundity and percent emergence of *Trichogramma* spp./strains (L:D- 12:12, RH- 60-70%)

Biological Parameters (Mean ± SE)	Tm (±1°C)	<i>T. jap</i>	<i>T. ach</i>	<i>T. cor</i>	<i>T. ch lab</i>	<i>T. ch Nilgiris</i>	<i>T. ch 15°C</i>	<i>T. ch Kodai</i>	df	F	P	LSD at P ≤ 0.05
Daily Fecundity* (Average progeny/day) 0.28	16	12.1±1.7	0	8.3±0.3	10.3±1.1	13.1±0.6	7.3±0.6	12.0±0.9	6, 28	102.5	≤0.001	0.28
	21	12.3±1.2	10.2±1.3	12.1±0.8	8.1±1.1	14.5±1.1	8.4±0.6	13.4±1.7	6, 28	203.5	≤0.001	0.4
	26	13.5±1.2	6.2±0.4	13.1±0.8	14.5±0.9	15.9±1.3	13.8±0.5	11.8±1.1	6, 28	15.2	≤0.001	0.3
	31	12.6±0.2	18.3±0.8	7.7±0.5	7.3±0.3	13.0±0.9	13.7±0.4	11.2±1.1	6, 28	21.4	≤0.001	
	36	11.8±1.3	12.7±0.8	0	7.7±1.02	14.0±0.6	11.7±0.5	9.8±0.6	6, 28	35.4	≤0.001	0.4
	df	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20				
	F	0.268	145	166.4	10.94	1.54	33.35	2.6				
	P	= 0.8	≤0.001	≤0.001	≤0.001	= 0.2	≤0.001	= 0.1				
LSD at P ≤ 0.05	NS	0.3	0.3	2.7	NS	1.5	NS					
Life-time fecundity (Total progeny/female's lifetime)	16	24.2±3.3	0	41.6±1.7	30.8±1.1	65.7±2.9	36.6±3.1	46.8±3.8	6, 28	138.9	≤0.001	0.6
	21	37.0±2.5	30.6±3.4	36.2±2.3	24.0±3.2	72.6±5.8	42.2±3	53.0±3.4	6, 28	19.52	≤0.001	0.8
	26	40.6±2.5	43.8±3.4	39.2±2.5	43.2±2	79.4±0.6	55.2±1.9	47.4±3.8	6, 28	12.81	≤0.001	0.7
	31	25.2±2.6	54.4±2.5	23.2±1.6	21.8±0.8	64.8±4.6	54.8±1.6	33.4±2	6, 28	56.00	≤0.001	0.5
	36	23.6±2.3	25.4±1.5	0	22.8±4.1	69.0±2.8	46.8±1.8	29.8±1.5	6, 28	87.04	≤0.001	0.7
	df	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20				
	F	8.65	25.72	0.5	7.7	1.54	11.4	10.5				
	P	≤0.001	≤0.001	≤0.001	≤0.001	= 0.2	≤0.001	≤0.001				
LSD at P ≤ 0.05	8.65	0.62	0.5	7.7	NS	7	8.7					
Emergence (%) (Mean ± SE)	16	68.6±0.2	77.6±2.2	80.2±1.5	75.0±3.23	82.2±2	84.4±2	9.6±2	6, 28	33.3	≤0.001	7
	21	82.0±1	65.6±2.2	77.6±2.6	81.2±4.14	87.6±2	81.0±1.5	93.4±2.2	6, 28	42.7	≤0.001	5.6
	26	92.6±1	94.2±1.6	92.0±3.4	94.6±1.2	79.0±2.3	89.8±2.5	88.4±2.8	6, 28	57.8	≤0.001	6.4
	31	79.8±1.3	82.4±1.4	54.0±2.4	70.6±1.6	71.6±1.5	77.4±1.5	75.2±2	6, 28	32.8	≤0.001	6.6
	36	64.8±2.3	71.2±3.7	44.4±1.6	59.6±2.8	59.4±3.7	52.8±3.2	58.8±3.2	6, 28	9.3	≤0.001	5.9
	df	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20	4, 20				
	F	42.88	25.72	67.18	20.72	21.58	32.5	29.3				
	P	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	= 0.4				
LSD at P ≤ 0.05	5	7	7.1	8.4	6.9	7.4	5.6					

T. jap- *T. japonicum*, T. ach- *T. achaeae*, T. cor- *T. cordubensis*, T. ch lab - *T. chilonis* Laboratory strain, T. ch Nilgiris- *T. chilonis* Nilgiris strain, T. ch 15°C- *T. chilonis* maintained at 15°C, T. ch Kodai- *T. chilonis* Kodaikanal strain # Analysis based on square root transformed values

except 31°C at which *T. achaeae* recorded significantly higher MDF (Table 2).

Mean life time fecundity (MLF)

MLF was influenced by temperature for all the spp./strains except *T. chilonis* Nilgiris. The highest MLF could be recorded at 21 and 26°C for *T. japonicum*, 31°C for *T. achaeae*, 26°C for *T. chilonis* lab population, 16 to 31°C for *T. chilonis* Kodaikanal and 21 and 26°C for *T. chilonis* 15°C strain. *T. cordubensis* could record equally good MLF from 16 to 26°C. When compared across the spp./strains *T. chilonis* Nilgiris predominantly recorded highest MLF at the five test temperatures (Table 2).

Percent emergence (%E)

Peak adult emergence was recorded at 26°C for all the spp./strains except *T. chilonis* Nilgiris where highest emergence was recorded at 26°C and 16°C, both being statistically on par. When data was on compared across the spp./strains at different temperature, at 16°C *T. chilonis* 15°C, *T. chilonis* Nilgiris and *T. cordubensis* recorded highest emergence and at 21°C *T. chilonis* Nilgiris and *T. japonicum* recorded peak emergence rate. At 26°C except *T. chilonis* Nilgiris and *T. chilonis* Kodaikanal all the other spp./strains showed significantly high percent adult emergence. At 31 and 36°C *T. achaeae* and *T. japonicum* recorded highest adult emergence (Table 2).

The current study indicates a clear inverse relationship between developmental duration and temperatures. This is probably because of the increasing metabolic activity in insects at higher temperatures. Though the trend of increasing developmental rate with rise in temperature was similar among the species and strains of *Trichogramma*, each spp./strain recorded significantly different response with respect to biological parameters indicating that biological performances depend not only on existing temperature but also on the adaptation of species and strains to that temperature (Pratissoli and Parra, 2000; Zago *et al.*, 2006).

For mass production and field release of a bio-agent, shorter developmental duration is considered desirable. In our present study, significantly shorter developmental duration coupled with good parasitizing ability (ranging between 44 to 65%) recorded at higher temperatures for all the test spp./strains (except *T. chilonis* lab and *T. cordubensis*) indicates that these species could be chosen as ideal candidates for field evaluations in high temperature zones. The inferior performance of *T. chilonis* lab strain and *T. cordubensis* with respect to longer developmental durations and low parasitism rates could be due to continuous lab rearing under controlled conditions in the case of the former and the exotic origin of the latter species.

The temperature threshold study was aimed to identify the temperature range within which normal development occurs and the species/strain can remain active. The lower threshold temperature (LT) for the different species/strains ranged from 9.3 to 12°C. The variation in LT in different species could be due to the different thermal requirements of the host as well as the strainal variations (Pratissoli, 1879). *Trichogramma japonicum*, *T. chilonis* lab, *T. chilonis* Nilgiris and *T. chilonis* Kodaikanal had similar thermal requirement of 166.66 heat units while *T. chilonis* 15°C required 142.85 heat units to complete development above the threshold temperature. However, the lower threshold temperature ranged between 10 to 12°C and upper threshold temperature ranged from 37.5 to 39.1 for all these indigenous species. This probably indicates that the above spp./strains share the same genetic make-up except the 15°C strain which showed a clear variation due to its long term acclimatization to a lower temperature. The higher thermal requirement, upper threshold and lower threshold temperature of the exotic *T. cordubensis* indicates that in spite of continuous lab rearing, this species remains to be the least heat sensitive one. The geographical origin of this species could have a bearing on its response to temperature.

Table 3. Lower temperature threshold (LT), upper threshold (UT) values and thermal constants (K) of different spp./strains of *Trichogramma*

Spp./Strains	Equation	R ²	P	LT	UT	K
<i>T. japonicum</i>	y = 0.006 x - 0.062	0.99	≤0.0001	10.3	38.1	166.66
<i>T. achaeae</i>	y = 0.005x - 0.053	0.99	≤0.0001	10.6	39.2	200.00
<i>T. cordubensis</i>	y = 0.003x - 0.028	0.98	≤0.0001	09.3	46.4	333.00
<i>T. chilonis</i> lab	y = 0.006x - 0.068	0.97	≤0.0001	11.3	39.1	166.66
<i>T. chilonis</i> Nilgiris	y = 0.006x - 0.072	0.95	≤0.0001	12.0	37.6	166.66
<i>T. chilonis</i> 15°C	y = 0.007x - 0.082	0.98	≤0.0001	11.7	35.5	142.85
<i>T. chilonis</i> Kodai	y = 0.006x - 0.061	0.94	≤0.0001	10.0	37.9	166.66

Longevity of *Trichogramma* spp. was observed to be clearly influenced by temperature. In general, higher longevity was recorded at lower temperature of 16°C, with *T. cordubensis* being significantly superior to the rest at this temperature. However, *T. chilonis* Nilgiris showed a clear preference for 21°C. At 21 and 26°C *T. chilonis* Nilgiris and at 31 and 36°C *T. achaeae* emerged as the superior strains with respect to longevity. This clearly indicates the low temperature preference and cold hardy nature of *T. cordubensis* and high temperature preference of *T. achaeae*. Temperature provided during development is known to affect the biological parameters of *Trichogramma* adults (Prasad *et al.*, 2002). This was true in the case of *T. chilonis* 15°C, which was acclimatized to low temperature and it recorded higher percent emergence and longevity at 16°C. Emergence rates of *T. japonicum*, *T. chilonis* lab, *T. achaeae* and *T. cordubensis* were best at 26°C, which is probably because the populations used for our study were reared for more than 200 generations at a lab temperature of 26±1°C.

Earlier studies have estimated the impact of temperature during development on fecundity of *Trichogramma* spp. Though the parasitism rate peaked at 20°C for some trichogrammatids, in most cases the highest number of host parasitized within a certain period of time was recorded at 25°C (Harrison *et al.*, 1985; Pavlik, 1992; Reznik and Vaghina, 2006). Our results coincide with the above studies with respect to fecundity of *T. chilonis* as all the strains of this species recorded higher fecundity at 26°C. *T. chilonis* Nilgiris recorded highest parasitism rates and fecundity in all the temperatures probably because of the fact that this strain had gone through few generations in the lab and hence biological attributes had not deteriorated. *Trichogramma achaeae* recorded highest parasitism and fecundity at 31°C which reflect its relative preference for higher temperatures. Similar observations were made in the case of *Trichogramma nubilate* Ertle & Davis, where maximum parasitism rate was recorded between 25 and 30°C (Russo and Voegelé, 1982). In the current study all the *T. chilonis* strains recorded higher fecundity at 26°C.

Based on the results of our current study, we could interpret that in general, considering parasitism and fecundity the suitable rearing temperature is 26°C for all the spp./strains of *Trichogramma*. Amongst the different strains of *T. chilonis*, the Nilgiris strain proved to be superior to all the other strains and species with reference to its high fecundity and parasitism. This strain also showed a clear adaptation to different temperatures. This strain can thus be identified for mass rearing and field releases. *T. chilonis* lab strain and *T. cordubensis* could not parasitize well at con-

stant higher temperatures. However, in the field situation the parasitoids would be exposed to varying temperatures with periodic respites from extreme hot or cold temperatures which would enhance the chances of survival of these spp./strains. The narrow temperature preferences of the spp./strains which were continuously lab reared for several generations and the plasticity of the recently field collected strains emerged through this study. It is thus important to identify the maximum number of generations each *Trichogramma* spp./strains can go through in the laboratory so that rejuvenation of the culture can be initiated at the right stage to prevent deterioration of its biological parameters.

It would be worth investigating if rejuvenation of the lab population of each species with the wild culture of the same species could improve its adaptability to a wider range of temperatures. Besides, we also suggest that the indigenous *T. chilonis* Nilgiris strain which holds the capacity to perform well at a wider range of temperatures is an ideal candidate for future studies on diapause induction (leading to long term storage). This would definitely address the current problem of low shelf-life of Indian Trichogrammatids.

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