Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2021; 10(1): 676-683
Received: 12-10-2020
Accepted: 10-12-2020

Deekshita K
Department of Entomology, Agricultural College, Bapatla, Andhra Pradesh, India

Krishnayya PV
Professor & Head, Department of Entomology, Agricultural College, Bapatla, Andhra Pradesh, India

Srinivasa Rao M
Principal Scientist, Division of Crop Sciences, Central Research Institute for Dryland Agriculture, Hyderabad, Telangana, India

Patibanda AK
Professor & Head, Department of Plant Pathology, Agricultural College, Bapatla, Andhra Pradesh, India

Nafeez Umar S
Associate Professor, Department of statistics and mathematics, Agricultural College, Bapatla, Andhra Pradesh, India

Corresponding Author:
Deekshita K
Department of Entomology, Agricultural College, Bapatla, Andhra Pradesh, India

Effect of sublethal concentrations of insecticides on the feeding indices of *Spodoptera litura* under *e*CO_2 and *e*Temp conditions

Deekshita K, Krishnayya PV, Srinivasa Rao M, Patibanda AK and Nafeez Umar S

Abstract
To better understand the sublethal effects of insecticides (Spinosad, emamectin benzoate, thiodicarb, monocrotophos and fenvalerate) on *Spodoptera litura*, under *e*CO_2 and *e*Temp several studies were carried out to investigate the sublethal effects on the developmental stages and feeding indices of *S. litura*. The Relative Growth Rate, Relative Consumption Rate, Efficiency of Conversion of Digested food and Efficiency of Conversion of Ingested food decreased with increase in temperatures after exposure to sublethal doses (LC_{10} and LC_{30}) of spinosad and fenvalerate . Contrastingly, higher feeding indices were recorded in the larvae treated with Emamectin benzoate, monocrotophos and thiodicarb.

Keywords: Climate change, carbondioxide, sublethal concentrations, temperature

1. Introduction
Climate change is the most important, complex environmental issue to date. Global Mean Surface Temperature (GMST) and atmospheric CO_2concentrations have been increasing at an alarming rate since 19thcentury. The projected increase in temperature by 2100 was set by 1.4 –5.8 °C with the increase in the amount of CO_2 in the atmosphere by about 40 per cent. The increase in the amount of CO_2 in the atmosphere would reach to 500 to 1000 ppm by the end of 21st century (IPCC, 2014). These two dimensions of climate change *viz.*, *e*Temp and *e*CO_2 influence the growth and development of insect pests directly and indirectly and in turn effect the population dynamics and their status (Srinivasa rao *et al.*, 2015) [21]. The combined effects of temperature and CO_2 dilutes the biochemical constituents of the foliage and inturn effects the growth parameters of the insect pests interms of lower growth rate, slow larval development and increased feeding (Fajer *et al.*, 1989) [6].
The only option for management of this pest is chemical control. Temperature has a prominent effect on insecticide effectiveness (Busvine, 1971) [2]. Elevated temperature results in breakdown of particular insecticide into either more or less toxic metabolites and may vary with type of insecticides. Therefore, warmer climate necessitate an increased insecticide usage (Noyes *et al.*, 2009) [17] which is expected in the form of higher amounts or dosages. Insecticidal effects on insects can be categorized into direct toxic effects and sublethal effects. The former one causes the mortality of insects and sublethal dose of insecticides have large influence on insect emergence, pupal weights, larval and pupal durations (Han *et al.*, 2012) [9] and feeding indices (Xu *et al.*, 2016) [25]. The target pest are not killed immediately after application and effects the physiological and behavioural changes of the target pest, till the insecticide is reduced over time. Though the temperature, CO_2 and insecticides have adverse affect on the growth and development of the insects but the combined effect was not studied so far. Hence an effort was made to study the combined effect of sublethal concentrations of insecticides (emamectin benzoate, thiodicarb and monocrotophos) under two CO2 levels (380 ± 25 and 550 ± 25 ppm) at five different temperatures *viz*., 28, 29, 31, 33 and 35 ± 0.5 ºC on the feeding indices of *S. litura*

2. Material and Methods
2.1 Maintenance of Crop
The popular variety of sunflower DSRH -1 procured from Indian Institute of Oilseed Research (IIOR) was raised at different set conditions comprising of ambient (380 ± 25 ppm; 28 ºC), *e*Temp. (380 ± 25 ppm; 29, 31, 33 and 35 ± 0.5 ºC), *e*CO2 + *e*Temp. (550 ± 25 ppm; 29, 31, 32 and 35 ± 0.5 ºC) and *e*CO2 (550 ± 25 ppm; 28 ºC) in Carbon dioxide and Temperature Gradient Chambers (CTGC). Similarly, the test insect *S.litura* was also maintained at same set

conditions in CO2 growth chamber. Enough caution was taken to have consensus between CTGC and growth chambers conditions.

2.2 Rearing of *S. litura* larvae

The egg masses of *S. litura* were collected from field and initially maintained in the entomology laboratory at Central Research Institute for Dryland Agriculture (CRIDA) to buildup the population. Later the insects were maintained under at respective set conditions (*e*CO2 and *e*Temp conditions *viz.*, 550 and 380 ± 25 ppm and 28, 29, 31, 33 and 35 ± 0.5 ºC inside the growth chambers).

2.3 Preparation of Sublethal Concentrations of Insecticides

Bioassays were conducted on third instar (six day old, 30 mg) larvae of *S. litura* (Balasubramanian, 1982) under laboratory conditions using leaf dip method (Method No. 7 of IRAC, 2014) [10]. Mortality data recorded after 72 HAT was subjected to probit analysis (Finney, 1971) [7] by using Statistical Packages for Social Sciences (SPSS) to calculate LC10, LC30 values and were considered as sublethal concentrations (Table 1). The effect of sublethal concentrations of insecticides on the feeding indices of *S.litura* was assessed at each concentration at respective set conditions. The data on growth parameters *viz.*, larval weight, amount of food ingested and amount of faeces excreted were used to estimate various insect performance or food conversion efficiency indices (Waldbauer, 1968 and Srinivasa Rao *et al*., 2009) [22] and the formulae for the estimation of the indices are given below.

Relative growth rate (RGR): It is defined as weight gained by the larva in a day. It is expressed in g g^{-1} day^{-1}.
RGR = Increase in larval body weight (g) / Average larval weight per day (g).

Relative Consumption Rate (RCR): It is defined as the per captia consumption of foliage by larva in a day. It is expressed in g g^{-1} d^{-1}. Calculated by the formulae
RCR = Weight of food consumed (g) / Average larval body weight (g) per day

Efficiency of conversion of ingested food (ECI): ECI is an overall measure of an insect's ability to utilize the ingested food for growth and development and expressed in terms of percentage.
Weight gained by larvae (g) during feeding period / Weight of the food consumed (g) X 100

Efficiency of conversion of digested food (ECD): It is the larval weight gain per unit weight of leaf digested and expressed interms of percentage. Calculated by the formulae
Weight gained by larvae (g) during feed period / Weight of the food consumed (g)-Weight of the faeces (g) X 100

2.4 Statistical analysis

The data on growth parameters of *S.litura* (*viz.*, weights and durations of larvae and pupae and per cent adult emergence) and insect feeding indices (AD, ECI, ECD, CI and RGR) after exposure to sublethal concentrations were analyzed using ANOVA with CO_2 level as main factor and temperatures as sub factor deployed in Factorial CRD.

3. Results and Discussion

The effect of sublethal concentrations of test insecticides *viz.*, Spinosad, Emamectin benzoate, thiodicarb, monocrotophos and fenvalerate on the feeding indices of *S. litura* were discussed below. The feeding indices RGR, RCR, ECI and ECD were significantly affected by *e*CO_2 and *e*Temp after exposure to sublethal concentrations of insecticides. In the present study, RGR and RCR of *S. litura* decreased with increase in sublethal doses of spinosad (LC_{10} to LC_{30}) and temperatures (28 to 35 ºC) under both levels of CO_2. The lowest relative growth rate (0.075 g g^{-1} day^{-1}), RCR (1.14 g g^{-1} day^{-1}), ECD (10.30%) and ECI (9.77%) was recorded at 550 ppm; 35 ºC after exposed to LC_{30} concentrations of spinosad compared to ambient conditions (RGR- 0.125 g g^{-1} day^{-1}; RCR - 1.28 g g^{-1} day^{-1}; ECD -18.45% and ECI - 16.38%) (Table 1 & Fig 1).

Lower feeding indices were recorded at LC_{30} values compared to LC_{10} and untreated control. Similar trend of lower feeding indices were recorded after exposure to sublethal concentrations of fenvalerate under both levels of CO_2 (Table 5). Analogously the findings of Ebeid and Gesraha, 2012 [4] also indicated the reduced growth rate and food consumption after exposure to sublethal doses of spinosad. The findings of Elsayed *et al*., 2013 [5] were on par with the present results and recorded reduced ECD and ECI.

Though the RGR and RCR decreased with increase in sublethal doses of emamectin benzoate, monocrotophos and thiodicarb (Table 2, 3 and 4 & Fig 1) but increased with increase in temperatures under both levels of CO_2. The highest relative growth rate (0.066 g g^{-1} day^{-1}), RCR (1.75 g g^{-1} day^{-1}), ECD (18.07%) and ECI (19.64%) was recorded at 550 ppm; 35 ºC after exposed to LC_{30} concentrations of spinosad compared to ambient conditions (RGR- 0.053 g g^{-1} day^{-1}; RCR – 0.66 g g^{-1} day^{-1}; ECD -9.86% and ECI – 4.52%). The feeding indices recorded at LC_{30} were lower than those recorded at LC_{10} and untreated control.

Similarly the other insecticides thiodicarb and monocrotophos also showed decrease in RGR, RCR, ECI and ECD compared to untreated control at temperatures (28, 29, 31, 33 and 35 ºC) under both *a*CO_2 and *e*CO_2 thus indicating lower feeding indices. This is due to larvae utilize all of its energy obtained from food sources for detoxification rather than development inturns affects the normal growth of the insect (Martinez and Emden, 1999) [14]. The reduced consumption rate and ability to convert food into biomass might have extended larval developmental period with increase in sublethal concentrations.

The present results indicated that larval indices significantly varied across two CO_2 levels and at five temperatures (28, 29, 31, 33 and 35 ºC). The larvae after exposure to test insecticides exhibited poorer insect feeding indices with decreased RCR, RGR, ECI and ECD compared to untreated control across temperatures. The relative growth rate (RGR), an index of growth coupled with the weight of the insect larvae declined greatly when larvae allowed to feed on foliage applied with sublethal concentrations. It represented that food might be inedible to the insects and might have acted as inhibitor so that the treated larvae did not have sufficient nutritional components for its normal growth (Schoonhoven *et al*., 2005) [19].

Earlier reports of Jansen and Groot (2004) [12] indicated that reduced RGR might be due to irreparable damage to the cellular surface of the midgut lumen. The RGR of insects increased with increase in temperatures under both *a*CO_2 and *e*CO_2 after exposure to sublethal doses of emamectin benzoate, thiodicarb and monocrotophos. But in contrast decreased in spinosad and fenvalerate treated insects under both *a*CO_2 and *e*CO_2. Relative consumption Rate measures quantity of food consumed per unit body weight of insect per day was significantly lower in *S. litura* larvae treated with sublethal doses compared to control across temperatures under both *a*CO_2 and *e*CO_2. The lower values of RCR is due to lowest food consumption and less larval weights due to insecticidal stress (Nagapasupathi *et al*., 2003) [15]. The RCR of insects increased with increase in temperature under both *a*CO_2 and *e*CO_2 after exposure to sublethal doses of emamectin benzoate, thiodicarb and monocrotophos and decreased in spinosad and fenvalerate treated insects.

The higher concentrations of five test insecticides significantly decreased the ECD and ECI and inturn affected the normal growth of the larvae (Martinez and Emden, 1999) [14]. The reduced consumption rate and ability to convert food into biomass might have extended the larval developmental period. The gain in larval weight was more at *e*CO_2 and corresponding temperatures compared to *a*CO_2. This might be due to lower protein content and higher carbon and CN ratio in the foliage, thus indicating reduced efficiency in the conversion of ingested and digested food by the larvae fed on leaves of sunflower grown under *e*CO_2 compared to *a*CO_2 (Manimanjari, 2017) [13].

The present results inidicating lower feeding indices with increase in sublethal doses were in conformity with Elsayed *et al*., 2013 [5] who reported decreased RGR , CI, ECD and ECI in the larvae treated with spinosad @ 70 and 200 g a.s. / 200 l compared to control. Naggar and Jehan, 2013 stated that the *S. littoralis* larvae treated with emamectin benzoate and spinosad, reduced RGR (7.12 and 15.17%, respectively), CI (2.9 and 3.8%, respectively), ECD (2.39 and 4.83%, respectively) and ECI (2.20 and 4.39%, respectively), respectively compared to control (20.6, 5.5, 8.70 and 7.60%, respectively). Similarly, the reduced CI and RGR in the abamectin treated *S. littoralis* larva was reported by Abo-El-Ghar *et al.*, 1993 [1]. Nagapasupathi *et al.*, 2003 [15] reported poor feeding indices (lower RGR, ECD, ECI and CI) in thiodicarb treated *S. litura* larvae compared to the control. The poor feeding indices in pyrethroid treated insects were reported by Gist and Pless (1985) [8] under insecticidal stress.

The indices *viz.*, RGR, CI, ECD and ECI increased with increase in temperature under both *a*CO_2 and *e*CO_2, and was less evident at *e*CO_2 due to poor nutritional quality of the foliage grown under *e*CO_2. The reduction in protein and nitrogen often leads to poorer feeding indices. Under *e*CO_2 and corresponding temperatures (28, 29, 31, 33 and 35 ºC), the leaf chewing herbivores responded by increasing the food consumption and reducing the food conversion effiiciency (Williams *et al*., 2000; Chen *et al*., 2004) [24, 3] compared to *a*CO_2 at corresponding temperatures.

The present results were also in conformity with Rama devi and Jha, 2018 [18] who recorded higher values of RGR, RCR, ECD and ECI with increase in temperature from 20 to 30 ºC. Similarly Shwetha *et al*., 2017 [20] reported significantly higher values of RCR and AD at *e*CO_2 + *e*Temp (285.59 mg/g/day, 77.13%, respectively) compared to *a*CO_2 + *e*Temp (270.35 mg/g/day and 73.83%, respectively). The increase in RGR with increase in temperature was reported by Akbar *et al*., 2015 where RGR was maximum at 35 ºC (0.1 g g^{-1} day^{-1}) compared to the insects reared at 15 and 25 ºC (0.073 and 0.083, g g^{-1} day^{-1}respectively).

The combined effect of *e*CO_2 and *e*Temp on the sublethal concentrations *viz.*, emamectin benzoate, thiodicarb and monocrotophos increased the RGR, RCR, ECD and ECI with increase in temperatures from 28 to 35 ºC under both *a*CO_2 and *e*CO_2 . The reduced feeding indices might be due to reduced biochemical components (Carbohydrate and protein content) in the insect body. The body weight of larvae was comparatively higher at higher temperatures compared to ambient under both levels of CO_2 which results in lower values of AD. On the other hand, the insecticides spinosad and fenvalerate decreased RGR, RCR, ECD and ECI at higher temperatures, as the leaf chewing herbivores were exposed to higher concentration of insecticides at higher temperatures which resulted in poor feeding indices. However, from this study it is evident that these insecticides regulated the growth of *S. litura* instead of instant killing.

Table 1: Effect of sublethal concentrations of spinosad on the RGR and RCR of *S.litura* at *e*CO_2 and *e*Temp. Conditions

Interaction (CO_2 X Temp (ºC)	RGR (g $g^{-1}$$day^{-1}$)						RCR (g g^{-1} day^{-1})					
	Control		LC_{10}		LC_{30}		Control		LC_{10}		LC_{30}	
	aCO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2		
28 ± 1 ºC	0.153 ± 0.002	0.137 ± 0.006	0.144 ± 0.001	0.128 ± 0.002	0.125 ± 0.001	0.115 ±0.002	1.76 ± 0.03	1.82 ± 0.02	1.56 ± 0.02	1.79 ± 0.05	1.28 ± 0.05	1.56 ± 0.04
29 ± 1 ºC	0.156 ± 0.002	0.141 ± 0.005	0.141 ± 0.002	0.120 ± 0.003	0.112 ± 0.002	0.102 ± 0.002	1.84 ± 0.03	1.96 ± 0.01	1.50 ± 0.04	1.74 ± 0.03	1.19 ± 0.01	1.42 ± 0.02
31 ± 1 ºC	0.160 ± 0.002	0.143 ± 0.003	0.138 ± 0.003	0.114 ± 0.002	0.109 ± 0.001	0.095 ± 0.002	1.98 ± 0.05	2.18 ± 0.03	1.46 ± 0.04	1.62 ± 0.03	1.08 ± 0.05	1.38 ± 0.04
33 ± 1 ºC	0.163± 0.003	0.148 ± 0.003	0.135 ± 0.003	0.108 ± 0.005	0.096 ± 0.001	0.082± 0.001	2.02 ± 0.01	2.24 ± 0.02	1.38 ± 0.04	1.50 ± 0.05	0.92 ± 0.03	1.26 ± 0.04
35 ± 1 ºC	0.166 ± 0.002	0.152 ± 0.002	0.131 ± 0.002	0.100 ± 0.001	0.082 ± 0.001	0.075 ± 0.001	2.14 ± 0.04	2.38 ± 0.02	1.25 ± 0.04	1.42 ± 0.03	0.84 ± 0.03	1.14 ± 0.04
F. test	316.78*		NS		39.74*		7.85*		187.10*		31.28*	
S.Em±	0.001		0.02		0.001		0.02		0.02		0.005	
CD(p = 0.05)	0.002		NS		0.002		0.05		0.04		0.014	
CO_2												
aCO_2	0.160		0.158		0.149		1.94		1.43		1.06	
eCO_2	0.141		0.139		0.130		2.12		1.62		1.35	
F. test	116.00*		NS		3205.67*		777.12*		453.88*		8222.06*	
S.Em±	0.001		0.007		0.0003		0.008		0.006		0.002	
CD(p = 0.05)	0.002		NS		0.001		0.021		0.017		0.006	
Temperatures												
28 ± 1 ºC	0.156		0.154		0.145		1.79		1.69		1.42	

29 ± 1 ºC	0.153	0.151	0.142	1.90	1.62	1.31
31 ± 1 ºC	0.149	0.148	0.139	2.07	1.54	1.23
33 ± 1 ºC	0.147	0.146	0.136	2.13	1.44	1.09
35 ± 1 ºC	0.145	0.143	0.133	2.25	1.34	0.99
F. test	316.78*	NS	237.72*	40.53*	51.39*	2273.63*
S.Em±	0.0003	0.012	0.001	0.012	0.01	0.004
CD(p = 0.05)	0.001	NS	0.002	0.033	0.03	0.011
CV (%)	2.12	1.84	1.06	1.81	3.19	1.92

aCO_2 – 380 ± 25 ppm; *e*CO_2 – 550 ± 25 ppm
All values are mean ± standard deviation
* Significant @ 5% level of significance
NS – Non significant
RGR – Relative Growth Rate
RCR – Relative Consumption Rate

Table 2: Effect of sublethal concentrations of emamectin benzoate on the RGR and RCR of *S.litura* at *e*CO_2 and *e*Temp. Conditions

Interaction (CO_2 X Temp (ºC)	RGR ($g\ g^{-1}\ day^{-1}$)						RCR ($g\ g^{-1}\ day^{-1}$)					
	Control		LC10		LC30		Control		LC10		LC30	
	aCO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2		
28 ± 1 ºC	0.148 ± 0.002	0.128 ± 0.001	0.080 ± 0.001	0.072 ± 0.001	0.053 ± 0.002	0.043 ± 0.002	1.85 ± 0.03	1.98 ± 0.02	1.25± 0.03	1.41 ± 0.04	0.66 ± 0.01	0.84 ± 0.02
29 ± 1 ºC	0.152 ± 0.001	0.132 ± 0.002	0.082 ± 0.003	0.078 ± 0.003	0.062 ± 0.001	0.05 ± 0.001	1.99 ± 0.03	2.06 ± 0.06	1.47 ± 0.03	1.64 ± 0.02	0.85 ± 0.01	1.01 ± 0.02
31 ± 1 ºC	0.159 ± 0.001	0.140 ± 0.003	0.087 ± 0.004	0.082 ± 0.001	0.065 ± 0.001	0.058 ± 0.002	2.12 ± 0.05	2.21 ± 0.06	1.62 ± 0.01	1.90 ± 0.05	1.02 ± 0.02	1.27 ± 0.05
33 ± 1 ºC	0.163 ± 0.002	0.150 ± 0.001	0.092 ± 0.001	0.088 ± 0.002	0.069 ± 0.002	0.063 ± 0.002	2.36 ± 0.04	2.42 ± 0.04	1.81 ± 0.05	2.12 ± 0.01	1.19 ± 0.07	1.52 ± 0.05
35 ± 1 ºC	0.168 ± 0.005	0.158 ± 0.001	0.099 ± 0.002	0.091 ± 0.002	0.074 ± 0.001	0.066 ± 0.004	2.52 ± 0.04	2.68 ± 0.06	2.03 ± 0.02	2.25 ± 0.07	1.48 ± 0.06	1.75 ± 0.06
F. test	374.06*		71.32*		130.70*		29.36*		65.23*		221.28*	
S.Em±	0.001		0.001		0.001		0.01		0.01		0.005	
CD(p = 0.05)	0.002		0.002		0.002		0.03		0.03		0.014	
CO_2												
aCO_2	0.091		0.089		0.060		2.17		1.64		1.04	
eCO_2	0.101		0.093		0.075		2.27		1.87		1.28	
F. test	582.31*		476.66*		520.73*		4521.25*		2015.23*		9124.29*	
S.Em±	0.0003		0.0004		0.0003		0.005		0.004		0.004	
CD(p = 0.05)	0.001		0.001		0.001		0.013		0.011		0.010	
Temperatures												
28 ± 1 ºC	0.105		0.087		0.062		1.92		1.33		1.02	
29 ± 1 ºC	0.103		0.089		0.064		2.03		1.56		1.25	
31 ± 1 ºC	0.096		0.092		0.067		2.16		1.76		1.34	
33 ± 1 ºC	0.091		0.095		0.070		2.39		1.97		1.48	
35 ± 1 ºC	0.087		0.096		0.073		2.60		2.14		1.52	
F. test	104.34*		45.33*		61.27*		356.95*		258.92*		3749.01*	
S.Em±	0.001		0.001		0.001		0.007		0.006		0.002	
CD(p = 0.05)	0.002		0.002		0.003		0.020		0.018		0.006	
CV (%)	2.32		2.47		2.32		2.02		2.26		2.06	

aCO_2 – 380 ± 25 ppm; *e*CO_2 – 550 ± 25 ppm
All values are mean ± standard deviation
* Significant @ 5% level of significance
NS – Non significant
RGR – Relative Growth Rate
RCR – Relative Consumption Rate

Table 3: Effect of sublethal concentrations of thiodicarb on the RGR and RCR of *S.litura* at *e*CO_2 and *e*Temp. Conditions

Interaction (CO_2 X Temp (ºC)	RGR ($g\ g^{-1} day^{-1}$)						RCR ($g\ g^{-1} day^{-1}$)					
	Control		LC10		LC30		Control		LC10		LC30	
	aCO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2
28 ± 1 ºC	0.142 ± 0.002	0.124 ± 0.001	0.082 ± 0.03	0.076± 0.05	0.060 ± 0.03	0.053 ± 0.01	1.84 ± 0.03	1.92 ± 0.02	1.66 ± 0.02	1.72 ± 0.02	1.28 ± 0.03	1.46 ± 0.04
29 ± 1 ºC	0.148 ± 0.003	0.128 ± 0.002	0.090 ± 0.01	0.082 ± 0.02	0.068 ± 0.02	0.057 ± 0.02	1.91 ± 0.03	2.00 ± 0.01	1.71± 0.03	1.84 ± 0.02	1.39 ± 0.03	1.52 ± 0.02
31 ± 1 ºC	0.152 ± 0.002	0.132 ± 0.003	0.093 ± 0.02	0.088 ± 0.03	0.072 ± 0.01	0.060 ± 0.02	2.06 ± 0.05	2.18 ± 0.03	1.86 ± 0.03	1.92 ± 0.03	1.48 ± 0.03	1.68 ± 0.04
33 ± 1 ºC	0.158 ± 0.003	0.142 ± 0.001	0.098 ± 0.03	0.094 ± 0.01	0.078 ± 0.02	0.063 ± 0.01	2.18 ± 0.01	2.24 ± 0.02	1.96 ± 0.02	2.12 ± 0.07	1.52 ± 0.04	1.76 ± 0.05
35 ± 1 ºC	0.163 ± 0.005	0.150 ± 0.001	0.112 ± 0.02	0.101 ± 0.02	0.081 ± 0.01	0.066 ± 0.03	2.25 ± 0.04	2.38 ± 0.02	2.04 ± 0.04	2.24 ± 0.06	1.64 ± 0.06	1.84 ± 0.03

F. test	801.82*	6.011*	116.61*	29.36*	55.20*	155.11*
S.Em±	0.001	0.001	0.001	0.01	0.009	0.009
CD(p = 0.05)	0.002	0.002	0.003	0.03	0.024	0.026
CO_2						
aCO_2	0.152	0.089	0.060	1.94	1.85	1.46
eCO_2	0.136	0.093	0.075	2.12	1.97	1.66
F. test	832.30*	172.36*	137.35*	4521.25*	3011.13*	2072.94*
S.Em±	0.0003	0.0003	0.0003	0.005	0.004	0.004
CD(p = 0.05)	0.001	0.001	0.001	0.013	0.011	0.011
Temperatures						
28 ± 1 ºC	0.133	0.087	0.062	1.79	1.69	1.37
29 ± 1 ºC	0.138	0.089	0.064	1.90	1.78	1.46
31 ± 1 ºC	0.142	0.092	0.067	2.07	1.89	1.58
33 ± 1 ºC	0.150	0.096	0.070	2.13	2.04	1.65
35 ± 1 ºC	0.158	0.095	0.073	2.25	2.14	1.74
F. test	176.28*	326.72*	26.28*	356.95*	263.87*	136.60*
S.Em±	0.0005	0.001	0.001	0.007	0.006	0.006
CD(p = 0.05)	0.0013	0.003	0.003	0.020	0.017	0.018
CV (%)	2.11	4.08	6.59	1.81	2.04	2.47

aCO_2 – 380 ± 25 ppm*;* *e*CO_2 – 550 ± 25 ppm
All values are mean ± standard deviation
* Significant @ 5% level of significance
NS – Non significant
RGR – Relative Growth Rate
RCR – Relative Consumption Rate

Table 4: Effect of sublethal concentrations of monocrotophos on the RGR and RCR of *S.litura* at *e*CO_2 and *e*Temp. Conditions

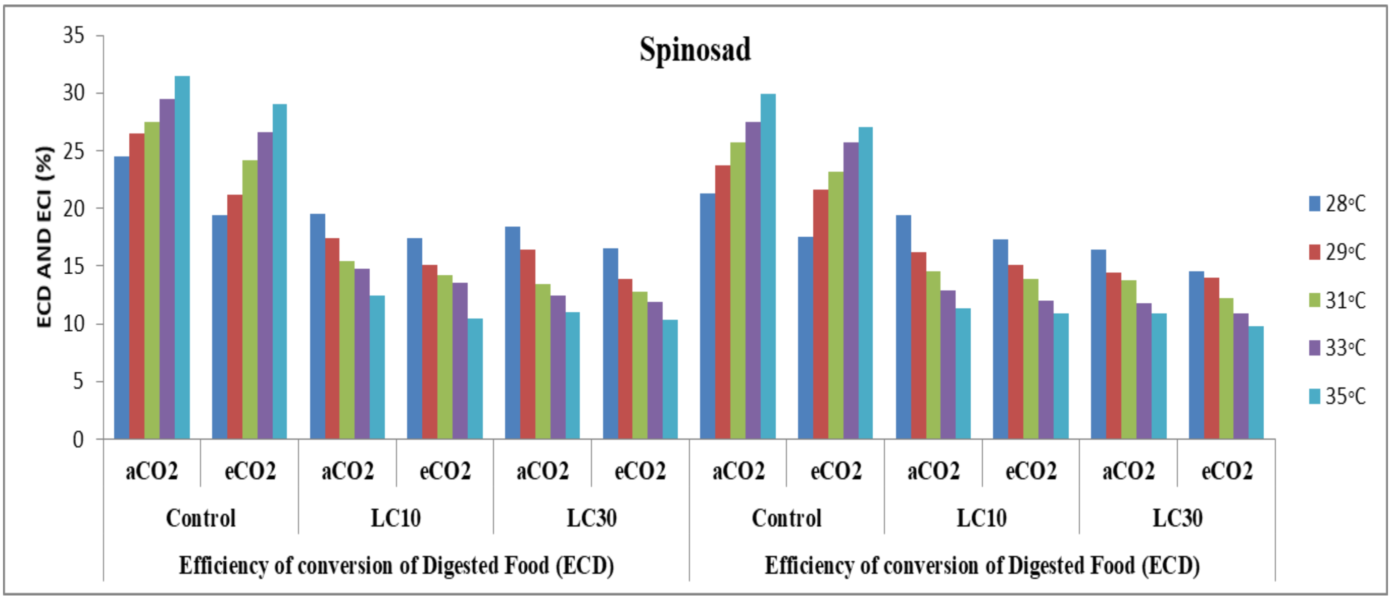
Interaction (CO_2 X Temp (ºC))	**RGR (g g^{-1} day^{-1})**						**RCR (g $g^{-1}$$day^{-1}$)**					
	Control		**LC10**		**LC30**		**Control**		**LC10**		**LC30**	
	***a*CO_2**	***e*CO_2**	***a*CO_2**	***e*CO_2**	***a*CO_2**	***e*CO_2**	***a*CO_2**	***e*CO_2**	***a*CO_2**	***e*CO_2**		
28 ± 1 ºC	0.142 ± 0.002	0.128 ± 0.002	0.082 ±0.002	0.078 ± 0.002	0.072±0.002	0.065 ± 0.001	1.88 ± 0.03	2.02 ± 0.02	1.52 ± 0.03	1.86 ± 0.04	1.02 ± 0.01	1.22 ± 0.02
29 ± 1 ºC	0.149 ± 0.002	0.134 ± 0.002	0.097 ± 0.002	0.089 ± 0.001	0.082±0.002	0.071±0.001	2.01 ± 0.03	2.16 ± 0.06	1.68 ± 0.03	1.92 ± 0.02	1.21 ± 0.01	1.38 ± 0.02
31 ± 1 ºC	0.153 ± 0.002	0.140 ± 0.003	0.106 ±0.001	0.100 ± 0.002	0.091±0.003	0.083±0.002	2.18 ± 0.05	2.22 ± 0.06	1.82 ± 0.01	2.08 ± 0.05	1.34 ± 0.02	1.52 ± 0.05
33 ± 1 ºC	0.158 ± 0.003	0.146 ± 0.002	0.112 ± 0.002	0.108 ± 0.001	0.102±0.001	0.092±0.002	2.39 ± 0.04	2.46 ± 0.04	1.98 ± 0.05	2.12 ± 0.01	1.48 ± 0.07	1.69 ± 0.05
35 ± 1 ºC	0.163 ± 0.004	0.152 ± 0.001	0.121 ± 0.001	0.114 ± 0.003	0.108±0.001	0.099±0.002	2.56 ± 0.04	2.69 ± 0.06	2.06 ± 0.02	2.21 ± 0.07	1.66 ± 0.06	1.75 ± 0.06
F. test	*		358.52*		4.99*		NS		12.54*		13.56*	
S.Em±	0.0005		0.0004		0.0001		0.01		0.02		0.003	
CD(p = 0.05)	0.0014		0.0011		0.0003		NS		0.05		0.008	
CO_2												
aCO_2	0.159		0.104		0.091		2.17		1.64		1.04	
eCO_2	0.140		0.098		0.082		2.27		1.87		1.28	
F. test	*		5353.2*		808.94*		NS		301.04*		256.14*	
S.Em±	0.0002		0.0003		0.00002		0.004		0.009		0.001	
CD(p = 0.05)	0.0006		0.001		0.00007		NS		0.024		0.003	
Temperatures												
28 ± 1 ºC	0.135		0.080		0.069		1.92		1.33		1.02	
29 ± 1 ºC	0.141		0.093		0.077		2.03		1.56		1.25	
31 ± 1 ºC	0.146		0.103		0.087		2.16		1.76		1.34	
33 ± 1 ºC	0.152		0.110		0.097		2.39		1.97		1.48	
35 ± 1 ºC	0.157		0.118		0.104		2.60		2.14		1.52	
F. test	*		592.19*		1644.85*		NS		184.41*		154.26*	
S.Em±	0.0004		0.0003		0.00006		0.007		0.014		0.002	
CD(p = 0.05)	0.0011		0.001		0.00016		NS		0.038		0.006	
CV (%)	1.65		1.77		2.45		2.02		4.63		2.13	

aCO_2 – 380 ± 25 ppm*;* *e*CO_2 – 550 ± 25 ppm
All values are mean ± standard deviation
* Significant @ 5% level of significance
NS – Non significant
RGR – Relative Growth Rate
RCR – Relative Consumption Rate

Table 5: Effect of sublethal concentrations of fenvalerate on the RGR and RCR of *S.litura* at *e*CO_2 and *e*Temp. Conditions

Interaction (CO_2 X Temp (ºC)	RGR (g g $^{-1}$day^{-1})						RCR (g g $^{-1}$day^{-1})					
	Control		LC_{10}		LC_{30}		Control		LC_{10}		LC_{30}	
	aCO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2	*a*CO_2	*e*CO_2		
28 ± 1 ºC	0.182 ± 0.01	0.176 ± 0.01	0.178 ± 0.012	0.162 ± 0.012	0.165 ±0.012	0.149 ±0.011	1.75 ±0.13	1.88 ± 0.01	1.68 ± 0.05	1.72 ± 0.05	1.42 ± 0.04	1.54 ± 0.02
29 ± 1 ºC	0.189 ± 0.02	0.182 ± 0.02	0.169 ± 0.009	0.155 ± 0.012	0.159 ±0.014	0.138 ±0.018	1.88 ± 0.01	1.95 ± 0.04	1.50 ± 0.03	1.65 ± 0.01	1.36 ± 0.03	1.42 ± 0.01
31 ± 1 ºC	0.197 ± 0.01	0.191 ± 0.02	0.157 ± 0.015	0.150 ± 0.014	0.148 ±0.015	0.127 ±0.013	1.95 ± 0.04	2.08 ± 0.05	1.48 ± 0.02	1.53 ± 0.05	1.28 ± 0.05	1.30 ± 0.05
33 ± 1 ºC	0.206 ± 0.02	0.202 ± 0.02	0.148 ± 0.013	0.142 ± 0.011	0.141 ±0.012	0.121 ±0.014	2.02 ± 0.01	2.16 ± 0.05	1.32 ± 0.05	1.40 ± 0.05	1.16 ± 0.05	1.21 ± 0.03
35 ± 1 ºC	0.224 ± 0.01	0.212 ± 0.03	0.144 ± 0.014	0.138 ± 0.013	0.134 ±0.018	0.117 ±0.013	2.15 ± 0.03	2.28 ± 0.03	1.28 ± 0.05	1.32 ± 0.02	1.08 ± 0.04	1.17 ± 0.08
F. test	102.43*		18.04*		164.74*		127.77*		69.58*		19.95*	
S.Em±	0.0005		0.0007		0.001		0.01		0.002		0.002	
CD(p = 0.05)	0.001		0.002		0.003		0.03		0.006		0.006	
CO_2												
aCO_2	0.198		0.159		0.149		2.31		1.91		1.26	
eCO_2	0.186		0.149		0.130		2.44		2.10		1.36	
F. test	1103.26*		605.68*		1667.45*		168.42*		968.19*		884.45*	
S.Em±	0.0002		0.0003		0.002		0.005		0.0004		0.0004	
CD(p = 0.05)	0.0006		0.0009		0.006		0.015		0.0012		0.0011	
Temperatures												
28 ± 1 ºC	0.185		0.170		0.157		1.86		1.56		0.88	
29 ± 1 ºC	0.192		0.162		0.149		2.13		1.78		1.01	
31 ± 1 ºC	0.199		0.153		0.138		2.42		1.97		1.31	
33 ± 1 ºC	0.202		0.145		0.131		2.56		2.24		1.52	
35 ± 1 ºC	0.212		0.141		0.125		2.90		2.50		1.82	
F. test	122.41*		49.47*		76.12*		1960.84*		58.45*		68.32*	
S.Em±	0.0004		0.005		0.006		0.01		0.001		0.0009	
CD(p = 0.05)	0.0012		0.014		0.018		0.03		0.003		0.0026	
CV (%)	2.03		2.04		1.47		2.23		1.79		2.57	

aCO_2 – 380 ± 25 ppm; *e*CO_2 – 550 ± 25 ppm
All values are mean ± standard deviation
* Significant @ 5% level of significance
NS – Non significant
RGR – Relative Growth Rate
RCR – Relative Consumption Rate



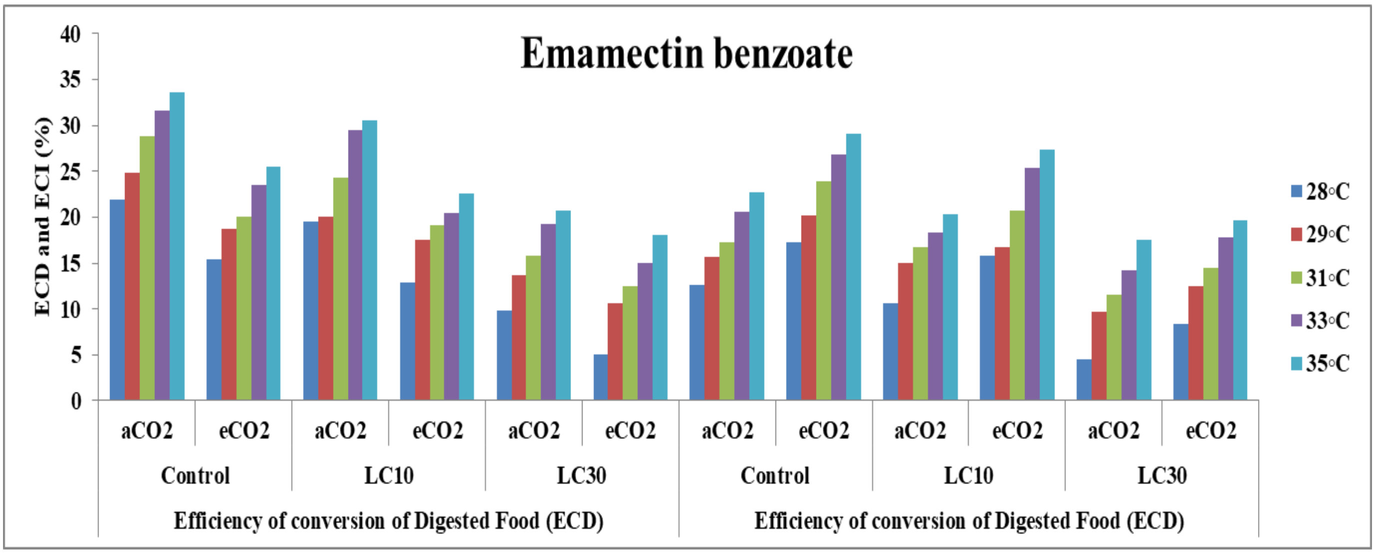


Fig 1: Effect of *e*co_2 and *e*Temp on the ECD and ECI of *S. litura* after exposure to sublethal concentrations of insecticides (Similar trend of increased ECD and ECI was recorded in Thiodicarb and monocrotophos treated insects and decreased ECD and ECI was recorded in fenvalerate treated insects)

Contrastingly the RGR and RCR increased with increase in temperatures under both levels of CO_2 after exposure to sublethal concentrations of emamectin benzoate, thiodicarb and monocrotophos.

The decrease in RGR and RCR might be due to test insects did not have sufficient nutritional components for its normal growth.

References

1. Abo-Elghar GES. Influence of abamectin and juvenile hormone analogues on food utilization of food by the larval stage of the khapra beetle., *Trogoderma granarium* Everts. Bull. Entomol. Soc 1993;24:81-88.
2. Busvine JR. A critical revicw of the techniques for testing insecticides. Commonwealth Agricultural Bureau. London 1971, 345.
3. Chen FJ, Wu G, Ge F. Growth, development and reproduction of the cotton bollworm, *Helicoverpa armigera* (Hubner) reared on milky grains of wheat grown in elevated CO_2 concentration. Acta Ecol. Sin. 2004;47(6):774-779.
4. Ebeid AR, Gesraha MA. Impact three commercial insecticides on some biological aspects of the cotton leafworm (*Spodoptera littoralis*) (Lepidoptera: Noctuiidae). J Appl Sci Res 2012;8(5):2620-2625.
5. Elsayed GA, Sakr H, Ammar HA, Yousef A, Nassar M. Sublethal effects of spinosad (Tracer) on the cotton leafworm. J Plant Prot. Res 2013;53(3):275-284.
6. Fajer ED, Bowers MD, Bazzaz FA. The effects of enriched carbon dioxide atmospheres on plant-insect herbivore interactions. Science 1989;243:1198-1200.
7. Finney DJ. Probit analysis. Cambridge University Press, London 1971, 109.
8. Gist GL, Pless CD. Effects of synthetic pyrethroids on growth and development of fall armyworm, *Spodoptera frugiperda*. Fla. Entomol Sci 1985;68(3):450-456.
9. Han W, Zhang S, Shen F, Liu M, Ren C, Gao X. Residual toxicity and sublethal effects of chlorantraniliprole on *Plutella xylostella* (Lepidoptera: Plutellidae). Pest Manag Sci 2012;68:1184-1190.
10. Insecticide Resistance Action Committee (IRAC). IRAC Susceptibility Test Methods Series Method No: 007 Version: 3.1. 2014. www.irac-online.org
11. IPCC, 2011. Climate change 2001: The scientific basis.
12. Jansen B, Groot A. Occurrence, biological activity and synthesis of drimane sesquiterpenoids. Natural Product Reports 2004;21:449-477.
13. Manimanjari D. Response of tobacco caterpillar, *Spodoptera litura* Fab. L. feeding on castor and sunflower to elevated CO_2. Ph. D Thesis. Osmania University, Hyderabad, India 2017.
14. Martinez SS, Emden V. Sublethal concentrations of azardirachtin affect food intake, converaion efficiency and feeding behavior of *Spodoptera littoralis* (Lepidoptera: Noctuidae). Bull of Entomol Res 1999;89(1):65-71.
15. Nagapasupathi N, Sreeramulu M, Sreenivasa Rao Ch. Effect of sublethal concentration of thiodicarb on food consumption and its utilization by *Spodoptera litura* (Fab.). J of Res ANGRAU 2003;31(3):96-99.
16. Naggar El, Jehan B. Sublethal effect of certain insecticides on biological and physiological aspects of *Spodoptera littoralis* (Boisd.). Nat Sci 2013;11(7):19-25.
17. Noyes PD, McElwee MK, Miller HD, Clark BW, Van Tiem LA, Walcott KC. The toxicology of climate change: Environmental contaminants in a warming. Environ Int 2009;35(6):971-86.
18. Rama Devi A, Jha S. Effect of different temperature regime on biology and food utilization of tobacco leaf eating caterpillar (*Spodoptera litura* F.) on sunflower (*Helianthus annuus* L.) under laboratory conditions 2017;5(5):602-606.
19. Schoonhoven LM, Van Loon JJ, Dicke M. Insect-plant biology: Oxford University Press 2005.
20. Shwetha, Sreenivas AG, Ashoka J, Sushila N, Kuchnoor PH. Host mediated effect of *Spodoptera litura* due to climate change. Int J Curr Microbiol Appl Sci 2017;6(7):641-650.
21. Srinivasa Rao M, Manimanjari D, Vanaja M, Rama Rao CA, Srinivas K, Raju BMK *et al*. Response of multiple generations of Tobacco caterpillar *Spodoptera litura* Fab, feeding on peanut, to elevated CO_2. Appl Ecol Environ Res 2015;13(2):373-386.
22. Srinivasa Rao M, Srinivas K, Vanaja M, Rao GGSN, Venkateshwarlu B, Ramakrishna YS. Host plant (*Ricinus communis* Linn) mediated effects of elevated CO_2 on growth performance of two insect folivores. Cur Sci 2009;97(7):1047-1054. .
23. Waldbauer GP. The consumption and utilization of food by insects. Adv In Insect Phys 1968;5:229-288.

24. Williams RS, Richard J, Norby, Lincoln DE. Effects of elevated CO_2 and temperature grown red and sugar maple on gypsy moth performance. Glob Chang Biol 2000;6:685-695.
25. Xu C, Zhang Z, Kaidi C, Zhao Y, Han J, Liu F *et al*. Effects of Sublethal Concentrations of Cyantraniliprole on the Development, Fecundity and Nutritional Physiology of the Black Cutworm *Agrotis ipsilon* (Lepidoptera: Noctuidae). PLoS ONE 2016;11(6):1-19.