

## Effects of elevated temperature and carbon dioxide on food consumption and growth of *Spodoptera litura* Fabricius on cauliflower

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### ABSTRACT

The studies on influence of temperature and carbon dioxide levels on food consumption and growth of *Spodoptera litura* on cauliflower were conducted in controlled environment during 2015-16 with two different temperature (25:11°C and 25:14°C) and three carbon dioxide regimes (350, 400, 450 ppm). Temperature and carbon dioxide had significant effect on food consumption parameters of *S. litura*. Overall the food consumption of *S. litura* increased from 0.18g larva<sup>-1</sup> at temperature of 25: 11°C and CO<sub>2</sub> of 350 ppm to 0.31g larva<sup>-1</sup> at temperature of 25: 14°C and CO<sub>2</sub> of 450 ppm. Similarly, relative growth rate increased from 0.15 to 0.27 mg mg<sup>-1</sup> day<sup>-1</sup> and larval weight gain increased from 0.14 to 0.28 g day<sup>-1</sup>. However, with increase in CO<sub>2</sub> concentration at 450 ppm, the larval weight gain decreased from 0.28 to 0.22g day<sup>-1</sup>.

**Keywords:** *Spodoptera litura*, nutritional indices, temperature, carbon dioxide, cauliflower.

Insects play significant roles as herbivores, pollinators, predators and parasitoids and any change in their abundance and diversity has the potential to alter the functioning of any ecosystem (Hillstrom and Lindroth, 2008). Global warming, resulting from increased level of CO<sub>2</sub>, could cause qualitative and quantitative changes in the agricultural, horticultural and forest plants that would alter the abundance and distribution pattern of insect pest species (Kiritani, 2006). Temperature has a direct effect on development of insects, but elevated carbon dioxide (eCO<sub>2</sub>) has an indirect and host-mediated effects (Yadugiri, 2010). It has been reported that Lepidopteran species, that feed on eCO<sub>2</sub>-grown foliage are likely to have decreased fitness, higher mortality, decreased larval weight and prolonged development times (Yin *et al.* 2010). Most published studies on response of insect herbivores to elevated temperature and CO<sub>2</sub> conditions had focused on short term feeding experiments (Bezemer and Jones, 1998), with majority of these dealing with individual effects of elevated CO<sub>2</sub> or temperature. But, these abiotic components do not exert independent effects on herbivores (Whittaker, 1999) due to the fact that rising atmospheric CO<sub>2</sub> concentrations would consequently increase the temperature (Thompson, 1989) hence, their interaction should be considered for a holistic approach. The tobacco caterpillar, *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae) is polyphagous pest, damaging many economically important vegetables and ornamental plants and has a huge potential to invade new areas by adapting to wide range of ecological situations. The

temperature rise of 2.7–4.7°C predicted due to potential climate change may have drastic consequences for future incidence of *S. litura* (IPCC, 2013). Studies by Fand *et al.* (2015) revealed that the development rate of *S. litura* increased linearly for all the immature stages until at 34–36°C. The results demonstrated the importance of optimum temperature in determining the suitability of climate for reproduction in *S. litura*. Hence present study aimed to understand the effect of elevated concentrations of CO<sub>2</sub> coupled with alternating temperature conditions on nutritional indices of *S. litura* on cauliflower.

### MATERIALS AND METHODS

An experiment was carried out during 2015-16 in Controlled Environment Chamber (PGW-40, M/s Percival Scientific, Inc., USA), at Department of Entomology, Punjab Agricultural University, Ludhiana to study the effect of temperature and carbon dioxide regimes on the food consumption and growth rate of *S. litura*.

#### *Rearing of the test insect*

The initial culture of *S. litura* was collected from cabbage and cauliflower fields and reared in jars under laboratory conditions. These larvae were fed with fresh and cleaned cauliflower leaves as per the methodology given by Pandey *et al.* (2015). The insect culture was maintained throughout the study period to get continuous supply of sufficient number of insects. The glassware used in the experiments was thoroughly washed in detergent, treated

with 2 per cent formalin and then dried in an oven at 30°C for 8 hours to check microbial contamination in the insect culture.

The treatments were comprised of temperature and carbon dioxide combinations as given below

Temperature (°C) T <sub>max</sub> : T <sub>min</sub>	CO <sub>2</sub> concentration (ppm)	Photoperiod (h) Light: Dark	Relative humidity (%)
(i) 25 : 11	(i) 350	14: 10	65 ± 5
(ii) 25 : 14	(ii) 400		
	(iii) 450		

### Food consumption

The data on food consumption, nutritional indices and growth indices were calculated on *S. litura* from third to fifth instars using cauliflower leaves as food. The experiment on feeding of larvae was performed in 4 replications. Each replication consisted of 25 larvae at each temperature and CO<sub>2</sub> condition, kept singly in plastic sample containers to avoid over crowding and congestion. Holes were made in lid of containers for aeration. Initial weight of each larva was recorded before the start of experiment. Before offering leaves as food to larva, the weight of larva and leaf were measured and then after 24 hours, weight of remaining leaf, larval weight and faecal matter was recorded. The leaves were provided to larvae until pupation. The data on weight of larva, food, faeces and pupa was recorded on electronic balance with a sensitivity of 0.1 mg. Under each condition, a set of control leaves was also kept and weighed every day to ascertain the moisture loss of leaves to calculate the actual weight of food eaten by larvae. A set of additional larvae were maintained under each temperature CO<sub>2</sub> conditions in similar way. Whenever any of the test larvae died, a larva from the additional set was added to replace it so that number of larvae in each replication remains same.

### Nutritional and growth indices

Data on larval weight (g), faecal matter (g), fresh food and uneaten food (g) was recorded daily and weight gained (g) was utilized to work out various nutritional indices on fresh weight basis according to Waldbauer (1968). Relative growth rate and larval weight gain were also calculated to ascertain the effect of elevated temperature and CO<sub>2</sub> on growth and food utilization by *S. litura* on cauliflower. Food consumption and relative growth rate (RGR) were calculated for third to fifth instar larvae (Waldbauer, 1968).

### Statistical analysis

Mean and standard error was calculated from the data under each head and data was analyzed for analysis of variance with two factor Factorial Completely Randomized Design (CRD) using computer software CPCS1 (Cheema and Singh, 1993).

## RESULTS AND DISCUSSION

### Food consumption by *S. litura* larvae

Mean food consumption by third, fourth and fifth instar larvae was observed to increase with increase in temperature from 11 to 14°C, and with CO<sub>2</sub> concentration from 350 to 400 and 450 ppm (Table 1). Temperature showed a significant effect on food consumption with highest mean food consumption (g larva<sup>-1</sup>) by fifth (0.36) followed by fourth (0.23) and third instars (0.20). Carbon dioxide also showed a significant effect on food consumption with highest mean food consumption (g larva<sup>-1</sup>) by fifth instar larva (0.39) followed by fourth (0.27) and third (0.24) instars at 450 ppm CO<sub>2</sub> concentration. Highest interactive effect of temperature and carbon dioxide was observed in third and fifth instars at temperature 25:14°C and carbon dioxide 450 ppm combinations. Maximum per cent increase over previous instar was observed in case of fifth instar larvae (45.45) at 25:14°C temperature and 350 ppm carbon dioxide concentration whereas lowest per cent increase was observed in fourth instar larvae (5.88) at 25:11°C and 350 ppm carbon dioxide concentration. Present studies are similar to those reported by Pandey *et al.* (2015) who reported that food consumption of *H. armigera* increased with increase in temperature. Khadar *et al.* (2014) also reported that food consumption by *H. armigera* increased by 81.6 per cent under elevated CO<sub>2</sub> conditions as compared to ambient conditions. Similar results were observed by Dalal and Arora (2016) who also observed that food consumption by *H. armigera* increased with increase in temperature. It has been reported that with increase in CO<sub>2</sub> concentration and with increase in minimum temperature the food consumption by *S. litura* larvae increases which might be due to the reduction in protein content and increase of C/N ratio in leaves under elevated CO<sub>2</sub> (Hunter, 2001).

### Relative growth rate

The data on relative growth rate (RGR, mg mg<sup>-1</sup> day<sup>-1</sup>) of *S. litura* larvae from third to fifth instars at different alternating temperatures and carbon dioxide are presented in Table 2. The overall mean RGR of 350, 400 and 450 ppm

**Table 1:** Effect of change in minimum temperature and carbon dioxide concentrations on food consumption (glarva<sup>-1</sup>) of *S. litura* larvae

CO <sub>2</sub> concentration (ppm)	Food consumption (glarva <sup>-1</sup> ) of <i>S. litura</i> larvae at temperature, Max: Min (°C)*											
	Third instar			Fourth instar			Fifth instar			Overall mean		
	25:11 (19.17)**	25:14 (20.42)**	Mean (19.17)**	25:11 (19.17)**	25:14 (20.42)**	Mean (19.17)**	25:11 (19.17)**	25:14 (20.42)**	Mean (19.17)**	25:11 (19.17)**	25:14 (20.42)**	Overall mean (19.17)**
350	0.16±0.01 (0.13-0.19)	0.16±0.02 (0.15-0.20)	0.16±0.02 (0.13-0.21)	0.17±0.02 (0.17-0.22)	0.18±0.03 (0.17-0.22)	0.17±0.01 (0.17-0.22)	0.21±0.02 (0.17-0.25)	0.33±0.03 (0.31-0.36)	0.27±0.06 (0.27±0.06)	0.18±0.04 (0.18±0.04)	0.22±0.09 (0.22±0.09)	
400	0.17±0.02 (0.14-0.21)	0.18±0.02 (0.12-0.20)	0.20±0.01 (0.14-0.23)	0.23±0.02 (0.20-0.26)	0.22±0.03 (0.20-0.26)	0.22±0.03 (0.20-0.26)	0.34±0.04 (0.27-0.37)	0.35±0.02 (0.32-0.37)	0.35±0.01 (0.35±0.01)	0.24±0.08 (0.24±0.08)	0.25±0.08 (0.25±0.08)	
450	0.22±0.01 (0.16-0.24)	0.26±0.03 (0.21-0.29)	0.24±0.03 (0.21-0.29)	0.27±0.04 (0.24-0.29)	0.27±0.04 (0.24-0.29)	0.27±0.02 (0.24-0.29)	0.38±0.03 (0.34-0.43)	0.40±0.01 (0.36-0.42)	0.39±0.02 (0.39±0.02)	0.29±0.09 (0.29±0.09)	0.31±0.08 (0.31±0.08)	
Mean	0.18±0.03	0.20±0.02	0.21±0.04	0.23±0.05	0.23±0.05	-	0.31±0.08	0.36±0.02	-	-	-	
CD (p=0.05)												
Temp	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	
CO <sub>2</sub>	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	
Temp x CO <sub>2</sub>	(0.02)	(0.02)	(0.02)	(NS)								

Values are Mean±SE of four replications; Figures in the parentheses denotes the range; \*These temperatures were maintained for 14:10 h with same duration of L:D at constant RH 65±5%; \*\*Figures in parentheses represent mean value of temperatures

**Table 2:** Effect of change in minimum temperature and carbon dioxide concentrations on relative growth rate (RGR)(mg mg<sup>-1</sup> day<sup>-1</sup>) of *S. litura* larvae

CO <sub>2</sub> concentration (ppm)	Relative growth rate (RGR)(mg mg <sup>-1</sup> day <sup>-1</sup> ) of <i>S. litura</i> larvae at temperature, Max: Min (°C)*											
	Third instar			Fourth instar			Fifth instar			Overall mean		
	25:11 (19.17)**	25:14 (20.42)**	Mean (19.17)**	25:11 (19.17)**	25:14 (20.42)**	Mean (19.17)**	25:11 (19.17)**	25:14 (20.42)**	Mean (19.17)**	25:11 (19.17)**	25:14 (20.42)**	Overall mean (19.17)**
350	0.19±0.01 (0.16-0.23)	0.21±0.02 (0.16-0.25)	0.20±0.03 (0.14-0.18)	0.16±0.02 (0.14-0.18)	0.19±0.02 (0.14-0.23)	0.18±0.03 (0.14-0.23)	0.10±0.01 (0.07-0.14)	0.13±0.01 (0.10-0.14)	0.12±0.02 (0.12±0.02)	0.15±0.01 (0.15±0.01)	0.18±0.02 (0.18±0.02)	
400	0.23±0.02 (0.18-0.28)	0.28±0.02 (0.24-0.32)	0.25±0.04 (0.09-0.16)	0.22±0.01 (0.19-0.24)	0.22±0.01 (0.19-0.24)	0.17±0.06 (0.17±0.06)	0.11±0.01 (0.08-0.13)	0.17±0.01 (0.15-0.19)	0.15±0.04 (0.15±0.04)	0.16±0.02 (0.16±0.02)	0.22±0.01 (0.22±0.01)	
450	0.25±0.02 (0.20-0.29)	0.32±0.01 (0.28-0.34)	0.28±0.05 (0.16-0.32)	0.27±0.01 (0.25-0.28)	0.27±0.01 (0.25-0.28)	0.24±0.04 (0.24±0.04)	0.15±0.02 (0.11-0.20)	0.21±0.02 (0.16-0.25)	0.18±0.05 (0.18±0.05)	0.20±0.01 (0.20±0.01)	0.27±0.02 (0.27±0.02)	
Mean	0.22±0.01	0.27±0.02	0.23±0.01	0.23±0.01	0.23±0.01	-	0.12±0.01	0.17±0.01	-	-	-	
CD (p=0.05)												
Temp	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	
CO <sub>2</sub>	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	
Temp x CO <sub>2</sub>	(NS)	(NS)	(NS)	(0.03)	(0.03)	(0.03)	(NS)	(NS)	(NS)	(NS)	(NS)	

Values are Mean±SE of four replications; Figures in the parentheses denotes the range; \*These temperatures were maintained for 14:10 h with same duration of L:D at constant RH 65±5%; \*\*Figures in parentheses represent mean value of temperatures

**Table 3: Effect of change in minimum temperature and carbon dioxide concentrations on larval weight gain (g day<sup>-1</sup>) of *S. litura***

CO <sub>2</sub> concentration (ppm)	Larval Weight (g day <sup>-1</sup> ) of <i>S. litura</i> larvae at temperature, Max: Min (°C)*											
	Third instar			Fourth instar			Fifth instar			Overall mean		
	25:11 (19.17)**	25:14 (20.42)**	Mean	25:11 (19.17)**	25:14 (20.42)**	Mean	25:11 (19.17)**	25:14 (20.42)**	Mean	25:11 (19.17)**	25:14 (20.42)**	Mean
350	0.25±0.04 (0.20-0.29)	0.28±0.02 (0.25-0.31)	0.26±0.04 (0.13-0.21)	0.18±0.03 (0.13-0.21)	0.23±0.03 (0.19-0.26)	0.21±0.03 (0.19-0.26)	0.06±0.02 (0.03-0.09)	0.09±0.01 (0.08-0.09)	0.07±0.04 (0.03-0.09)	0.14±0.09 (0.08-0.09)	0.20±0.09 (0.14-0.20)	0.20±0.09 (0.14-0.20)
400	0.28±0.02 (0.25-0.36)	0.36±0.01 (0.34-0.36)	0.33±0.02 (0.25-0.36)	0.24±0.03 (0.23-0.28)	0.29±0.01 (0.28-0.30)	0.27±0.04 (0.28-0.30)	0.16±0.01 (0.14-0.17)	0.20±0.02 (0.19-0.20)	0.18±0.02 (0.19-0.20)	0.23±0.09 (0.19-0.20)	0.28±0.07 (0.19-0.20)	0.28±0.07 (0.19-0.20)
450	0.31±0.04 (0.28-0.36)	0.34±0.02 (0.32-0.37)	0.32±0.04 (0.28-0.36)	0.14±0.05 (0.09-0.19)	0.19±0.01 (0.18-0.20)	0.17±0.04 (0.18-0.20)	0.07±0.02 (0.05-0.10)	0.14±0.01 (0.13-0.15)	0.11±0.03 (0.13-0.15)	0.17±0.11 (0.13-0.15)	0.22±0.09 (0.13-0.15)	0.22±0.09 (0.13-0.15)
Mean	0.28±0.04	0.33±0.03	-	0.19±0.05	0.23±0.04	-	0.10±0.05	0.14±0.04	-	-	-	-
CD (p=0.05)												
Temp	(0.02)	(0.02)		(0.02)	(0.02)		(0.01)	(0.01)		(0.01)	(0.01)	(0.01)
CO <sub>2</sub>	(0.02)	(0.02)		(0.02)	(0.02)		(0.01)	(0.01)		(0.01)	(0.01)	(0.01)
Temp x CO <sub>2</sub>	(NS)	(NS)		(NS)	(NS)		(0.01)	(0.01)		(0.01)	(0.01)	(0.01)

Figures in the parentheses denotes the range;  
\*These temperatures were maintained for 14:10 h with same duration of L:D at constant RH 65±5%; \*\*Figures in parentheses represent mean value of temperatures

was recorded to be 0.15, 0.15 and 0.20 mg mg<sup>-1</sup>day<sup>-1</sup>, respectively at 25:11°C whereas at 25:14°C the mean RGR values was recorded to be 0.18, 0.22 and 0.27 mg mg<sup>-1</sup> day<sup>-1</sup> of 350, 400 and 450 ppm CO<sub>2</sub> concentration, respectively. It was found that temperature had a significant effect on RGR of third fourth and fifth instars. The RGR was highest in the third instar, and lowest in the fifth instar with intermediate values in the fourth instar at the two alternating temperatures. The highest values of mean RGR of third, fourth and fifth were observed to be 0.27, 0.23 and 0.17 mg mg<sup>-1</sup>day<sup>-1</sup>, respectively at 25:14 °C irrespective of the carbon dioxide concentration. Carbon dioxide also had significant effect on third, fourth and fifth instars. Highest RGR values of third, fourth and fifth instars (0.28, 0.24 and 0.18, respectively) were observed at 450 ppm concentration of carbon dioxide. The interactive effect of temperature and carbon dioxide was observed to be insignificant in third and fifth instars larvae whereas these factors showed significant effect on fourth instar larvae with highest RGR value (0.27) at 25:14 °C and 450 ppm carbon dioxide combination. The per cent increase in RGR with an increase in minimum temperature of 3°C from 11 to 14°C was recorded to be 29.95. Also per cent increase from 350 to 400 ppm, 400 to 450 ppm and 350 to 450 ppm was recorded to be 12.12, 27.02 and 42.42, respectively. These results are similar to those reported by Dalal and Arora (2016) that the RGR of *H. armigera* increased with increase in temperature. These results are in contrast with those reported by Rao *et al.* (2012) that RGR of *S. litura* decreased when feed on peanut foliage under elevated CO<sub>2</sub> conditions which may be because of effect of elevated CO<sub>2</sub> on host and its effect on insect, while in our case this increase in RGR is due to the effect of elevated temperature and CO<sub>2</sub> on *S. litura* larvae and there are no host mediated effects.

#### Larval weight gain

The data on mean larval weight gain (g day<sup>-1</sup>) of *S. litura* larvae from third to fifth instars at different alternating temperatures and CO<sub>2</sub> are presented in Table 3. Mean larval weight gain of third instar larvae was recorded to be 0.28, 0.33 at 25:11°C and 25:14°C, respectively and 0.26, 0.33 and 0.32 g day<sup>-1</sup> at CO<sub>2</sub> concentration of 350, 400 and 450 ppm, respectively. Mean larval weight gain (g day<sup>-1</sup>) of fifth instar larvae was recorded to be 0.10, 0.20 at 25:11°C and 25:14°C, respectively and 0.07, 0.18 and 0.11 at CO<sub>2</sub> concentration of 350, 400 and 450 ppm, respectively. The overall mean larval weight gain (g day<sup>-1</sup>) of 350, 400 and 450 ppm was recorded to be 0.14, 0.23 and 0.17, respectively at

25:11°C whereas at 25:14°C the mean larval weight gain was recorded to be 0.20, 0.28 and 0.22 g day<sup>-1</sup> of 350, 400 and 450 ppm CO<sub>2</sub> concentration, respectively. It was found that temperature and CO<sub>2</sub> had a significant effect on larval weight gain in these three instars. The interactive effect of temperature and carbon dioxide was observed to be insignificant in third and fourth instars larvae whereas interaction of temperature and carbon dioxide showed significant effect on fifth instar larvae with highest value of 0.20 g day<sup>-1</sup> at 25:14 °C and 450 ppm CO<sub>2</sub>. It was observed that maximum weight gain was recorded at ambient CO<sub>2</sub> conditions but with any increase or decrease in CO<sub>2</sub> concentration, the weight gain of larvae decreased. On the contrary, with increase in minimum temperature the weight gain of *S. litura* larvae increased. These results are contrary to the findings of Rao *et al.* (2012) who reported higher larval weight in 550 ppm (18%) and 700 ppm (32 %) CO<sub>2</sub> conditions, which could be attributed to higher RCR values in their studies. As earlier stated, the results in present study are effects of elevated CO<sub>2</sub> and temperature on insect and no indirect effects though host have affected *S. litura* larvae. Similarly, Khadar *et al.* (2014) reported that inspite of increase of food consumption, RCR and AD; the gain in larval weight was nearly 4.4 per cent over ambient conditions. This could be attributed to lower protein content and higher carbon content in plant tissues thus reducing the efficiency of conservation of ingested food and digested food. Temperature has been generally considered the single most significant environmental factor influencing behaviour, distribution, development, survival and reproduction in insects (Bale *et al.* 2002). It was observed that under elevated temperature and CO<sub>2</sub> conditions increased herbivory and ultimately higher crop damage could be observed, but decreased larval weight gain and relative consumption rate indicate smaller larvae and affected development. These results could lead to an improved understanding of the field dynamics and the activity of *S. litura* under elevated temperature and CO<sub>2</sub> conditions. Further studies on more detailed insights are required to quantify these effects and predicting the damage potential under climate change scenario.

## CONCLUSION

It can be concluded that food consumption, relative growth rate and larval weight gain increased with increase in minimum temperature by 3°C. These parameters also increased with increase in carbon dioxide concentration from 350 to 450 ppm. It can be concluded that minimum

temperature, carbon dioxide and their interactive effect influences the nutritional and growth indices of *S. litura*.

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