Influence of Temperature and *Helicoverpa armigera* Food on Survival and Development of the Parasitoid, *Campoletis chlorideae*

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Abstract

Climate change is likely to affect the insect host and the activity and abundance of biological control agents. Therefore, the present studies were conducted to understand the influence of temperature and source of insect host, Helicoverpa armigera *on survival and development of the ichneumonid parasitoid,* Campoletis chlorideae. *Temperatures <12°C and >35°C were detrimental to the survival and development of the larvae of* C. chlorideae. *Post-embryonic development period of* C. chlorideae *was significantly and negatively associated with increase in temperature. The parasitoid required more numbers of degree days to complete development at lower temperatures, and took about 2.5-fold more time to complete development at 18°C than at 27°C. The parasitoid development was prolonged by six days under ambient conditions (average 23°C; range 12 to 25°C) than at a constant temperature of 27°C, indicating that fluctuations in temperature have a significant influence on parasitoid development. The males and females were heavier when reared at 18 and 27°C than when reared under ambient conditions. Percentage parasitization and adult emergence were influenced by host insect food, and parasitoid strain × temperature. The results indicated that changes in temperature as a result of climate change would have considerable influence on survival and development of* C. chlorideae. *This information would be useful for understanding the influence of climate change on the activity and abundance of natural enemies, which in turn would have great bearing on insect-pest population dynamics, insect damage and crop production.*

Keywords: Climate change, *Campoletis chlorideae*, *Helicoverpa armigera*, temperature, survival and development, biological control

Introduction

The ichneumonid endoparasitoid, *Campoletis chlorideae* Uchida (Hymenoptera: Ichneumonidae) is an important biocontrol agent of the noctuid, *Helicoverpa armigera* (Hubner) and other lepidopteran insects in pigeonpea, chickpea, and cotton (Bhatnagar *et al.*, 1982; Romeis and Shanower, 1996; Dhillon and Sharma, 2007a). Under field conditions, parasitism of *H. armigera* larvae by *C. chlorideae* varies between 4 to 44% across regions and crops (Pawar *et al.*, 1989; Tikar *et al.*, 2001). It preferentially attacks second- and third-instar larvae, and the parasitoid larvae emerge from the fourth-instars. After parasitization, the eggs hatch in 1.0 to 1.5 days inside the insect larvae, and complete development in 6 to 8 days under laboratory conditions (Sharma *et al.*, 2008). On completion of development, the parasitoid larva emerges from the insect host, killing the latter in the process. It then weaves a cocoon around itself, and the pupal period lasts for 5 to 7 days. The life cycle is completed in 12 to 16 days (Nandihalli and Lee, 1995; Sharma *et al.*, 2008). There is a significant correlation between the age of host larvae and percent parasitism (Gunasena *et al.*, 1989), and parasitism potential varies across crops and insect hosts (Dhillon and Sharma, 2007a).

The parasitism levels vary across crops, cropping systems, and locations, which might be attributed to variation in environmental conditions such as temperature, relative humidity, insect hosts, and heterogeneity in insect populations. Insects adjust their life cycles to the variation in environmental conditions so that growth, development, and reproduction coincide with favorable conditions. Thermal requirements and survival threshold also influence the activity and abundance of natural enemies, which in return influence the success of biological control programs (Butler and Lopez, 1980; Chihrane *et al.*, 1993; Bernal, 1995). Therefore, the response of insects to environmental extremes, and their interaction with natural enemies and environmental factors is critical for the success of biological control. The likely shifts in climate change would have a great bearing on the effectiveness of natural enemies for pest management, which in turn would affect insect host-natural enemy associations, crop production, and food security. Therefore, the present studies were aimed at

understanding the influence of variations in temperature and insect host on survival and development of the endoparasitoid, *C. chlorideae*.

Materials and methods

Insect culture

The *H. armigera* larvae were reared on chickpea-based semi-synthetic artificial diet in the insectary at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India. The 50 generations old ichneumonid parasitoid, *C. chlorideae* culture (laboratory strain) was maintained under laboratory conditions on *H. armigera* larvae at 27 ± 1°C, and 65 to 85% R.H. (Dhillon and Sharma, 2007a). Field culture (field strain) of the parasitoid was initiated from cocoons collected from chickpea fields at the ICRISAT farm during the 2007 postrainy season. The neonate *H. armigera* larvae obtained from laboratory culture were fed on chickpea leaves from plants raised under field conditions, and the late second-instars were used for parasitization by *C. chlorideae*.

Influence of temperature and *H. armigera* food on survival and development of the parasitoid, *C. chlorideae* strains

The effect of temperature and insect host food [larvae reared on artificial diet in the laboratory, and on natural host plant-chickpea], on the survival and development of the parasitoid, *C. chlorideae* strains (laboratory and field strains) was studied under laboratory conditions. The experiments comprised of following treatment combinations: i) crop host reared *H. armigera* larvae + field strain of the parasitoid (FLFC), ii) crop host reared *H. armigera* larvae + laboratory strain of the parasitoid (FLLC), iii) artificial diet reared *H. armigera* larvae + field strain of the parasitoid (LLFC), and iv) artificial diet reared *H. armigera* larvae + laboratory strain of the parasitoid (LLLC). Five pre-mated *C. chlorideae* females from the laboratory and field strains were used for parasitizing *H. armigera* larvae reared on artificial diet or on chickpea leaves. After parasitization, the *H. armigera* larvae were kept at 12 ± 1°C, 18 ± 1°C, 27 ± 1°C, 35 ± 1°C, and ambient conditions (where temperature varied between 12 to 25°C, averaging 23°C), till emergence of parasitoid adults. Fifteen *H. armigera* larvae were parasitized in each replication, and there were five replications for each treatment in a completely randomized design. Observations were recorded on larval and pupal periods, percentage parasitization of *H. armigera* larvae, adult emergence, and male and female weights to gain an understanding of the influence of temperature and insect host on the survival and development of two different strains of the parasitoid, *C. chlorideae*.

Statistical analysis

Data were subjected to analysis of variance. The significance of differences between the treatments was judged by F-test, while the treatment means were compared using LSD at P = 0.05. There was no parasitism in the *H. armigera* larvae kept at 12 ± 1°C and 35 ± 1°C after parasitization, and these were not included in the analysis of variance. The degree-days were calculated using a modified formula given by Dhillon and Sharma (2007b).

Total degree-days for treatments under constant temperatures = [Total development period (days)] × [storage temperature]

Total degree-days for treatments under ambient conditions = [Total development period (days)] × [average of minimum and maximum temperatures across the developmental period.]

Results and discussion

Influence of temperature and *H. armigera* food on development of the parasitoid, *C. chlorideae* strains

The *H. armigera* food (artificial diet or chickpea leaves) and temperature showed a significant effect ($F_{6, 24} = 3.51$, P = 0.006) on survival and development of the parasitoid, *C. chlorideae* strains. There was no parasitoid larval survival in *H. armigera* larvae kept at 12 ± 1°C and 35 ± 1°C after parasitization, might be because of incompatible growth of the host and the parasitoid larvae, suggesting >12°C to <35°C as the minimum and maximum threshold temperatures for the survival and development of the parasitoid. However, Pandey and Tripathi (2008) reported 24.6 and 9.4 days as the developmental periods of the parasitoid, *C. chlorideae* at 12°C and 37°C, respectively, and suggested the range for successful development of the parasitoid, which seems to be unrealistic, because the *H. armigera* larval development itself takes two months at 13.3°C (4th instar at about 45 to 48 days), and 11 days at 32.5°C (4th instar at about 8 to 8.5 days) (Jallow and Matsumura, 2001).

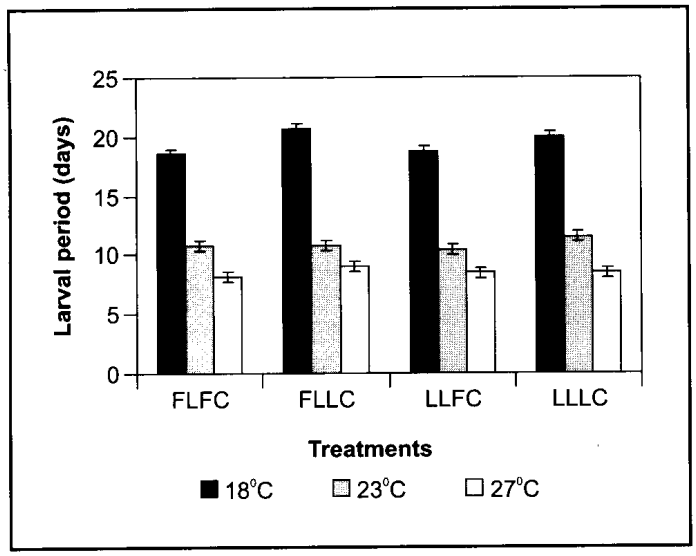
The larval period of the parasitoid was prolonged on *H. armigera* fed on chickpea leaves, and laboratory strain of the parasitoid at 18 ± 1°C and 27 ± 1°C (Fig. 1a). Under ambient conditions, the larval period of the parasitoid was also prolonged on *H. armigera* larvae fed on artificial diet and of the progeny of the laboratory strain of the parasitoid, indicating poor adaptation of laboratory strain to ambient conditions. The larvae took more time to complete development (18.6 to 20.7 days) at 18 ± 1°C than at 27 ± 1°C (8.1 to 9.1 days) (Fig. 1a). The pupal period was significantly ($F_{2, 8} = 94.05$, P<0.001) more (15.4 days) at 18 ± 1°C as compared to the insects reared at 27 ± 1°C (6.5

days) and under ambient conditions (9.9 days) (Fig. 1b). Thus, the *C. chlorideae* took about 2.5 fold more time to complete development at 18°C than at 27°C, suggesting a significant influence of temperature on the development of the parasitoid. Decrease in developmental period with an increase in temperature between 20°C and 32°C has also been reported in case of *Bemisia tabaci* (Gennadius) endoparasitoid, *Eretmocerus* sp. nr. *furuhashii* Rose & Zolnerowich (Qiu *et al.*, 2007). There was no effect of source of insects or temperature on the weight of parasitoid cocoons. There was a significant influence of temperature ($F_{2, 8}$ = 117.0, P<0.001) on numbers of degree-days required for completing parasitoid, *C. chlorideae* development (Table 1). The numbers of degree-days required for completing parasitoid development were significantly more at 18 ± 1°C (628 degree-days) than under ambient conditions (479 day degrees) and at 27 ± 1°C (405 degree-days) (Table 1). There was a significant and negative association between temperature and *C. chlorideae* larval (r = -0.99**) and pupal (r = -0.98**) periods. Negative association between developmental period of the *C. chlorideae* and temperature has also been reported by Teggelli *et al.* (2004). A decrease in development period of immature stages of *Pnigalio pectinicornis* L. has been observed on citrus leaf miner, *Phyllocnistis citrella* Stainton with an increase in temperature from 15 to 30°C (Kalaitzaki *et al.*, 2007). Therefore, biological control agents should be selected for tolerance to a maximum temperature range in order to avoid incompatibility with harsh climates.

Influence of temperature and *Helicoverpa armigera* food on survival of the parasitoid, *C. chlorideae* strains

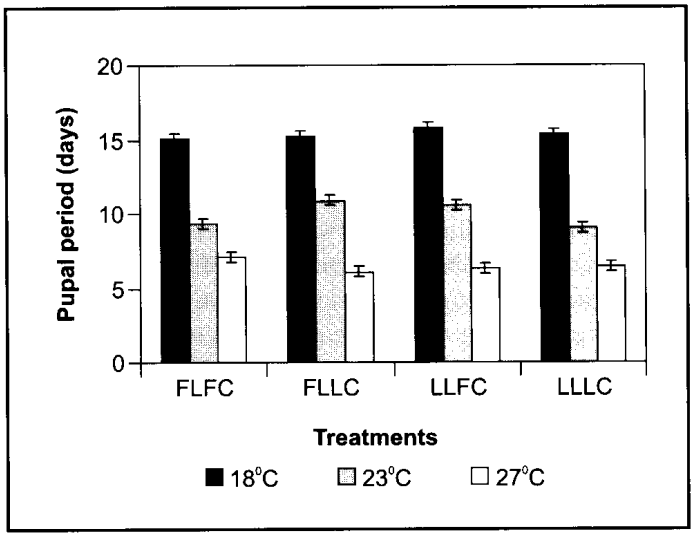
Changes in temperature regimes and food source influences growth and development of the insect host, which indirectly may result in asynchrony in growth, leading to reduced survival of the endoparasitoids. Although, temperature had no influence on cocoon formation and adult emergence of *C. chlorideae*, insect host diet, and parasitoid strain × temperature had a significant influence on cocoon formation and adult emergence during the present studies. Cocoon formation (Fig. 2a) and adult emergence (Fig. 2b) was greater when both the insect host and the parasitoids were from the laboratory (84.4 and 75.1%) than when *H. armigera* larvae were fed on chickpea leaves and parasitoid was from the laboratory strain (61.3 and 51.1%, respectively). The effects of nutritional quality of food of the insect host, its growth and development, on natural enemies have earlier been reported by Nordlund *et al.* (1988) and Murugan *et al.* (2000). There was a significant influence of source of insects and temperature on the adult male and female weights of the parasitoid (Table 2). The male parasitoid weight was also significantly influenced by source of insects × temperature ($F_{6, 24}$ = 10.38, P<0.001). The adult weights were significantly lower under ambient conditions than at 18 ± 1°C and 27 ± 1°C (Table 2), indicating that the fluctuations in temperature influence adult development.

Thus, the present studies suggest that the change in



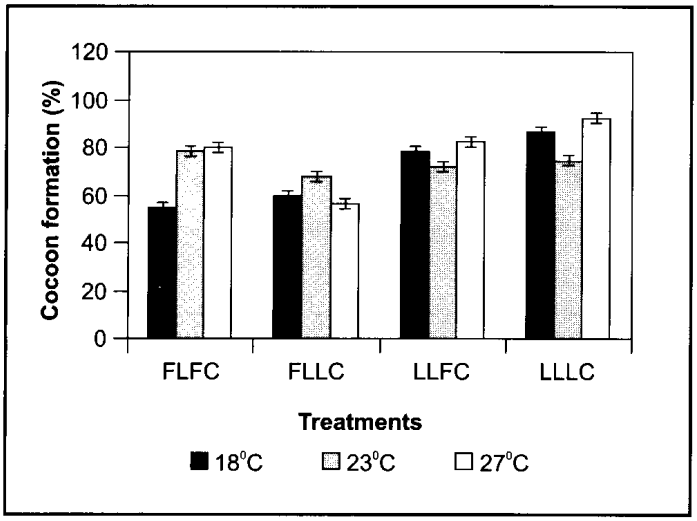
FLFC = Field larvae and field strain; FLLC = Field larvae and laboratory strain; LLFC = Laboratory larvae and field strain; LLLC = Laboratory larvae and laboratory strain

Figure 1a. Effect of temperature and *H. armigera* larval food on post-embryonic larval developmental period of field and laboratory strains of *C. chlorideae*.



FLFC = Field larvae and field strain; FLLC = Field larvae and laboratory strain; LLFC = Laboratory larvae and field strain; LLLC = Laboratory larvae and laboratory strain

Figure 1b. Effect of temperature and *H. armigera* larval food on post-embryonic pupal developmental period of field and laboratory strains of *C. chlorideae*.



FLFC = Field larvae and field strain; FLLC = Field larvae and laboratory strain; LLFC = Laboratory larvae and field strain; LLLC = Laboratory larvae and laboratory strain

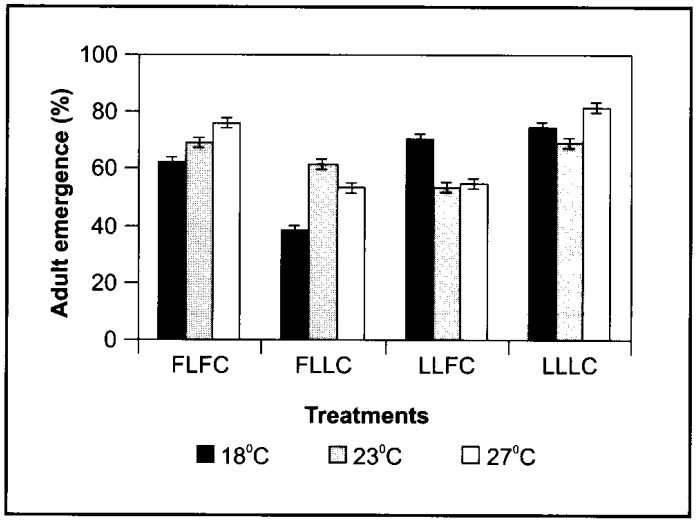
Figure 2a. Effect of temperature and *H. armigera* larval food on survival (cocoon formation) of field and laboratory strains of *C. chlorideae*.

Table 1. Day degrees required for development of the parasitoid across different treatments and temperature regimes

Treatments	Day degrees		
	18 ± 1°C	23°C (ambient conditions)	27 ± 1°C
FLFC	674	379	462
FLLC	719	379	499
LLFC	693	369	484
LLLC	705	372	473
Mean	698	375	479
LSD (P = 0.05) for comparing	Treatments	Temperatures	Treatments × Temperatures
	34.54	29.91	59.82

FLFC = Field larvae and field strain; FLLC = Field larvae and laboratory strain; LLFC = Laboratory larvae and field strain; LLLC = Laboratory larvae and laboratory strain

temperature is likely to affect the growth and development of insect host, *H. armigera*, resulting in considerable influence on the survival and development of its parasitoid, *C. chlorideae*. Therefore, the information will be useful for understanding the influence of temperature on the activity and abundance of natural enemies, which will have great bearing on insect-pest population dynamics, insect damage and crop production.



FLFC = Field larvae and field strain; FLLC = Field larvae and laboratory strain; LLFC = Laboratory larvae and field strain; LLLC = Laboratory larvae and laboratory strain

Figure 2b. Effect of temperature and *Helicoverpa armigera* larval food on survival (adult emergence) of field and laboratory strains of *C. chlorideae*.

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Table 2. Effect of temperature and insect host on adult weights of field and laboratory strains of the parasitoid

Treatments	Male weight (mg male^{-1})			Female weight (mg female^{-1})		
	18 ± 1°C	23°C (ambient conditions)	27 ± 1°C	18 ± 1°C	23°C (ambient conditions)	27 ± 1°C
FLFC	2.85	2.25	2.63	3.20	2.56	2.95
FLLC	2.68	2.44	3.18	3.26	3.20	3.30
LLFC	2.60	3.10	3.20	2.98	3.05	3.53
LLLC	3.14	2.99	3.48	3.46	3.14	4.43
Mean	2.82	2.70	3.12	3.23	2.99	3.55
LSD (P = 0.05) for comparing						
	Treatments	Temperatures	Treat × Temp	Treatments	Temperatures	Treat × Temp
	0.13	0.12	0.23	0.41	0.35	NS

FLFC = Field larvae and field strain; FLLC = Field larvae and laboratory strain; LLFC = Laboratory larvae and field strain; LLLC = Laboratory larvae and laboratory strain; NS = Nonsignificant at P = 0.05

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