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Effect of Elevated CO_2 on Population Dynamics of Beet Armyworm *Spodoptera Exigua* (Noctuidae: Lepidoptera) on Chickpea

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ABSTRACT

The potential population dynamics and potential consumption of four successive generations of beet armyworm, *Spodoptera exigua* (Hubner), fed on chickpea foliage grown under ambient and elevated CO_2 conditions in open-top chambers were examined. The larval survival rate and pupation rate were higher under elevated CO_2 compared to ambient CO_2 conditions. Significantly lower potential total eggs laid by all females, potential number of larval numbers and potential total larval consumption were found in the third and fourth generations of *S. exigua* fed on chickpea foliage grown under elevated CO_2 conditions. The integrative effect of higher larval mortality rate and lower fecundity resulted in significant decreases in potential population consumption in the latter two generations.

Key words: *Mortality rate and fecundity, Population dynamics, Spodoptera exigua.*

Atmospheric CO_2 concentrations had increased to as high as 380 ppm by 2005 and have been predicted to reach at least 550 ppm by the year 2050 and to double by the end of the 21st century due to continuing high levels of fossil fuel consumption and various agricultural practices. The increase in the amount of atmospheric CO_2 will be about 40 per cent compared with pre-industrial levels of 280 ppm (IPCC, 2007 and 2013). Because of the increasing concentrations of greenhouse gases, there is much concern about future changes in climate and its effect on the biology of living organisms including insects and agricultural crop plants (Garg *et al.*, 2001, Aggarwal, 2003 and IPCC, 2007).

Chickpea (*Cicer arietinum* L.) is a highly nutritious pulse crop with 38-59 per cent carbohydrates and 25.3-28.9 per cent protein (Hulse, 1991). Its response to enriched CO_2 conditions, chickpea being a C_3 crop, is more evident and significant. Increased photosynthesis and enhanced crop growth but lower nutritional qualities of crop plants were reported under eCO_2 conditions (Rogers *et al*., 2009; Abdul khadar *et al*., 2014). Among insect pests, the beet armyworm, *S. exigua* (Noctuiidae: Lepidoptera) is an important pest of numerous c**u**ltivated crops including cotton, tomato, celery, cabbage, onion and alfalfa in India (Singh and Bichoo, 1976). Recently the infestation of *S. exigua* is noticed at significant levels in different states of south India and is gaining major insect pest status on chickpea.

Limited information on the effect of elevated CO_2 on chickpea and *S. exigua* interaction is available. Much of the information on the response of insect herbivores to elevated CO_2 was dealt with single generation studies pertaining to the growth and development of insect pests. Multiple generation studies are required as they can effectively highlight the differential responses of the herbivores through successive generations (Lindroth *et al*., 1995). This information is useful to accurately estimate and develop insect models which are central to population dynamics.

MATERIAL AND METHODS

Studies on the population dynamics of *S. exigua* were conducted for four generations at both ambient CO_2 (aCO_2; 380 ± 25 ppm) and elevated CO_2 (eCO_2; 550 ± 25 ppm) conditions. Ten neonate larvae were reared in 110 mm diameter petridish (110 x 10 mm) with ten replications (total of 50 larvae per treatment). Fresh chickpea leaves obtained from the corresponding ambient and elevated CO_2 chambers were collected and the left over leaves were measured for their weight and to calculate the fed leaf weight and larval duration. The rate of pupation was recorded. To study the fecundity, the adults emerged from the sexed pupae were paired in separate plastic containers (15 x 15 x 15 cm) and were fed with 10 % honey solution through cotton swabs. The egg masses laid on the filter paper and inner wall of plastic containers were daily collected and counted.

The data was collected on various life history parameters *viz.*, larval survival rate, pupation rate, fecundity and egg hatching rate. These parameters were calculated for four generations at both CO_2 conditions. The data on life history parameters were used for estimating (ii) Total eggs laid by all females (i) Potential number of larval individuals (iii) Potential population increase index (PPII) and (iv) Potential total larval consumption (PTLC). Potential population dynamics and population consumption were estimated (Wu *et al*., 2006) for the second, third and fourth generation of *S. exigua* has given below

A. Total eggs laid by all females = Initial numbers of larval individuals X larval survival rate X pupation rate X rate of adult emergence X ratio of females X eggs laid per female

B. Potential no. of larval individuals for the 2nd (or) 3rd (or) 4th generation = Total eggs laid by all females in previous generation X hatch rate

C. Potential population increase index for the 2nd (or) 3rd (or) 4th generation = Total eggs laid by all females in previous generation / Total eggs laid by all females in this generation.

D. Potential total larval consumption (g) for 2nd (or)3rd (or) 4th generation = Potential initial numbers of larval individuals for second or third or fourth generation X larval survival rate X consumption rate per larvae

STATISTICAL ANALYSIS

The data on weight of foliage ingested, larval survival rate, fecundity and hatching rate were analyzed using ANOVA with CO2 and generations as sources of variability where CO2 level was main factor and generation as sub factor deployed in a split plot design. Differences between mean values were determined using an LSD test.

RESULTS AND DISCUSSION

The results pertaining to the studies on population dynamics of *S. exigua* in four generations on chickpea under ambient CO_2 (aCO_2) and elevated CO_2 (eCO_2) conditions were presented.

Life history parameters

Larval survival rate

The survival rates of *S. exigua* larvae did not vary significantly under varied CO_2 concentrations ($F_{1, 9}$=3.33, p=>0.05), but varied significantly in different generations ($F_{3, 9}$ = 14.46, P = <0.01). Lower and higher survival rates were observed in first generation (92.00 and 94.00 %), second generation (88.00 and 90.00 %), third generation (86.00 and 82.00 %) and fourth generations (76.00 and 78.00 %), respectively. The interaction between CO_2 concentrations and generations on survival rate was found non-significant ($F_{5, 9}$ = 0.08, P = <0.05) (Table 1). The results indicated that the survival rates decreased from one generation to next generation when the larvae grown under eCO_2 conditions. The present results are in conformity with findings of Akbar *et al* (2015), who reported that highest larval survival (50.00%) at the lowest carbon dioxide concentration of 350 ppm. These results are in agreement to those of Kangjam (2016) who also reported the larval survival rates of 95.00, 93.33 and 88.33 per cent were recorded at 350, 550 and 750 ppm CO_2 concentrations, respectively.

Pupation rate

The pupation rates of *S. exigua* varied significantly under the two test CO_2 concentrations ($F_{1, 9}$ = 8.34, p=<0.05) and for generations ($F_{3, 9}$ = 14.46, P = <0.01). Lower and higher pupation rates were observed in first generation (86.00 and 90.00 %), second generation (80.00 and 82.00 %), third generation (76.00 and 80.00 %) and fourth generation (70.00 and 74.00 %) under eCO_2 and aCO_2 conditions, respectively. The interaction between CO_2 concentrations and generations was found non-significant ($F_{5, 9}$ = 0.08, P = <0.05) (Table 1). The results indicated that the pupation rates were decreased from one generation to next generation when the larvae grown under eCO_2 conditions. These results are in agreement with findings of Akbar *et al* (2015), who reported that lower per cent of 29.33 at 550 ppm to 38.67 at 350 ppm at a constant temperature of 27±1°C in case of *H. armigera* larvae reared on a chickpea based semi-synthetic diet.

Fecundity

The fecundity of *S. exigua* varied significantly among CO_2 concentrations ($F_{1, 9}$ = 34.76, p=<0.01) and generations ($F_{3, 9}$ = 301.22, P = <0.01). The lower fecundity of 409.40, 446.80, 409.20 and 374.40 eggs were observed in first, second, third and fourth generations under eCO_2 conditions compared to aCO_2 conditions *viz.*, 423.40, 508.40, 432.00 and 406.00 eggs, respectively. The interaction between CO_2 concentrations and generations was found non-significant ($F_{5, 9}$ = 23.66, P = <0.01). Results revealed that the fecundity was reduced observed over generations under eCO_2 condition compared to that of aCO_2 conditions (Table 1). The reduction of fecundity capacity of *S. exigua* is due to cumulative effects of eCO_2 and the fecundity capacity is likely to be reduced even further in the next generation. Because precise nutritive requirements for success of most arthropod herbivores are not known (Heagle *et al*., 2002), it is possible only to guess which nutritive changes may have affected the fecundity capacity of *S. exigua*. Another important aspect is sequestration of food in the different developmental stages of holometabolous insects. Where the sequestration of larval food into pupal stage is significantly reflected to lower pupal weight under eCO_2 conditions and this could be the reason for lower fecundity and hatchability.

Hatching rate

The hatching percentage of *S. exigua* varied significantly among CO_2 concentrations ($F_{1, 9}$ = 94.16, p=<0.05) and generations ($F_{3, 9}$ = 80.57, P = <0.05). Lower and higher hatching percentage of *S. exigua* females were observed in first generation (92.20 and

95.28 %), second generation (90.65 and 93.83 %), third generation (86.40 and 89.40 %) and fourth generation (82.86 and 84.76 %) under eCO$_2$ and aCO$_2$ conditions, respectively. The interaction between CO$_2$ concentrations and generations was found non-significant ($F_{5, 9}$ = 0.36, P = <0.05). The results indicated lower hatching percentage of *S. exigua* was recorded under eCO$_2$ condition compared to that of aCO$_2$ condition. Present results are in agreement with findings of Liu *et al.* (2017) who reported that the highest hatching percentage (93.90 %) of *H. armigera* females observed under the aCO$_2$ compared to eCO$_2$ conditions.

Potential population dynamics and population consumption

The four parameters *viz.*, (i) Potential number of larval individuals (ii) Potential total eggs laid by all females (iii) Potential population increase index (PPII) and (iv) Potential total larval consumption (PTLC) were used to estimate potential population dynamics and population consumption for second, third and fourth generations of *S. exigua* fed on chickpea were furnished in Table 2.

Potential initial number of larval individuals

The potential number of larval individuals of *S. exigua* varied significantly from second generation to fourth generation of *S. exigua* when fed on chickpea foliage grown under eCO$_2$ conditions compared to aCO$_2$ conditions. The impact of eCO$_2$ was significant ($F_{1, 9}$ = 10.15, P =<0.05) and resulted lower number of potential initial number of larval individuals were produced under eCO$_2$ than aCO$_2$ conditions. Significant differences were observed across generations ($F_{1, 9}$ = 223.09, P =<0.01). In the first generation, the same number of larval individuals (10.00) were maintained under both eCO$_2$ and aCO$_2$ conditions. But thereafter significantly lower and higher potential initial numbers of larval individuals were recorded in second generation (1908.41 and 2152.20), third generation (50.40 **x**10^4 and 37.10 **x**10^4) and fourth generation (9102.86 **x**10^4 and 5927.17 **x** 10^4) under eCO$_2$ and aCO$_2$ conditions, respectively. The interaction between CO$_2$ concentrations and generation were found to be significant ($F_{5, 9}$ = 8.97, P =<0.01). Results indicated that the potential initial number of larval individuals was significantly lower in eCO$_2$ conditions than in aCO$_2$ conditions from second to fourth generations. The potential initial number of larval individuals decreased by 11.33 per cent in second generation, 26.39 per cent in third generation and 34.89 per cent in fourth generation under eCO$_2$ conditions.

Potential total eggs laid by all females

The potential total number of eggs laid by all females was significantly effected by CO$_2$ levels ($F_{1, 9}$ = 98.09, P =<0.01) and generations ($F_{3, 9}$ = 498.27, P =<0.05). The potential total number of eggs laid by all females of *S. exigua* varied significantly from first generation to fourth generation when fed on chickpea foliage grown under eCO$_2$ conditions compared to that of aCO$_2$ conditions. In first generation, lower potential total eggs laid by all females were recorded under eCO$_2$ conditions (2066.88) compared to aCO$_2$ conditions (2258.42). Similar trend of lower and higher potential total eggs laid by all females were recorded in second (41.07 **x** 10^4 and 53.74 **x**10^4), third (6871.40 **x**10^4 and 10192.08 **x**10^4) and fourth generations (915530.49 **x** 10^4 and 1570731.94 **x**10^4) under eCO$_2$ and aCO$_2$ conditions, respectively. The interaction between CO$_2$ conditions and generations was also found significant ($F_{5, 9}$ =36.46, P= <0.01).

Results indicated that the potential total number of eggs laid by all females was significantly lower in eCO$_2$ conditions than aCO$_2$ conditions from first generation to fourth generation. The potential total number of eggs laid by all females decreased by 8.48 per cent in first generation, 23.57 per cent in second generation, 32.58 per cent in third generation and 41.71 per cent in fourth generation under eCO$_2$ conditions.

Potential population increase index (PPII)

The PPII for successive generations was found lower under eCO$_2$ conditions compared to that of aCO$_2$ conditions. The PPII of *S. exigua* was significantly affected by CO$_2$ conditions ($F_{1, 9}$ = 80.21, P =<0.01) and generations ($F_{3, 9}$ = 110.40, P =<0.01). The PPII of *S. exigua* were lower under eCO$_2$ conditions than aCO$_2$ conditions in second (237.85 and 197.97), third (189.81 and 166.29) and fourth (154.11 and 134.03) generations, respectively. The interaction between CO$_2$ concentrations and generation were found to be non-significant ($F_{5, 9}$ = 3.33, P = >0.05). Results indicated that the PPII was significantly lower under eCO$_2$ conditions than aCO$_2$ conditions from second generation to fourth generation. PPII of *S. exigua* reduced by 16.77 per cent in second generation, 12.39 per cent in third generation and 13.03 per cent in fourth generation under eCO$_2$ conditions.

Potential total larval consumption (PTLC)

The PTLC for consecutive generations was found lower under eCO$_2$ conditions as compared with aCO$_2$ conditions. The PTLC of *S. exigua* showed significant differences across CO$_2$ conditions ($F_{1, 9}$ = 45.58, P =<0.01) and generations ($F_{1, 9}$ = 386.92, P =<0.01). Significantly different values of PTLC were recorded in first generation (10.35 and 9.47 g), second generation (1934.71 and 1734.24 g), third generations (37.24 **x** 10^4 and 40.25 **x** 10^4 g) and fourth generation (4398.19 **x** 10^4 and 5981.16 **x** 10^4 g) under eCO$_2$ and

Table 1: Effect of elevated CO_2 on life history parameters of *S. exigua* on chickpea in different generations

CO_2 Concentration (ppm)		Survival rate (%)	Pupation rate (%)	Hatching rate (%)	Fecundity
F1	*a* CO_2 (380 ppm)	94.00 ± 5.48	90.00 ± 4.48	95.28 ± 0.65	423.40 ± 5.59
	e CO_2 (550 ppm)	92.00 ± 8.36	86.00 ± 5.48	92.20 ± 2.35	409.40± 7.98
F2	*a* CO_2 (380 ppm)	90.00 ± 2.24	82.00 ± 4.47	93.83 ± 1.34	508.40 ± 6.27
	e CO_2 (550 ppm)	88.00 ± 4.47	80.00 ± 7.07	90.65 ± 2.25	446.80 ± 7.79
F3	*a* CO_2 (380 ppm)	86.00 ± 5.47	80.00 ± 7.07	89.40 ± 1.95	432.00 ± 8.86
	e CO_2 (550 ppm)	82.00 ± 4.47	76.00 ± 5.48	86.40 ± 1.14	409.20 ± 2.95
F4	*a* CO_2 (380 ppm)	78.00 ± 4.47	74.00 ± 5.48	84.76 ± 0.95	406.00 ± 4.95
	e CO_2 (550 ppm)	76.00 ± 5.48	70.00 ± 6.12	82.86 ± 0.34	374.40 ± 7.76
	F test	0.08NS	0.08NS	0.36NS	23.66**
	S.Em±	3.43	3.25	0.91	4.08
	CD (p= 0.05)	NS	NS	NS	8.97
	CD (p = 0.01)	NS	NS	NS	12.81
	CV (%)	5.05	4.81	1.02	1.32
Main factor - CO_2					
a CO_2 (380 ppm)		87.00	81.50	90.82	442.5
e CO_2 (550 ppm)		84.50	78.00	88.03	409.95
F test		3.33NS	8.34*	94.16*	34.76**
S.Em ±		1.37	1.21	0.29	1.78
CD (p = 0.05)		NS	3.36	0.8	4.94
CD (p = 0.01)		NS	NS	1.32	8.19
CV (%)		6.69	6.9	1.77	1.57
Sub factor- Generations					
F1		93	88	93.74	416.5
F2		89	81	92.24	477.6
F3		84	78	87.90	420.6
F4		77	72	83.81	390.2
F test		14.46**	14.60**	80.57**	301.22**
S.Em±		2.57	2.46	0.71	3
CD (p= 0.05)		5.29	5.08	1.46	6.19
CD (p= 0.01)		7.17	6.89	1.98	8.38

aCO_2 = Ambient CO_2; *e*CO_2 = Elevated CO_2
F1, F2, F3and F4 are the first, second, third and fourth generations
All values are mean ± standard deviation
*Significant @ 5 % level of significance
** Significant @ 1% level of significance
NS = Non-significant

Table 2 Effect of elevated CO_2 on potential population dynamics and potential population consumption of *S. exigua* in different generations on chickpea

Generation	Parameter	Ambient CO_2 (380 ppm)	Elevated CO_2 (550 ppm)	
F1	Initial no. of larval individuals	10 ± 0.001	10 ± 0.001	
	Total eggs laid by all females	2258.42 ± 117.23	2066.88 ± 299.21	
	Total larval consumption (g)	9.47 ± 0.35	10.35 ± 0.45	
F2	Potential initial no. of larval individuals	2152.20 ± 119.23	1908.41 ± 305.19	
	Potential total eggs laid by all females	53.74 $x10^4$ ± 4599.42	41.07 x 10^4 ± 7714.49	
	Potential Population increase index	237.85 ± 13.74	197.97 ± 12.82	
	Potential total larval consumption (g)	1734.24 ± 96.03	1934.71 ± 87.70	
F3	Potential initial no. of larval individuals	50.40 $x10^4$ ± 3.98 x 10^4	37.10 $x10^4$ ± 6.03 x 10^4	
	Potential total eggs laid by all females	10192.08 $x10^4$ ± 1605.58 x 10^4	6871.40 $x10^4$ ± 1605.58 x 10^4	
	Potential Population increase index	189.81 ± 10.70	166.29 ± 13.47	
	Potential total larval consumption (g)	40.25 x 10^4 ± 2.70 x 10^4	37.24 x 10^4 ± 7.07 x 10^4	
F4	Potential initial no. of larval individuals	9102.86 $x10^4$ ± 716.65 x 10^4	5927.17 x 10^4 ± 1342.68 x 10^4	
	Potential total eggs laid by all females	1570731.94 $x10^4$ ± 15026.72 x 10^4	915530.49 x 10^4 ± 18541.18 x 10^4	
	Potential Population increase index	154.11 ± 6.32	134.03 ± 5.95	
	Potential total larval consumption (g)	5981.16 $x10^4$ ± 268.77 x 10^4	4398.19 x 10^4 ± 708.33 x 10^4	
LSD p=<0.05 / 0.01		CO_2	Generations	CO_2 x Generations
Potential initial no of larval individuals		10.15*	223.09**	8.97**
Potential total eggs laid by all females		98.09**	498.27**	36.46**
Potential Population increase index		80.21**	110.40**	3.33^{NS}
Potential total larval consumption		45.58**	386.92**	34.97**

All values are mean ± standard deviation

F1, F2, F3and F4 are the first, second, third and fourth generations

*Significant @ 5% level of significance

**Significant @ 1 % level of significance

NS = Non-significant

aCO_2 conditions, respectively. The interaction between CO_2 concentrations and generation were found to be significant ($F_{5, 9} = 34.97$, $P = <0.01$). Results indicated that the PTLC was significantly increased by 9.29 and 11.56 per cent in first and second generations, respectively, but was significantly decreased by 7.45 and 26.47 per cent in third and fourth generations, respectively under eCO_2 over aCO_2 conditions.

Thus, significantly higher PTLC of *S. exigua* larvae under eCO_2 over aCO_2 conditions in first (9.29 %) and second generations (11.56 %). It generally explained as a response of herbivorous insects to reduced foliage quality, especially the reduction in nitrogen as reported in short term studies (e.g., one generation or a certain instar) (Du *et al*., 2004; Gao *et al*., 2008). Contrastingly, significantly lower PTLC of *S. exigua* larvae in third (7.45 %) and fourth generations (26.47 %). These results are agreement with the reports on more than one generation (Brooks and Whittaker, 1998 and 1999; Lindroth *et al*., 1995). Further, the decreased population consumption of *S. exigua* in the third generation, it could be attributed to lower fecundity and higher mortality under eCO_2 compared with aCO_2 conditions. Thus, the potential population dynamics and potential population consumption of *S. exigua* would exhibit lower fitness and cause less damages in the future scenarios with increasing CO_2 concentrations.

Present results are in agreement with findings of Wu *et al.* (2006) who reported that the potential larval numbers and consumption of *H. armigera* under eCO_2 were reduced by 8.81 per cent and 14.31 per cent in the second generation; 23.87 per cent and 23.77 per cent in the third generation, respectively. Potential population increase index values were 115 and 98.9 in the second generation, 113 and 85.8 in the third generation under eCO_2 treatment and aCO_2 treatment, respectively. These results also are in conformity with findings of Srinivasa Rao *et al*. (2013), who reported that the population consumption and number of larval individuals were observed to be significantly lower from second to fourth generations of *A. janata* when fed on castor foliage grown under eCO_2 when compared to the aCO_2 conditions. The potential larval individuals were reduced by 0.84, 12.15 per cent; 10.32, 29.34 per cent and 19.82, 43.13 per cent in second, third and fourth generations under 550 ppm and 700 ppm conditions, respectively. The potential total number of eggs laid by all females was significantly affected by CO_2 levels and generation. Similarly the potential population increase index for successive generations was found lower under eCO_2 conditions than those under aCO_2 conditions.

CONCLUSION

Measuring the development and food consumption over more than one generation provides a complete evaluation of eCO_2 effects and enable more meaningful predictions of pest population dynamics than experiments on single generation.

LITERATURE CITED

Abdul Khadar B, Prabhuraj A, Srinivasa Rao M, Sreenivas A G and Naganagoud A 2014 Influence of elevated CO_2 associated with chickpea on growth performance of gram caterpillar, *Helicoverpa armigera* (HUB.). *Applied Ecology and Environmental Research.* 12(2): 345-353.

Aggarwal P K 2003 Impact of climate change in Indian agriculture. *Journal of Plant Biology.* 30:189-98.

Akbar S M D, Pavani T, Nagaraja T and Sharma H C 2015 Influence of CO_2 and temperature on metabolism and development of *Helicoverpa armigera* (Noctuiidae: Lepidoptera). *Environmental Entomology*. 45: 229–236.

Brooks G L and Whittaker J B 1998 Responses of multiple generations of *Gastrophysa viridula* feeding on *Rumex obtusifolius*, to elevated CO_2. *Global Change Biology.* 4(1): 63-75.

Brooks G L and Whittaker J B 1999 Responses of three generations of a xylem feeding insect, *Neophilaenus lineatus* (Homoptera), to elevated CO_2. *Global Change Biology*. 5(4): 395-401.

Du L, Ge F, Zhu S R and Parajulee M N 2004 Effect of Cotton cultivar on development and reproduction of *Aphis gossypii* (Homoptera: Aphididae) and its predator *Propylaea japonica* (Coleoptera: Coccinellidae). *Journal of Economic Entomology.* 97(4): 1278-1283.

Gao F, Zhu S R, Du L, Parajulee M, Kang L and Ge F 2008 Interactive effects of elevated CO_2 and cotton cultivar on tri-trophic interaction of *Gossypium hirsutum*, *Aphis gossyppii*, and *Propylaea japonica*. *Environmental Entomology.* 37(1): 29-37.

Garg A, Shukla P R, Bhattacharya S and Dadhwal V K 2001 Sub-region (district) and sector level SO_2 and NOX emission for India: assessment of inventories and mitigation flexibility. *Atmospheric Environment.* 35: 703-713.

Heagle A S, Burns J C and Fisher D S 2002 Effects of carbon dioxide enrichment on leaf chemistry and reproduction by two spotted spider mites (Acari: Tetranychidae) on white clover [J]. *Environmental Entomology*. 34(4): 594-601.

Hulse J H 1991 Nature, composition and utilisation of grain legumes, In: Uses of tropical Legumes: *Proceedings of a Consultant Meetings*, 27-30 March 1989, ICRISAT Centre, Patancheru, India.

IPCC 2007 Climate change 2007: Synthesis Approach. Intergovernmental Panel on Climate Change. *Cambridge University Press*, Cambridge, UK.

IPCC 2013 Climate Change: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press*, Cambridge, UK.

Kangjam B 2016 Effect of varying levels of temperature and carbon dioxide on selected insect pests of vegetable. *Ph. D thesis.* Punjab Agricultural University, Ludhiana.

Lindroth R L, Arteel G E and Kinney K K 1995 Responses of three saturniid species to paper birch grown under enriched CO_2 atmospheres. *Functional Ecology*. 9: 306-311.

Liu J, Huang W, Chi H, Wang C, Hua H and Wu G 2017 Effects of elevated CO_2 on the fitness and potential population damage of *Helicoverpa armigera* based on two-sex life table. *Scientific Reports*. 7: 1-13.

Rogers A, Ainsworth E A and Leakey A D B 2009 Will elevated carbon dioxide concentrations amplify the benefits of nitrogen fixation in legumes?. *Plant physiology.* 151: 1009-1016.

Singh Y and Bichioo S L 1976 Bionomics of *Spodoptera exigua* (Hubner) on gram. *Indian Journal of Entomology.* 38 (2): 138 - 141.

Srinivasa Rao M, Srinivas K, Vanaja M, Manimanjari D, Ramarao C A and Venkateswarlu B 2013 Response of multiple generations of semilooper, *Achaea janata* feeding on castor to elevated CO_2. *Journal of Environmantal Biology*. 34(5): 877-883.

Wu G, Chen F J and Ge F 2006 Response of multiple generations of cotton bollworm *Helicoverpa armigera* Hubner, feeding on spring wheat, to elevated CO_2. *Journal of Applied Entomology*. 130(1): 2-9.

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