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Variations in the Toxicity of Insecticides against *Spodoptera litura* (Fab.) at Elevated CO_2 and Temperature Conditions

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ABSTRACT

The effect of eCO_2 ad *e*Temp on the toxicity of insecticides viz., spinosad, emamecctin benzoate, thiodicarb, monocrotophos and fenvalerate against *S. litura* grown under different set conditions was studied. The efficacy of spinosad and fenvalerate decreased with increase in temperature under both aCO_2 and eCO_2 and exhibited negative temperature coefficient. The toxicity of spinosad decreased by 3.33 folds at eCO_2 over aCO_2 (3.07 folds) at temperature difference of 7°C (28 - 35°C), which indicated 3.07 and 3.33 times higher concentration of spinosad was required at 35°C than at 28°C of both aCO_2 and eCO_2 to achieve equal control levels. Similarly fenvalerate also exhibited negative relationship with temperature and 4.93 and 5.75 times higher insecticide concentration was required at warmer conditions. The insecticides emamectin benzoate, thiodicarb and monocrotophos were positively correlated with temperature. The lethality of emamectin benzoate (3.62 and 3.20 folds), thiodicarb (4.00 and 3.43 folds) and monocrotophos (4.10 and 3.43 folds) increased at the temperature difference of 7°C when compared with 28°C of both aCO_2 and eCO_2.

Keywords Climate change, Elevated carbondioxide, Elevated temperature, Lethal concentrations, Temperature coefficient.

INTRODUCTION

Global Mean Surface Temperature (GMST) and atmospheric CO_2 concentrations have been increasing at an alarming rate since 19th century. 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% when compared with pre-industrial levels. 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). Agriculture in future will inevitably face challenges in terms of production, productivity, herbivore damage and alteration in higher trophic levels. The prime drivers of climate change viz., elevated temperature (*e*Temp.)

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and carbondioxide (eCO$_2$) have lot of implications in agricultural sector, influencing crops and herbivore insect pests.

Sunflower (*Helianthus annuus* L.) an edible oilseed affected several biotic and abiotic stresses, among the biotic stresses, tobacco caterpillar, *Spodoptera litura* Fab. (Lepidoptera: Noctuidae) is a major insect pest causes total losses in crop yields (Bilapate and Chakravarthy 1999). Integration of cultural, physical, mechanical, biological and need based application of insecticides formed into IPM module for the management of *S. litura*.

Higher crop yields depend on adoption of effective plant protection measures. The efficacy of insecticides is influenced by variety of factors viz., type of insect pests (Sparks *et al*. 1982), metabolic activities of insects (Malik *et al*. 2018), detoxification enzymes and environmental conditions (Punzo and Kirk 1992). Temperature coefficients of the insecticides show the association between temperatures and insecticide toxicity and with a positive or negative temperature coefficients (Glunt *et al*. 2013).

Elevated temperature has prominent effect on insecticide effectiveness and results in breakdown of particular insecticide into either more or less toxic metabolites and may vary with type of insecticides. The influence of temperature is well documented (Mansoor *et al*. 2015, Teja *et al*. 2018) but on CO$_2$ is scanty. Reduced efficacy of insecticides under eCO$_2$ and *e*Temp conditions was reported due to altered metabolism or increasing insecticide detoxification (Matzrafi 2019).

It is predicted that incidence of *S. litura* would be higher in near and distant future climate change scenarios (Srinivasa Rao *et al*. 2015) and control of this pest is important to reduce the yield losses to ensure food security.The present pest control strategies need to be altered while selecting the appropriate insecticides during climate change scenario. The higher temperatures usually influence the efficacy of insecticides and often cause ‘differential toxicity’ either with ‘increased’ or ‘decreased’ toxic levels against insect pests and in turn effect the biochemical reactions (Srigiriraju *et al*. 2010). It was hypothesized that eCO$_2$ and *e*Temp influences the toxicity of insecticides and in turn may lead to frequent applications of insecticides. The estimation of temperature coefficients at eCO$_2$ and *e*Temp conditions will give scope for the future requirement of insecticide during climate change periods. This will help in framing pest control strategies.

MATERIALS AND METHODS

The experiment was conducted by using an unique facility Carbondioxide and Temperature Gradient Chambers (CTGC) which was designed realistically to study the combined impact of eCO$_2$ and *e*Temp which are the prime drivers of climate change. The chambers represent field like environment with higher CO$_2$ and temperature conditions which influence the crop growth and insect pests (Srinivasa Rao *et al*. 2018) and the facility has eight chambers with 30 meters length, 6 meters width and 4 meters height at center. The eight chambers represent different set conditions and are categorized as follows; two chambers with uniform concentrations of ambient CO$_2$ (aCO$_2$; 380 ± 25 ppm at 28ºC); two chambers with only elevated temperatures (‘*e*Temp’ of 29ºC, 31ºC, 33ºC and 35ºC); two chambers with elevated carbon dioxide and temperature (eCO$_2$ + *e*Temp, 550 ± 25 ppm at 29ºC, 31ºC, 33ºC and 35ºC) and two chambers with elevated CO$_2$ concentration (*e*CO2, 550 ± 25 ppm at 28ºC).

Maintenance of crop

Sunflower crop was sown in the CTGC chambers during June 2017 at ambient (380 ± 25 ppm at 28ºC), *e*Temp (29, 31, 33 and 35ºC), eCO$_2$ + *e*Temp (550 ± 25 ppm at 29ºC, 31ºC, 33ºC and 35ºC) and eCO$_2$ (550 ± 25 ppm; 28 ºC). Thirty days after sowing, the leaves of sunflower grown at respective conditions were used for conducting bioassays. The crop was maintained under insecticide free condition to facilitate the provision of untreated leaf in the bioassay experiments and to capture the impacts of eCO$_2$ and *e*Temp appropriately on test insect.

Maintenance of test insect

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

Preparation of insecticides

Five insecticides (Spinosad, Emamectin benzoate, Thiodicarb, monocrotophos and fenvalerate) with different mode of action were selected for testing the effect of *e*CO_2 and *e*Temp on their toxicity against *S. litura*. The required amount of insecticide for preparing one per cent stock solution was weighed accurately, further required working solutions were prepared following serial dilution technique. 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). The tender leaves of sunflower grown at respective set conditions dipped in the respective test insecticidal solutions for about 25 seconds and then shade dried at room temperature. Ten newly moulted third instar larvae were released for each concentration, at each set condition and the leaves dipped in distilled water was considered as untreated control. Initially bracketing was conducted for each insecticide at each set conditions with wider range of concentrations followed by narrow range to get mortality in the range of 15-95%.

Statistical analysis

The dead or moribund larvae of *S.litura* in each concentration at each set conditions was assessed at 24 h interval up to three days (24, 48 and 72 h after treatment HAT). The mortality at 72 HAT was considered as end point for the assessment of the toxicity of test insecticide as reported by (Fisk and Wright 1992). The per cent mortality in each concentration was calculated and corrected by Abbott's formula (Fleming and Ratnakaran 1985).

The per cent Mortality data recorded after 72 HAT was subjected to probit analysis (Finney 1971) by using Statistical Packages for Social Sciences (SPSS) to calculate LC_{50}, LC_{75} and $LC_{99.9}$ of all insecticides, with corresponding slope of regression lines, fiducial limits and chi-square values at each set conditions. The temperature coefficients of each individual insecticide were calculated as the ratio of higher LC_{50} to that of lower LC_{50} (Musser and Shelton 2005).

RESULTS AND DISCUSSION

In the current study, the impact of *e*Temp and *e*CO_2 were measured by estimating LC_{50} values and temperature coefficients of insecticides against *S. litura*.

Table 1. Effect of *e*CO_2 and *e*Temp on lethal concentrations (%) of spinosad against third instar larvae of *S. litura*. *a*CO_2 – 380 ± 25 ppm, *e*CO_2 – 550 ± 25 ppm. SE – Standard error. * χ 2 (chi square) values given in the above table are less than the tabular values and are homogenous. ** Temperature coefficient = Ratio of higher to lower LC_{50} value for 2 and 7°C difference in temperature. Lethal concentrations (LC) were recorded at 95% Fiducial limits.

Set conditions	LC_{50}	LC_{75}	$LC_{99.9}$	Slope (±SE)	χ2*	**Temperature coefficients 2ºC	7ºC
aCO_2 + 28 ºC	0.0026 (0.0022 - 0.0031)	0.0061 (0.0053 - 0.0074)	0.0520 (0.0340 - 0.0950)	1.94 (±0.15)	4.46		
aCO_2 + 29 ºC	0.0033 (0.0029 - 0.0038)	0.0074 (0.0064 - 0.0082)	0.0521 (0.0352 - 0.0699)	1.85 (±0.16)	5.55	-1.26	
aCO_2 + 31 ºC	0.0043 (0.0033 -0.0047)	0.0101 (0.0086 - 0.0120)	0.0989 (0.0892 - 0.1183)	1.87 (±0.20)	4.18	-1.24	
aCO_2+ 33 ºC	0.0058 (0.005 - 0.0066)	0.0135 (0.012 - 0.0151)	0.1042 (0.0912 - 0.1162)	1.65 (±0.21)	8.73	-1.41	
aCO_2+ 35 ºC	0.0083 (0.0074 - 0.0094)	0.0177 (0.0162 - 0.0240)	0.1321 (0.0120 - 0.1511)	1.54 (±0.29)	1.68	-1.43	-3.07

Table 1. Continued.

Set conditions	LC_{50}	LC_{75}	$LC_{99.9}$	Slope (±SE)	χ2*	**Temperature coefficients 2ºC	7ºC
eCO_2 + 28 ºC	0.0043 (0.0035 - 0.0053)	0.0108 (0.0094 - 0.0131)	0.0840 (0.0546 - 0.1022)	2.22 (±0.16)	7.35		
eCO_2 + 29 ºC	0.0055 (0.046 - 0.0060)	0.0123 (0.0111 - 0.0150)	0.0951 (0.0704 - 0.1162)	2.07 (±0.26)	8.85	-1.28	
eCO_2 + 31 ºC	0.0072 (0.0061 - 0.0077)	0.0153 (0.0131 - 0.0191)	0.1180 (0.0924 - 0.1240)	1.85 (±0.26)	7.76	-1.31	
eCO_2+ 33 ºC	0.0099 (0.0089 - 0.0111)	0.0201 (0.0170 - 0.0212)	0.1290 (0.1125 - 0.1320)	1.93 (±0.19)	7.84	-1.38	
eCO_2+ 35 ºC	0.0143 (0.1190 - 0.0140)	0.0251 (0.0207 - 0.0360)	0.1600 (0.1412 - 0.1820)	1.77 (±0.18)	8.41	-1.44	-3.33

The findings of the study indicated that LC_{50} values of selected insecticides varied significantly at both *e*Temp and *e*CO_2 levels.

The Lethal concentrations (LC_{50}, LC_{75} and $LC_{99.9}$) of tested five insecticides varied significantly across all conditions and the results were presented

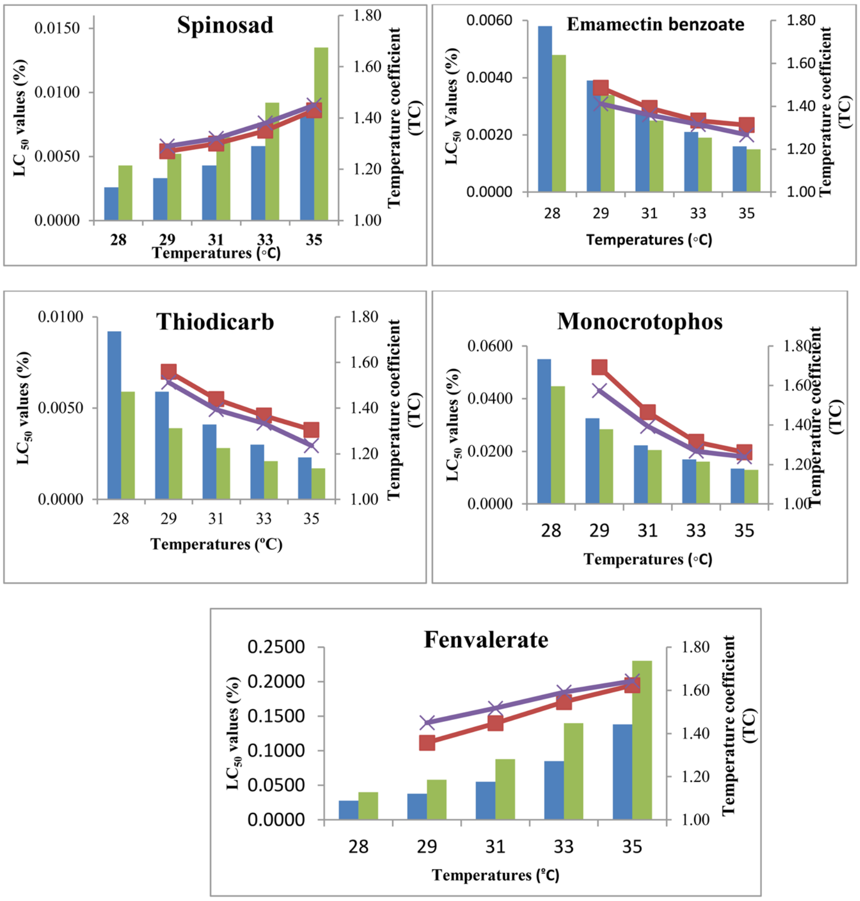

Fig. 1. Effect of *e*CO_2 and *e*Temp on the toxicity of insecticides aganist *S. litura.*

in Tables 1 - 5 and Fig. 1. The Lethal values (LC_{50}, LC_{75} and $LC_{99.9}$) of spinosad increased with increase in temperatures (28, 29, 31, 33 and 35 ºC) at *a*CO_2 (380 ± 25 ppm) and *e*CO_2 (550 ± 25 ppm) levels. The LC_{50} values of spinosad increased from 0.0033 to 0.0083 % with increase in temperature from 29 - 35ºC at *a*CO_2 and were higher than at reference (0.0026 %). Similar increase in LC_{50} values from 0.0055 to 0.0143% with increase in temperatures (29 - 35ºC) were noted at *e*CO_2 conditions and were higher than at *a*CO_2 and *e*Temp conditions (29 - 34 ℃) which indicated the higher reduction in efficacy at eCO_2 and eTemp conditions. Similar trend was noted with LC_{75} and $LC_{99.9}$ concentrations. Higher lethal concentrations of spinosad were recorded with increase in temperature from 29 to 35 ºC at both *a*CO_2 and *e*CO_2 and were higher than the LC_{50} values at reference (*a*CO_2 + 28ºC). Thus spinosad exhibited negative temperature coefficients of 3.07 to 3.33 folds with increase in 7ºC, temperature (28 - 35 ºC) at both *a*CO_2 and *e*CO_2 (Table 1). which indicated 3.07 and 3.33 times higher concentration of spinosad was required at 35°C than at 28°C of both *a*CO_2 and *e*CO_2 to achieve equal control levels.

The results obtained in other studies of spinosad toxicity to *Phenococcus solenopsis* (Mansoor *et al.* 2014) and *Ostrinia nubilalis* (Musser and Shelton 2005) indicate a similar pattern of toxicity. High temperature controls the activity of microbial insecticides, and similar observation of reduced lethality at higher temperatures was noted with spinosad since it was a microbial insecticide (Weinzierl *et al.* 1998). Further, the negative temperature coefficient of insecticides might be due to higher rate of excretion of parent compound by the test insect (Weston *et al.* 2009) and this might be the reason for reduced toxicity of spinosad at higher temperature.

The LC_{50} values of fenvalerate increased from 0.04 to 0.23% at eCO_2 with increase in temperatures from 28 - 35 ºC and were higher than the values at *a*CO_2 (0.028 - 0.138) and corresponding temperatures, showing the clear 'reduction of toxicity' of these

Table 2. Effect of *e*CO_2 and *e*Temp on lethal concentrations of fenvalerate against third instar larvae of *S. litura*. *a*CO_2 – 380 ± 25 ppm, *e*CO_2 – 550 ± 25 ppm. SE – Standard error, FL - Fiducial limits. * χ 2 (Chi square) values given are less than the tabular values and are homogenous. ** Temperature coefficient = Ratio of higher to lower LC_{50} value for 2ºC and 7ºC differences in temperature. Lethal concentrations (LC) were recorded at 95% Fiducial limits.

Set Conditions	LC_{50}	LC_{75}	$LC_{99.9}$	Slope (±SE)	χ2*	**Temperature coefficients	
						2ºC	7ºC
aCO_2 + 28 ºC	0.028 (0.022 - 0.033)	0.087 (0.0074 - 0.0107)	0.1448 (0.0892 - 0.1806)	1.48 (±0.11)	8.03		
aCO_2 + 29 ºC	0.038 (0.034 - 0.051)	0.108 (0.0107 - 0.0161)	0.1918 (0.1096 - 0.1371)	1.40 (±0.14)	10.70	-1.36	
aCO_2 + 31 ºC	0.055 (0.052 - 0.073)	0.191 (0.0159 - 0.0237)	0.2899 (0.2659 - 0.3735)	1.35 (±0.11)	7.19	-1.45	
aCO_2 + 33 ºC	0.085 (0.081 - 0.116)	0.312 (0.0259 - 0.0393)	0.5344 (0.3148 - 0.6028)	1.39 (±0.11)	6.91	-1.55	
aCO_2 + 35 ºC	0.138 (0.133 - 0.183)	0.448 (0.037 - 0.0568)	0.6818 (0.3486 - 0.6586)	1.33 (±0.12)	7.35	-1.62	-4.93
eCO_2 + 28 ºC	0.040 (0.026 - 0.038)	0.105 (0.087 - 0.13)	0.1857 (0.1106 - 0.2782)	1.48 (±0.11)	6.81		
eCO_2 + 29 ºC	0.058 (0.044 - 0.067)	0.137 (0.0134 - 0.019)	0.2024 (0.1255 - 0.25680	1.44 (±0.14)	9.79	-1.45	
eCO_2+ 31 ºC	0.088 (0.072 - 0.102)	0.257 (0.0217 - 0.0315)	0.3711 (0.2307 - 0.7092)	1.42 (±0.11)	3.43	-1.52	
eCO_2+ 33 ºC	0.140 (0.117 - 0.168)	0.347 (0.0364 - 0.0582)	0.7484 (0.4156 - 0.5382)	1.34 (±0.12)	8.01	-1.59	
eCO_2 + 35 ºC	0.230 (0.186 - 0.261)	0.653 (0.0540 - 0.0829)	0.9104 (0.7371 - 0.1052)	1.32 (±0.14)	6.86	-1.64	-5.75

insecticides with *e*Temp and *e*CO_2 interactive conditions. Increased lethal values at higher temperatures indicates negative temperature coefficient of -5.75 folds at *e*CO_2 over *a*CO_2 (4.93 folds) at temperature difference of 7ºC (28 - 35ºC).

This clearly indicated that 5.75 and 4.93 times higher concentration of insecticides required at warmer temperatures (35ºC) than at ambient temperatures (28ºC) of both levels of CO_2 (Table 2).

Reduced pyrethroid toxicity with increase in temperature was documented with several insect species viz., *Spodoptera frugiperda* (Punzo 1993), *Trichopulsia ni*, *S. frugiperda* and *Heliothis virescens* (Sparks *et al*. 1982); *Chilo suppressalis* (Li *et al*. 2006) and *Musca domestica* (Khan and Akram 2014). The possible reasons for the reduced toxicity might be due to at low temperatures, pyrethroid exposed neurons receive a high concentration of the toxicant due to reduced biotransformation (Salgado *et al*. 1989). The biotransformation of pyrethroids was by means of ester hydrolysis leads to formation of less toxic metabolites at higher temperatures (Harwood *et al*. 2009). Pyrethroids are the axonic poisons which controls the movement of sodium ions during nerve impulse. The sensitivity of neurons increase between 15 - 20°C, which causes repetitive nerve firing resulting higher mortality of insects whereas at temperatures 30 - 35 °C, reverse was reported (Song and Narahashi 1996). At elevated temperatures, reduced nerve firing leads to lower mortality of insects.

In contrast to the results obtained with the spinosad and fenvalerate the lethal values of emamectin benzoate against third instar larvae of *S. litura* decreased from 0.0058 to 0.0016% and 0.0042 to 0.0014% with enhancing temperatures from 28 - 35^{O}C at *a*CO_2 and *e*CO_2 thus reflecting higher toxicity of insecticide at higher temperatures under both levels of CO_2. Analogous trend was noted with LC_{75} and LC_{99} values. Higher toxicity of emamectin at higher temperatures indicate positive temperature coefficients of 3.20 folds and 3.62 folds with 7^{o}C increase

Table 3. Effect of *e*CO_2 and *e*Temp on lethal concentrations (%) of emamectin benzoate against third instar larvae of *S. litura*. *a*CO_2 – 380 ± 25 ppm, *e*CO_2 – 550 ± 25 ppm. SE – Standard error, FL – Fiducial limits. * χ 2 (chi square) values given in the above table are less than the tabular values and are homogenous. ** Temperature coefficient = Ratio of higher to lower LC_{50} value for 2 and 7 °C difference in temperature. Lethal concentrations (LC) were recorded at 95% Fiducial limits.

Set *C*onditions	LC_{50}	LC_{75}	$LC_{99.9}$	Slope (±SE)	χ2*	**Temperature coefficients	
						2ºC	7ºC
aCO_2 + 28 ºC	0.0058 (0.0048 - 0.0062)	0.0146 (0.0107 - 0.0233)	0.2849 (0.1259 - 1.0089)	1.28 (±0.14)	8.26		
aCO_2 + 29 ºC	0.004 (0.0036 - 0.0046)	0.0136 (0.0110 - 0.0142)	0.1688 (0.1428 – 0.1739)	1.27 (±0.14)	7.28	+1.45	
aCO_2 + 31 ºC	0.0028 (0.0026 - 0.0034)	0.0105 (0.0092 - 0.0109)	0.1484 (0.1292 - 0.1528)	1.29 (±0.14)	8.41	+1.43	
aCO_2+ 33 ºC	0.0021 (0.0019 - 0.0024)	0.0078 (0.0061 - 0.0085)	0.1137 (0.1082 - 0.1285)	1.30 (±0.14)	8.15	+1.33	
aCO_2+ 35 ºC	0.0016 (0.0014 - 0.0018)	0.0056 (0.0046 - 0.0059)	0.0775 (0.0562 - 0.0850)	1.45 (±0.12)	4.85	+1.31	+3.62
eCO_2 + 28 ºC	0.0042 (0.0035 - 0.0046)	0.0094 (0.0073 - 0.0133)	0.1548 (0.0784 - 0.4288)	1.35 (±0.14)	1.91		
eCO_2 + 29 ºC	0.0034 (0.0029 - 0.0034)	0.0083 (0.0081 -0.0092)	0.1384 (0.1184 - 0.1452)	1.35 (±0.14)	1.80	+1.41	
eCO_2 + 31 ºC	0.0025 (0.0019 - 0.0026)	0.0073 (0.0068 - 0.008)	0.1304 (0.1201 -0.1501)	1.32 (±0.12)	8.29	+1.36	
eCO_2+ 33 ºC	0.0019 (0.0016 - 0.0020)	0.0055 (0.0052 - 0.0062)	0.0902 (0.0712 - 0.1000)	1.36 (±0.12)	9.78	+1.32	
eCO_2+ 35 ºC	0.0014 (0.0012 - 0.0016)	0.0043 (0.0036 - 0.0049)	0.0498 (0.0362 - 0.0601)	1.44 (±0.12)	3.66	+1.27	+3.20

in temperatures from 28 - 35 ^{O}C at *e*CO_2 than *a*CO_2 (Table 3).

Analogous trend of increased toxicity of emamectin was also reported with other species viz., *Plutella xylostella* (Teja *et al*. 2018), *Sitophilus oryzae* (Malik *et al*. 2018) and *Diaphornia citri* (Boina *et al*. 2009). The increased mortality might be due to increase in physical activity of insects at higher temperature, enhancing the toxicity of avermectins (emamectin benzoate and abamectin) (Lin *et al*. 2013). At higher temperatures the insects treated with avermectins were more mobile on the treated surface and thus picking up more poisons, which leads to higher mortalities.

Similar to that observed with emamectin benzoate, the monocrotophos and thiodicarb insecticides showed positive correlation with temperature (Tables 4, 5). A similar increase in toxicity of both monocrotophos and thiodicarb was observed from 28 - 35ºC under both levels of CO_2. The LC_{50} values of monocrotophos decreased from 0.055 - 0.0134% and 0.0447 - 0.0128% with increase in temperature from 28 - 35ºC. The LC_{50} values of thiodicarb also decreased from 0.0092 - 0.0017% and 0.0059 - 0.0015% with rise in temperatures (28 - 35ºC) under *a*CO_2 and *e*CO_2. The toxicity of monocrotophos and thiodicarb was increased by + 4.10 and +4.00 folds at *a*CO_2 and + 3.47 and 3.43 folds at *e*CO_2 with 7ºC rise in temperature from 28 - 35ºC.

The $\chi 2$ values obtained in the study for all the insecticides across different set conditions indicated that the population of *S. litura* was homogenous as reflected in lower $\chi 2$ values than the tabular values at both levels of CO_2. The slope values were related with LC_{50} values and were varied with insecticides. Higher the slope value, higher is the mortality (Jyothi and Brewer 1999). The slope values of spinosad and fenvalerate were higher at lower temperatures than at higher temperatures which indicated lower mortality of target species at higher temperature vice versa with emamectin benzoate, monocrotophos and thiodicarb.

Table 4. Effect of *e*CO2 and *e*Temp on lethal concentrations (%) of thiodicarb against third instar larvae of *S. litura*. *a*CO_2 – 380 ± 25 ppm, *e*CO_2 – 550 ± 25 ppm. SE – Standard error, FL - Fiducial limits. * χ 2 (Chi square) values given are less than the tabular values and are homogenous. ** Temperature coefficient = Ratio of higher to lower LC_{50} value for 2 ºC and 7ºC differences in temperature. Lethal concentrations (LC) were recorded at 95% Fiducial limit.

Set conditions	LC_{50}	LC_{75}	$LC_{99.9}$	Slope (±SE)	$\chi 2$*	**Temperature coefficients	
						2ºC	7ºC
aCO_2+28ºC	0.0092 (0.0078 – 0.0131)	0.0512 (0.0357 – 0.0857)	0.348 (0.335 – 0.355)	0.830 (±0.107)	4.935		
aCO_2+ 29ºC	0.0059 (0.0053 – 0.0091)	0.0371 (0.024 – 0.069)	0.264 (0.248 – 0.284)	0.896 (±0.106)	1.783	+1.56	
aCO_2+31ºC	0.0042 (0.0038 – 0.0049)	0.0190 (0.0139 – 0.0309)	0.202 (0.190 – 0.228)	0.920 (±0.115)	0.464	+1.40	
aCO_2+33ºC	0.0031 (0.0029 – 0.0035)	0.0105 (0.0080 – 0.0148)	0.174 (0.168 – 0.182)	0.936 (±0.086)	1.159	+1.35	
aCO_2+35ºC	0.0017 (0.0012 – 0.0019)	0.0057 (0.0040 – 0.0091)	0.126 (0.112 – 0.138)	0.958 (±0.087)	10.260	+1.24	+4.00
eCO_2+28ºC	0.0059 (0.0049 – 0.0062)	0.0279 (0.019 – 0.048)	0.284 (0.265 – 0.295)	0.798 (±0.106)	4.100		
eCO_2+ 29ºC	0.0039 (0.0032 – 0.0045)	0.0227 (0.0158 – 0.0371)	0.192 (0.189 – 0.219)	0.835 (±0.086)	1.292	+1.51	
eCO_2+31ºC	0.0029 (0.0024 – 0.0030)	0.0110 (0.0084 – 0.019)	0.178 (0.162 – 0.185)	0.893 (±0.087)	1.528	+1.39	
eCO_2+33ºC	0.0022 (0.0016 -0.0024)	0.0106 (0.0069 – 0.0174)	0.148 (0.135 – 0.154)	0.932 (±0.084)	1.209	+1.33	
eCO_2+35ºC	0.0015 (0.0015 – 0.0019)	0.0047 (0.00327 – 0.00778)	0.106 (0.098 – 0.115)	0.920 (±0.895)	0.893	+1.24	+3.47

Table 5. Effect of *e*CO_2 and *e*Temp on lethal concentrations (%) of monocrotophos against third instar larvae of *S. litura*. *a*CO_2 – 380 ± 25 ppm; *e*CO_2 – 550 ± 25 ppm. SE – Standard error ; FL - Fiducial limits. * χ 2 (Chi square) values given are less than the tabular values and are homogenous. ** Temperature coefficient = Ratio of higher to lower LC_{50} value for 2 ºC and 7ºC differences in temperature. Lethal concentrations (LC) were recorded at 95% Fiducial limits.

Set conditions	LC_{50}	LC_{75}	$LC_{99.9}$	Slope (±SE)	$\chi2$*	**Temperature coefficients	
						2ºC	7ºC
aCO_2 + 28ºC	0.0550 (0.0445 - 0.0468)	0.0635 (0.0556 - 0.0782)	0.2075 (0.1460 - 0.3660)	2.91 (±0.32)	6.22		
aCO_2 + 29ºC	0.0325 (0.03 - 0.035)	0.0543 (0.0472 - 0.0691)	0.1915 (0.1669 - 0.2029)	2.67 (±0.23)	1.35	+1.69	
aCO_2 + 31ºC	0.0222 (0.0209 - 0.0236)	0.0388 (0.0352 - 0.0441)	0.1606 (0.1208 - 0.1495)	2.75 (±0.20)	4.20	+1.46	
aCO_2 + 33ºC	0.0169 (0.0155 - 0.0182)	0.0296 (0.0273 - 0.0327)	0.1176 (0.1037 - 0.1187)	2.87 (±0.30)	4.22	+1.31	
aCO_2 + 35ºC	0.0134 (0.0117 - 0.0149)	0.0231 (0.0211 - 0.0257)	0.0866 (0.0659 - 0.1000)	3.01 (±0.44)	1.23	+1.26	+4.10
eCO_2 + 28ºC	0.0447 (0.0281 - 0.0329)	0.0517 (0.0456 - 0.0623)	0.1908 (0.1748 - 0.2082)	3.21 (±0.39)	5.13		
eCO_2 + 29ºC	0.0284 (0.0263 - 0.03050	0.0472 (0.0423 - 0.0551)	0.164 (0.1503 - 0.1627)	2.45 (±0.23)	1.48	+1.57	
eCO_2 + 31ºC	0.0204 (0.0186 - 0.0221)	0.0358 (0.0327 - 0.0402)	0.1429 (0.1296 - 0.1506)	2.62 (±0.21)	1.69	+1.39	
eCO_2 + 33ºC	0.0161 (0.0155 - 0.0163)	0.0269 (0.0246 - 0.0301)	0.1044 (0.0981 - 0.1243)	2.75 (±0.23)	3.23	+1.27	
eCO_2 + 35ºC	0.0128 (0.0112 - 0.0135)	0.0209 (0.0195 - 0.0215)	0.0725 (0.0062 - 0.0085)	3.05 (±0.32)	1.45	+1.24	+3.43

CONCLUSIONS

The insecticides spinosad and fenvalerate exhibited negative temperature coefficient whereas the insecticides emamectin benzoate, monocrotophos and thiodicarb exhibited positive temperature coefficient. The positive temperature coefficient of insecticides, suggest that these insecticides might provide effective control of *S. litura* under higher temperatures and the inverse relationship between temperature and toxicity of spinosad and fenvalerate suggest that these insecticides perform better under lower temperatures. The findings of the present study have important implications for the management of *S. litura*.

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