Int.J.Curr.Microbiol.App.Sci (2019) *8*(7): 1668-1677

International Journal of Current Microbiology and Applied Sciences
***ISSN: 2319-7706* Volume 8 Number 07 (2019)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2019.807.198

Effect of Sublethal Concentrations of Insecticides on the Larval and Pupal Duration of *S. litura* under *e*CO_2 and *e*Temp Conditions

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Keywords

Sublethal concentrations, Larval duration, Pupal duration, Insecticides

Article Info

Accepted:
12 June 2019
Available Online:
10 July 2019

A B S T R A C T

Experiment was conducted to study the effect of *e*CO_2 and *e*Temp on the on the larval and pupal developmental periods of *S. litura* after exposed to sublethal concentrations of insecticide *viz*., spinosad, emamectin benzoate, thiodicarb and monocrotophos. Among these insecticides emamectin, thiodicarb and monocrotophos was positively related with temperature and proved effective at higher temperatures, whereas spinosad was negatively related with temperature. The test insecticides prolonged the larval and pupal durations with increase in sublethal concentrations. But in contrats with increase in temperature from 28 to 35 ºC under both *a*CO_2 (380 ± 25 ppm) and *e*CO_2 (550 ± 25 ppm), the larval and pupal durations were decreased significantly. Negatively correlated with temperatures exhibited reduced efficacy at higher temperatures which results in higher lethal concentrations, this might be reason for prolonged larval durations at higher temperatures

Introduction

The leaf eating caterpillar, *Spodoptera litura* (Fab.) is a major polyphagous pest widely distributed across world and severe infestation results in reduction of crop yield, based on the stages of the crop and its infestation level in the field (Dhir *et al.*, 1992). It has wider distribution range and affects nearly 27 plant species belonging to 25 genera of 14 families which include cultivated crops, vegetables, weeds, fruits and ornamental plants. This pest challenged the agricultural production throughout the world by causing damage to important crops like castor, sunflower, tobacco, soybean, cotton and groundnut. It is reported that it is a major pest of sunflower, causes total losses in crop yields (Bilapate and Chakravarthy, 1999). Initially gregarious larvae cause skeletonization of leaves later

they cause severe defoliation which lead to reduced supply of assimilates to the capitulum, affecting the production of floret and seeds (Sujatha and Lakshminarayana, 2005). Chemical control is a standard measure for managing *S. litura* as nonchemical methods alone cannot reduce the economic damage. However, this pest has acquired resistence several insecticides due to indiscriminate usage. 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). 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. The increased concentration of CO_2 and temperature has lot of implications in agricultural sector, influencing crops and herbivore insect pests. 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.,* 2016). The combined effect of CO_2, temperature and sublethal concentrations on the growth and development of *S.litura* was not studied so far.

Hence the aim of the present study was to examine the combined effect of sublethal concentrations of insecticides (emamectin benzoate, thiodicarb and monocrotophos) under two CO_2 levels (380 ± 25 and 550 ± 25 ppm) at five different temperatures *viz*., 28, 29, 31, 33 and 35 ± 0.5ºC.

Materials and Methods

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 ^{o}C), *e*Temp. (380 ± 25 ppm; 29, 31, 33 and 35 ± 0.5 ^{o}C), *e*CO_2 + *e*Temp. (550 ± 25 ppm; 29, 31, 32 and 35 ± 0.5 ^{o}C) and *e*CO_2 (550 ± 25 ppm; 28 ^{o}C) in Carbondioxide and Temperature Gradient Chambers (CTGC). Similarly, the test insect *S.litura* was also maintained at same set conditions in CO_2 growth chamber. Enough caution was taken to have consensus between CTGC and growth chambers conditions.

Rearing of *S. litura*

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*CO_2 and *e*Temp conditions *viz.,* 550 and 380 ± 25 ppm and 28, 29, 31, 33 and 35 ± 0.5 ºC inside the growth chambers).

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). Mortality data recorded after 72 HAT was subjected to probit analysis (Finney, 1971) by using Statistical Packages for Social Sciences (SPSS) to calculate LC_{10}, LC_{30} and LC_{50} and were considered ad sublethal concentrations (Table 1). Newly moulted third instar larvae obtained from the insect culture maintained at different set conditions were starved for 2 hours prior to exposure to the treated leaves. The larvae were fed with treated leaves for 24 hours under respective set conditions. There after the surviving larvae were reared on untreated sunflower leaves obtained from respective conditions.

Observations recorded

Total time required for the larvae to enter into pupal stage after treatment and for the pupae to emerge as adults was recorded and expressed in days as larval and pupal periods, respectively.

Statistical analysis

The data on larval and pupal developmental period of *S. litura* were analyzed using ANOVA with CO_2 level as main factor and temperatures as sub factor deployed in factorial CRD.

Results and Discussion

Effects of sublethal concentrations of insecticides on the larval durations and pupal duration of *S. litura* under *e*CO_2 and *e*Temp conditions

The larval bioassay studies conducted at different set conditions revealed that the insecticides emamectin benzoate, monocrotophos and thiodicarb were positively correlated with temperature (lower lethal concentrations at higher temperatures) whereas spinosad and was negatively correlated with insecticides (higher lethal concentrations at higher temperatures). Data related to effect sublethal concentration of spinosad, emamectin benzoate, thiodicarb, and monocrotophos on the larval duration with increase in temperatures under both *a*CO_2 and *e*CO_2 was presented in the table 2. The larval period of *S.litura* in untreated control significantly decreased with increase in temperature (28, 29, 31, 33 and 35 ºC) but after exposed to sublethal concentrations (LC_{10} and LC_{30}) extension in larval was noted across all temperatures under both CO_2 conditions. But in contrast with increase in temperatures, the developmetal period of larvae of *S. litura* treated with emamectin benzoate, thiodicarb and monocrotophos decreased under *a*CO_2 and *e*CO_2 but was more evident at *a*CO_2. On the other hand, spinosad prolonged the larval duration significantly with increase in temperature.

The larval periods were prolonged after exposed to sublethal concentrations of emamectin benzoate at temperatures (28, 29, 31, 33 and 35 ºC) under *a*CO_2 and *e*CO_2, compared to untreated control. The developmental period of larvae decreased by (3.01 and 3.02 days) and (2.91 days) at higher temperatures of both *a*CO_2 and *e*CO_2, respectively compared to 28 ºC after exposed to sublethal concentrations (LC_{10} and LC_{30}) of emamectin benzoate. These findings were in line with Venkateswari (2006) who reported prolongation of larval periods of *S. litura* from 7.4 to 11.20 days with increase in emamectin concentrations from 0.00002 to 0.00012 ppm at ambient conditions. The current findings were also in conformity with Naggar and Jehan (2013), who also reported prolongation in the larval period of *S. littoralis* by 3 days compared to the control after treated with emamectin benzoate.

The larval period of *S. litura* significantly decreased after exposure to sublethal concentrations of thiodicarb by 3.16 and 2.97 days at *a*CO_2 and 3.04 and 3.50 days at *e*CO_2 compared to 28 ºC at both levels of CO_2. The results were in conformity with Saber *et al*., 2013 whose findings reported increase in larval duration of *H. armigera* by 2.1 days after treatment with LC_{30} concentration of thiodicarb compared to control. Monocrotophos also prolonged the larval duration of *S.litura* with increase in concentrations and decreased with increase in temperature. Similar prolongation of larval period of *Spodoptera littoralis* by 4.2 days was reported by Ibrahim and Halawa, 2012 when treated with different sublethal concentrations of chlorpyriphos.

The larvae after exposure to sublethal concentrations of spinosad showed extended the larval period by 1.54 and 1.71 days at LC_{10}, 3.34 and 3.40 days at LC_{30} concentrations when comparisons made with higher and lower temperatures of both aCO_2 and eCO_2. Similarly, the pupal period was prolonged by 1.63 and 2.04 days at LC_{10}, 1.77 and 2.70 days at LC_{30} concentrations. In the untreated control contrastingly the larval and pupal periods decreased with increase in temperatures. The variation might be due to spinosad being a negatively correlated with temperatures exhibited reduced efficacy at higher temperatures which results in higher lethal concentrations, this might be reason for prolonged larval durations at higher temperatures. The present findings were in accordance with Gamal *et al*., 2013 who reported significant prolongation in larval periods of spinosad treated *Spodoptera littoralis* larvae (9.9 days) in comparison with control (7.16 days).

Table.1 Sublethal concentrations of insecticides used in the experiment

Insecticide	Set condition	LC 10		LC30	
		aCO_2	eCO_2	aCO_2	eCO_2
Spinosad	**28**	0.0005	0.0010	0.0013	0.0018
	29	0.0007	0.0011	0.0018	0.0020
	30	0.0008	0.0015	0.002	0.0028
	33	0.0012	0.0027	0.003	0.0037
	35	0.0022	0.0034	0.0058	0.0066
Emamectin benzoate	**28**	0.00047	0.00022	0.0017	0.0012
	29	0.00028	0.00015	0.0015	0.0011
	30	0.00017	0.0001	0.0012	0.0009
	33	0.00012	0.00008	0.0009	0.0007
	35	0.00005	0.00003	0.0008	0.0005
Thiodicarb	**28**	0.0008	0.00062	0.0028	0.002
	29	0.0006	0.00048	0.0020	0.0014
	30	0.0004	0.00025	0.0014	0.001
	33	0.0002	0.00015	0.001	0.0008
	35	0.0001	0.00008	0.0009	0.0003
Monocrotophos	**28**	0.0156	0.0110	0.027	0.020
	29	0.0122	0.0108	0.022	0.019
	30	0.0072	0.0068	0.014	0.013
	33	0.0058	0.0049	0.011	0.009
	35	0.0048	0.0032	0.009	0.007

Table.2 Effect of sublethal concentrations of spinosad on larval and pupal duration of *Spodoptera litura* at *e*CO_2 and *e*Temp conditions

Interaction (CO_2 X Temp (^oC)	Pupal duration (days)						Larval duration (Days)					
	Control		LC_{10}		LC_{50}		Control		LC_{10}		LC_{50}	
	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	8.52 ± 0.60	9.05 ± 0.36	8.89 ± 0.23	9.25 ± 0.48	10.02 ± 0.25	11.05 ± 0.41	9.56 ± 0.40	10.05 ± 0.22	9.98 ± 0.36	10.35 ± 0.51	11.52 ± 0.44	12.46 ± 0.50
29 ± 1 ^oC	8.29 ± 0.48	8.71 ± 0.40	9.21 ± 0.42	9.85 ± 0.42	10.56 ± 0.49	11.70 ± 0.52	9.29 ± 0.30	9.61 ± 0.48	10.21 ± 0.60	10.95 ± 0.22	12.48 ± 0.58	13.09 ± 0.67
31 ± 1 ^oC	7.95 ± 0.22	8.52 ± 0.51	9.86 ± 0.50	10.02 ± 0.32	11.06± 0.41	12.21 ± 0.51	8.95 ± 0.50	9.25 ± 0.22	10.86 ± 0.22	11.02 ± 0.50	13.02 ± 0.40	14.06 ± 0.40
33 ± 1 ^oC	7.67 ± 0.56	8.19 ± 0.46	10.21 ± 0.42	10.42± 0.38	11.58 ± 0.76	13.05 ± 0.41	8.47 ± 0.32	8.89 ± 0.48	11.21 ± 0.51	11.43 ± 0.48	14.03 ± 0.44	14.98 ± 0.78
35 ± 1 ^oC	7.48 ± 0.51	7.86 ± 0.22	10.52± 0.46	11.02 ± 0.23	12.06 ± 0.51	13.75 ± 0.51	7.98 ± 0.50	8.25 ± 0.32	11.52 ± 0.48	12.06 ± 0.44	14.86 ± 0.60	15.86 ± 0.60
F. test	NS		*		*		*		NS		*	
S.Em±	0.09		0.023		0.03		0.085		0.09		0.12	
LSD(p = 0.05)	NS		0.065		0.09		0.24		NS		0.33	
CO_2												
***a*CO_2**	7.98		8.56		9.77		9.80		10.75		13.18	
***e*CO_2**	8.47		9.15		10.67		9.21		11.16		14.09	
F. test	*		*		*		*		*		*	
S.Em±	0.04		0.005		0.006		0.04		0.04		0.06	
CD(p = 0.05)	0.12		0.013		0.018		0.11		0.12		0.17	
Temperatures												
28 ± 1 ^oC	7.67		8.32		9.40		9.80		10.16		11.99	
29 ± 1 ^oC	7.93		8.61		9.90		9.45		10.58		12.78	
31 ± 1 ^oC	8.24		8.74		10.20		9.10		10.94		13.54	
33 ± 1 ^oC	8.50		8.89		10.60		8.68		11.32		14.50	
35 ± 1 ^oC	8.79		9.71		11.00		8.12		11.79		15.36	
F. test	*		*		*		*		*		*	
S.Em±	0.07		0.012		0.016		0.06		0.07		0.14	
CD(p = 0.05)	0.20		0.033		0.045		0.17		0.19		0.38	
CV (%)	5.48		5.00		4.76		3.07		3.42		4.58	

aCO_2 - 380 ± 25 ppm; *e*CO_2 - 550 ± 25 ppm
All values are mean ± standard deviation
* Significant at 5 % level; NS – Non significant

Table.3 Effect of sublethal concentrations of emamectin benzoate on larval and pupal duration of *Spodoptera litura* at *e*CO_2 and *e*Temp conditions

Interaction (CO_2 X Temp (^oC)	Pupal duration (days)						Larval duration (Days)					
	Control		LC_{10}		LC_{50}		Control		LC_{10}		LC_{50}	
	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 °C	8.86 ± 0.34	9.42 ± 0.44	11. 02 ± 0.51	12.09 ± 0.30	12.01 ± 0.48	13.12 ± 0.51	8.88 ± 0.53	9.98 ± 0.55	11.05 ± 0.47	12.25 ± 0.45	14.23 ± 1.05	15.98 ± 0.77
29 ± 1 °C	8.02 ± 0.41	8.88 ± 0.24	10.86 ± 0.56	11.76 ± 0.43	11.86 ± 0.38	12.11 ± 0.32	7.94 ± 0.52	9.08 ± 0.68	10.74 ± 0.60	11.94 ± 0.78	13.05 ± 0.70	14.94 ± 0.77
31 ± 1 °C	7.64 ± 0.49	8.12 ± 0.34	10.04 ± 0.66	10.61 ± 0.49	10.58± 0.50	11.88 ± 0.32	7.09 ± 0.63	8.28 ± 0.56	10.21 ± 0.71	11.09 ± 0.54	12.56 ± 0.60	14.28 ± 0.68
33 ± 1 °C	7.04 ± 0.49	7.74 ± 0.51	8.90 ± 0.30	9.89 ± 0.49	9.85± 0.38	10.67 ± 0.48	6.63 ± 0.36	7.95 ±0.63	9.95 ± 0.47	10.63 ± 0.56	11.98 ± 0.83	13.65 ± 0.86
35 ± 1 °C	6.52 ± 0.45	7.02 ± 0.79	8.01 ± 0.49	9.07 ± 0.32	9.10 ± 0.24	10.22 ± 0.42	6.00 ± 0.54	7.04 ± 0.85	8.95 ± 0.51	9.70 ± 0.52	11.02 ± 0.63	12.08 ± 0.56
F. test	*		*		*		7.09*		7.13*		*	
S.Em±	0.02		0.01		0.01		0.009		0.015		0.018	
LSD(p = 0.05)	0.05		0.03		0.04		0.024		0.041		0.049	
CO_2												
***a*CO_2**	9.07		8.76		9.68		8.45		10.18		12.57	
***e*CO_2**	10.27		9.78		10.55		5.96		11.12		14.19	
F. test	*		*		*		551.97*		535.04*		1258.97*	
S.Em±	0.004		0.002		0.003		0.002		0.003		0.003	
CD(p = 0.05)	0.011		0.006		0.008		0.007		0.008		0.010	
Temperatures												
28 ± 1 °C	8.10		8.54		9.66		9.39		11.65		15.11	
29 ± 1 °C	8.65		9.39		10.26		8.51		11.34		14.00	
31 ± 1 °C	9.56		10.32		11.23		7.68		10.65		13.42	
33 ± 1 °C	10.79		11.31		11.98		7.29		10.29		12.82	
35 ± 1 °C	11.27		11.80		12.49		6.52		9.33		11.55	
F. test	*		*		*		965.07*		405.35*		675.53*	
S.Em±	0.01		0.005		0.007		0.004		0.007		0.009	
CD(p = 0.05)	0.03		0.016		0.019		0.012		0.021		0.024	
CV (%)	5.38		2.08		2.08		2.23		2.64		2.22	

aCO_2 - 380 ± 25 ppm; *e*CO_2 - 550 ± 25 ppm

All values are mean ± standard deviation; * Significant at 5 % level; NS – Non significant

Table.4 Effect of sublethal concentrations of Thiodicarb on the pupal and larval duration of *Spodoptera litura* at *e*CO_2 and *e*Temp conditions

Interaction (CO_2 X Temp (^oC)	Pupal duration (days)						Larval duration (Days)					
	Control		LC_{10}		LC_{50}		Control		LC_{10}		LC_{50}	
	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 °C	8.39 ± 0.98	9.17 ± 0.95	9.00 ± 0.38	10.18 ± 0.51	11.21 ± 0.94	12.24 ± 0.90	8.58 ± 0.53	9.85 ± 0.56	9.86 ± 0.66	10.72 ± 0.51	12.06 ± 0.59	13.76 ± 0.53
29 ± 1 °C	7.86 ± 1.02	8.68 ± 0.79	8.65 ± 0.50	9.74± 0.48	10.32± 0.95	11.21 ± 0.93	7.92 ± 0.53	9.02 ± 0.52	8.82 ± 0.43	10.56 ± 0.49	11.43 ± 0.88	13.06 ± 0.51
31 ± 1 °C	7.13 ± 1.14	8.04 ± 0.69	8.01 ± 0.48	9.02± 0.36	9.86 ± 0.51	10.56 ± 0.83	7.36 ± 0.56	8.56 ± 0.63	8.36 ± 0.51	9.91 ± 0.56	10.56 ± 1.01	12.56 ± 0.70
33 ± 1 °C	6.96 ± 1.17	7.28 ± 0.60	7.24 ± 0.36	8.42± 0.57	8.96 ± 0.59	9.68 ± 0.47	6.99 ± 0.53	7.95 ± 0.25	7.98 ± 0.50	8.76 ± 0.38	9.93 ± 0.79	11.93 ± 0.83
35 ± 1 °C	6.02 ± 0.94	6.94 ± 0.72	6.92 ± 0.63	7.58± 0.70	8.24 ± 0.51	9.01 ± 0.47	6.25 ± 0.48	7.52 ± 0.56	7.04 ± 0.50	8.38 ± 0.46	9.06 ± 0.36	11.25 ± 0.25
F. test	NS		*		*		*		*		*	
S.Em±	0.018		0.048		0.015		0.007		0.067		0.024	
LSD(p = 0.05)	NS		0.134		0.042		0.020		0.187		0.057	
CO_2												
***a*CO_2**	7.29		7.94		9.72		8.86		9.69		10.61	
***e*CO_2**	8.10		8.96		10.53		7.74		8.41		12.53	
F. test	*		*		*		*		*		*	
S.Em±	0.004		0.021		0.003		0.001		0.030		0.004	
CD(p = 0.05)	0.011		0.060		0.009		0.004		0.084		0.011	
Temperatures												
28 ± 1 °C	8.74		9.52		11.73		9.62		7.71		12.92	
29 ± 1 °C	8.24		9.12		10.73		8.60		8.38		12.21	
31 ± 1 °C	7.61		8.52		10.21		8.31		9.12		11.62	
33 ± 1 °C	7.26		7.83		9.32		7.79		9.72		10.94	
35 ± 1 °C	6.61		7.25		8.63		7.19		10.31		10.16	
F. test	*		*		*		*		*		*	
S.Em±	0.009		0.034		0.007		0.003		0.048		0.02	
CD(p = 0.05)	0.025		0.094		0.027		0.009		0.132		0.06	
CV (%)	5.91		2.60		2.20		2.12		3.40		2.48	

aCO_2 - 380 ± 25 ppm; *e*CO_2 - 550 ± 25 ppm
All values are mean ± standard deviation
* Significant at 5 % level; NS – Non significant

Table.5 Effect of sublethal concentrations of monocrotophos on larval and pupal duration of *Spodoptera litura* at *e*CO_2 and *e*Temp conditions

Interaction (CO_2 X Temp (°C)	Pupal duration (days)						Larval duration (Days)					
	Control		LC_{10}		LC_{50}		Control		LC_{10}		LC_{50}	
	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 °C	8.48 ± 0.44	8.95 ± 0.32	9.28 ± 0.61	10.06 ± 0.42	11.02 ± 0.35	11.98 ± 0.35	8.71 ±0.38	9.05 ± 0.30	9.56 ± 0.45	10.49 ± 0.42	11.53 ± 0.51	12.56 ± 0.43
29 ± 1 °C	7.69 ± 0.30	8.06 ± 0.36	8.48 ± 0.37	9.02± 0.50	10.14 ± 0.49	11.02 ± 0.53	7.86 ± 0.41	8.62 ± 0.44	8.89 ± 0.50	9.42 ± 0.41	10.20 ± 0.38	11.80 ± 0.35
31 ± 1 °C	7.04 ± 0.36	7.64 ± 0.51	7.85 ± 0.51	8.48 ± 0.51	9.85 ± 0.25	10.24 ± 0.46	7.02 ± 0.36	7.72 ± 0.41	7.98 ± 0.40	9.00 ± 0.42	9.56 ± 0.42	10.53 ± 0.35
33 ± 1 °C	6.24 ± 0.46	7.14 ± 0.48	7.04 ± 0.61	7.98 ± 0.37	8.48 ± 0.41	9.58 ± 0.49	6.57 ± 0.40	7.06 ± 0.50	7.32 ± 0.51	8.84 ± 0.46	9.13 ± 0.41	10.00 ± 0.41
35 ± 1 °C	5.68 ± 0.41	6.86 ± 0.22	6.12 ± 0.48	7.04 ± 0.37	7.98 ± 0.52	8.48 ± 0.36	5.36 ± 0.46	6.26 ± 0.42	6.21 ± 0.32	7.54 ± 0.46	8.13 ± 0.35	9.24 ± 0.42
F. test	*		*		*		*		*		*	
S.Em±	0.074		0.014		0.022		0.093		0.023		0.032	
LSD(p = 0.05)	0.021		0.038		0.055		0.260		0.065		0.090	
CO_2												
***a*CO_2**	7.01		7.75		9.49		10.47		10.72		13.57	
***e*CO_2**	7.74		8.25		10.26		10.93		11.18		14.37	
F. test	*		*		*		*		*		*	
S.Em±	0.033		0.003		0.004		0.042		0.005		0.007	
CD(p = 0.05)	0.092		0.008		0.011		0.116		0.013		0.018	
Temperatures												
28 ± 1 °C	8.72		9.67		11.50		10.21		10.47		12.77	
29 ± 1 °C	7.88		8.75		10.58		10.40		10.71		13.57	
31 ± 1 °C	7.35		8.17		10.05		10.64		10.89		14.20	
33 ± 1 °C	6.72		7.51		9.03		10.90		11.16		14.50	
35 ± 1 °C	6.21		6.58		8.23		11.33		11.50		14.83	
F. test	*		*		*		*		*		*	
S.Em±	0.052		0.007		0.009		0.066		0.012		0.016	
CD(p = 0.05)	0.146		0.019		0.027		0.146		0.019		0.027	
CV (%)	4.61		3.17		2.94		4.61		3.17		2.94	

aCO_2 - 380 ± 25 ppm; *e*CO_2 - 550 ± 25 ppm
All values are mean ± standard deviation
* Significant at 5 % level; NS – Non significant

The pupal duration of *S. litura* treated with sublethal concentrations of all five tested insecticides prolonged the pupal durations, but with increase in temperature the pupal duration of larvae treated with emamectin benzoate, thiodicarb and monocrotophos was decreased. Whereas, the pupal duration was prolonged in the larvae treated with spinosad and fenv The prolonged pupal periods with increase in sublethal concentrations were in tune with the findings of Moustafa *et al.,* 2016 who reported prolongation of pupal duration by 5 days with increase in concentrations of spinosad from 0.005 to 0.5 µg/g. Zaka *et al.,* (2014) reported similar decrease in pupal duration of *S. litura* to 9.29 days after treated with emamectin benzoate compared to control (8.33 days). Similarly the findings of Saber *et al.,* (2013) and Su *et al.,* (2015) reported expended pupal periods after treated with thiodicarb and chloripyriphos, respectively.

The extended the larval and pupal durations of *S. litura* after exposure to sublethal concentration might be due to insecticide prevents insects from feeding, leading to insufficient nutrients for normal insect growth (Xu *et al.,* 2016). Lepidopteran larvae feeds voraciously especially in the final instar inorder to attain critical weight and for pupation. The larvae store enough food reserves and energy for metabolism and metamorphosis in the inactive stages of pupae (Chapman, 1968).In order to reach the critical weight, the larval period was prolonged under toxicant stress.

Temperature also significantly affected the growth and development of insects. The insects treated with emamectin benzoate, thiodicarb and monocrotophos exhibited shorter larval and pupal days with increase in concentration within temperature, with increase in temperatures from 28 to 35 ºC, This might be attributed due to increased metabolism at higher temperatures which may lead to more number of generations of *S. litura*. On the other hand compared to *a*CO_2, the larval and pupal periods were longer at *e*CO_2 might be due to negative effect of CO_2 on the metabolic rate or lower nutritional quality of foliage grown under *e*CO_2 (Nitin *et al.,* 2018).

Insects being poikilothermic organisms, their growth and development were significantly affected by temperatures. Elevated CO_2 and temperatures influenced survival and growth and development of *S. litura*. Higher consumption rates during elevated levels of CO_2 and temperature may cause more damage to crop yields. Insects exposed to sublethal concentrations for longer period of time often leads to resistance of pest to particular insecticides. The present study focused on the interactive effect of *e*CO_2 and *e*Temp on the development period of larvae and pupae of *S. litura* after treated with sublethal concentrations of insecticides. It is mandatory to consider sublethal effects of insecticides under warmer temperatures when pest control strategies were made.

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How to cite this article:

Deekshita, K., P.V. Krishnayya, M. Srinivasa Rao, P. Anil Kumar and Nafeez Umar, S. 2019. Effect of Sublethal Concentrations of Insecticides on the Larval and Pupal Duration of *S. litura* under *e*CO_2 and *e*Temp Conditions. *Int.J.Curr.Microbiol.App.Sci.* 8(07): 1668-1677.
doi: https://doi.org/10.20546/ijcmas.2019.807.198