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Host Mediated Effect on *Spodoptera litura* Due to Climate Change

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A B S T R A C T

Changes in quality of host plants under elevated CO_2 (eCO_2) conditions likely in future can affect the survival, growth and development, and population dynamics of insect herbivores. The present study aimed to examine the growth and development of leaf feeding *Spodoptera litura* (Fabricius) (Noctuidae: Lepidoptera) reared on groundnut (*Arachis hypogaea* L.) grown under elevated CO_2 condition in open top chambers at Main Agricultural Research Station (MARS), University of Agricultural Sciences, Raichur, Karnataka, India. Significantly lower leaf nitrogen, higher carbon, higher relative proportion of carbon to nitrogen and higher phenols and tannins observed in the groundnut foliage grown under elevated CO_2 levels. This alteration in food quality significantly affected the growth parameters of *S. litura* in the form of increased food consumption, gain in larval weight and more faecal matter production due to extended larval duration, pupal duration. This resulted in reduced fecundity, particularly in the population raised under elevated CO_2 conditions compared to ambient condition. Further physiological parameters were recorded revealed increased approximate digestibility and relative consumption rate by the larva under elevated CO_2 condition coupled with reduced efficiency of conversion of ingested food and digested food. As a result, the relative growth rate was decreased under elevated CO_2 conditions. In a nutshell, it can be concluded that elevated CO_2 concentrations altered the quality of groundnut foliage and has the negative effect on the growth and development of *S. litura*.

Keywords

CO_2 concentration, Consumption, Groundnut, Foliage, Insect growth performence indices.

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Introduction

Climate change is closely linked with atmospheric concentration of CO_2, methane, nitrous oxide and other green house gases which are known to trap the heat from solar radiations. As the concentrations of green house gases increase, the overall temperature also increase resulting in differential precipitation leading to abrupt variation in crop productivity and herbivore action in agriculture. It is well established that the global atmospheric CO_2 level is increasing due to eater process (Berner, 1992) and biological activity (Watson *et al.*, 1991). It has been reported by federal agencies that CO_2 has been increased approximately 30 per cent since the industrial revolution which is believed to be responsible for an increase of about 0.66 °C in mean annual global surface temperature. Further, the temperature is anticipated to increase 1.4 to 5.8 °C by 2100 with equally increasing atmospheric CO_2, which is considered to be chiefly responsible for the greenhouse effect, which has increased from approximately 310 ppm in 1950 to about

400 ppm in the year 2011. This concentration is estimated to reach levels of 421 to 936 ppm by the end of the 21st century, according to forecasting models, depending on the magnitude of future human activities (IPCC, 2013).

Elevated CO_2 can directly stimulate plant growth, affect plant resource allocation and change plant tissue quality and it is consequently predicted to indirectly affect insect- herbivory. Increased CO_2 lead to decline in nutritional quality of host plant and affect the performance of herbivore insects (Whittaker, 1999). As nitrogen is an important limiting factor for phytophagous insects and reduce in per cent nitrogen alone may have potential effects on insect performance. Since, leaf nitrogen is considered to be imperative factor for growth and reproduction of insects, reduction in leaf nitrogen content in the plants grown under enriched CO_2 condition result in a nutritionally depleted food source for leaf eating insects (Lindroth *et al.*, 1993). As a result of which insect herbivores which feed on those plants will have increased consumption rate, developmental times, decreased fitness and fecundity (Feng *et al.*, 2010).

In general C_3 plants are more responsive to elevated CO_2, which lead to greater main shoot length, elongation of branches, individual leaf area per plant and dry mass. It is understood that accumulation of sugars and starch in the leaves of elevated CO_2 grown plants reflect higher photosynthetic carbon assimilation (Cure and Acock, 1986). So, to study the implications of climate change in terms of eCO_2 and temperature, groundnut was being as a C_3 plant and a representative of oilseed group. The groundnut is attacked by many species of insects that cause damage ranging from incidental feeding to near total plant destruction and yield loss. Among the damaging species, the tobacco armyworm, *S. litura* (Fab.) is a major pest and can cause yield losses of 35-55 % (Wightman and Ranga Rao, 1994). Since groundnut is one of the important oil seed crop, the studies on the effect of elevated CO_2 and temperature would alter the growth and development of herbivore, *S. litura*. So, to investigate the response of groundnut crop to climate change in turn its effect on pest herbivory.

Materials and Methods

Open top chamber

Four circular open top chambers (OTC's) with a dimension of five meter diameter and four meters height constructed at MARS, Raichur were used for the present investigations. The structure of OTC was fabricated with aluminium round shaped frame installed on the ground covered with double walled six mm thick polycarbonate sheets, which traps air within, providing thermal insulation and have more than 82 per cent transmittance of light. Chambers were equipped with a frustum at the top to deflect air and prevent dilution of the desired CO_2 concentrations within the chamber. The top of chamber was kept open to provide the near natural conditions.

To maintain the above said conditions, pure CO_2 mixed with ambient air was supplied to the chambers and maintained at set levels using manifold gas regulators, pressure pipelines, solenoid valves, rotameters, sampler, pump and CO_2 analyzer. The opening and closing of these valves were regulated on the basis of actual concentration of CO_2 within the OTC and the set CO_2 level for that particular OTC which was regulated by PC through linked Program Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA) system (www.neogenesisengg.com).

The temperature was maintained using infrared radiations mounted two meters above canopy. The computer with uninterrupted power supply was established for uninterrupted data recording and storing. Each chamber was fitted with sensors to measure temperature and relative humidity and this facilitated the continuous monitoring of temperature, CO_2 and relative humidity. The data was continuously recorded for the temperature, relative humidity and actual CO_2 concentration in ppm and displayed on the monitor continuously.

The eCO_2 and temperature (abiotic factors) were considered as the main treatments in the present investigations. Each OTC was considered as a treatment for this study and the set of treatments designed as the recommendations of IPCC, (2013) are as follows.

T_1: Ambient CO_2 of 390 ± 25 ppm with 2º C rise in temperature.
T_2: Elevated CO_2 of 550 ± 25 ppm.
T_3: Elevated CO_2 of 550 ± 25 ppm with 2º C rise in normal temperature.
T_4: Reference OTC
T_5: Reference plot (as saturated chek)

Popular groundnut variety TMV-2 was raised in cement pots of size 1×1 ft and as recommended package of practices in the OTC

Biochemical analysis of groundnut foliage

Leaves of chickpea from respective OTCs were analyzed to estimate carbon, nitrogen, C: N ratio and phenol content through standard procedures. To estimate carbon, nitrogen, phenol and tannins content, leaf samples taken from 60 days old plants were dried at 80 °C and subsequently ground to powder. Organic carbon was estimated by dry combustion method Nitrogen content by using Micro-Kjeldahl technique, discovered by McKenzie (1994), and proteins by Lowry's method.

Feeding trails

On the day of initiating feeding trail, freshly hatched neonates were kept in Petriplates of 110 mm ×10 mm. Twenty neonates were used in each Petriplate forming one replication. Four such replications were maintained for each CO_2 conditions (treatments). Fully matured groundnut leaves obtained from each treatment was weighed separately and given to larvae in Petriplates. These Petriplates placed in the growth chamber in which temperature, RH, light intensity and day/night length was maintained 25±2º C, RH of 75-80 per cent with a 14-h day/10-h night cycle respectively. Every day, Petridishes were taken out, the weight of larvae was recorded, and the larvae were placed back into the Petridish and provided with known quantity of leaves. The leaf bits remained after feeding was weighed separately and the fecal matter excreted by larvae was separated and weights were recorded. Once larvae entered third in star they were transferred to breadbox size of 8×4 inch and covered with muslin cloth to provide proper space for larvae. One larvae from each replication at each instar was taken out and preserved for morphometric measurement.

After cessation of feeding, prepupa were collected and transferred to plastic jars of size 10 cm ×10 cm. containing sand. Total larval duration was calculated from date of hatching to pupation. Pupal weight was recorded about 12h after pupation.

The rate of pupation and pupal duration was calculated as the date of pupation to emergence of adults. Sexing was done at the pupal stage to differentiate male and female. In each treatment, four pairs of *Spodoptera* *litura* were used to study reproductive biology. Each pair was kept in separate container and fed with honey solution. The container was closed with clothes to facilitate oviposition eggs laid on clothes were collected with the help of camel hair brush and counted. The morphometric measurements of larvae and adults were recorded with the help of microscopic image analyser fitted with camera along with monitor.

Various insect performance indices were determined by using the data relating to larval body, amount of food ingested and fecal matter excreted (Waldbauer, 1968). Relative growth rate (mg mg^{-1} day^{-1}), relative consumption rate (mg mg^{-1} day^{-1}), efficiency of conversion of ingested food, efficiency of conversion of digested food and approximate digestibility were computed.

Statistical analysis

The effects of CO_2 treatment on larval parameters were analyzed using one way ANOVA. Treatment means were compared and separated using least significant difference (LSD) at $p < 0.01$. The data on larval weight, larval duration, pupal weight, pupal duration, moth emergence, fecundity were analysed using ANOVA.

Results and Discussion

Biochemical analysis of groundnut foliage

Carbon and C: N ratio content was significantly highest (46.95 % and 14.29 %) in eCO_2 (550 ppm). The same parameters were recorded significantly lowest in rest of the treatments. In contrast, nitrogen and protein content was significantly highest (3.88 % and 4.00 mg/g) in reference plot and significantly least in eCO_2 (550 ppm) treatment (3.18 % and 3.45 mg/g) (Figure 1).

Larval growth performance

Relative consumption rate for *S. litura* differed significantly among five treatments. Highest consumption rate of 285.59 mg g^{-1} d^{-1} was noticed in eCO_2 +eTemperature (550 ppm + 2ºC). The drastic reduction in RCR of 270.35 mg g^{-1} d^{-1} was observed under reference plot. Significantly highest AD of 77.13 per cent was recorded in eCO_2 +eTemperature (550 ppm + 2ºC) followed by 76.31 per cent in eCO_2 (550 ppm). The lowest AD of 73.83 per cent was found in reference plot followed by 74.55 per cent in reference OTC (390ppm). Significantly highest ECI of 47.59 per cent was noticed under reference plot which was significantly superior over eCO_2. The lowest ECI of 41.65 per cent was recorded in eCO_2 +eTemperature (550 ppm + 2ºC). The results revealed that, reference plot registered significantly highest ECD of 64.53 per cent. The least ECD of 54.04 and 56.40 per cent was recorded under eCO_2 +eTemperature (550 ppm + 2ºC) and eCO_2 (550 ppm), respectively. Significantly highest RGR of 128.50 mg g^{-1} d^{-1} was recorded in reference plot followed by 125.95 mg g^{-1} d^{-1} reference OTC (390 ppm). On the contrary, significantly lowest RGR of 118.76 and 120.06 mg g^{-1} d^{-1} was recorded in eCO_2 +eTemperature (550 ppm + 2ºC) and eCO_2 (550 ppm) respectively (Table 1).

Significantly highest leaf consumption by *S. litura* during its entire larval period was noticed when it fed on groundnut foliage grown under eCO_2 +eTemperature (550 ppm + 2ºC) treatment 3758.07 mg. Least consumption (3341.28 mg) was recorded in reference plot. Significantly highest faecal matter (893.72 mg/larvae) was produced by the larvae fed on groundnut foliage grown under eCO_2 +eTemperature (550 ppm + 2ºC) treatment. While, the same parameter registered was significantly least in reference plot (884.38 mg/larvae). A significant difference in growth and development of *S. litura* observed when fed with groundnut leaves grown under climate changed conditions. Larval weight differed significantly across all treatments. Higher larval weight gain, 2678.01 mg per larvae recorded under eCO_2 +eTemperature (550 ppm + 2ºC) which was non- significantly differed with eCO_2 (550 ppm) treatment (2656.98 mg/larvae) and the corresponding values were significantly lower, 2613.95 mg per larvae in reference plot followed by reference OTC (2617.28 mg/larvae) (Table 2).

Larval duration extended significantly under eCO_2 +eTemperature (550 ppm + 2ºC) treatment (22.8 d) and shorter larval duration recorded under reference plot (20.575 days) followed by (21.025 d) under reference OTC (390ppm). Similarly, pupal duration was shorter in reference plot (6.20 d). Significantly longer pupal duration was seen in eCO_2 +eTemperature (550 ppm + 2ºC) treatment (8.38 d). The results on the influence of elevated CO_2 and temperature on weight of pupa revealed that, there was significant difference with respect to the pupal weight of *S. litura* in all the treatments. Reference plot registered significantly highest pupal weight of 0.81 g and significantly least pupal weight recorded under eCO_2 +eTemperature (550 ppm + 2ºC) treatment (0.52 g) (Table 2).

There was significant difference in fecundity of *S. litura* in all the treatments. Reference plot recorded significantly maximum fecundity (520.67 eggs/female) followed by (510.25 eggs/female) in reference OTC (390 ppm). A significant decrease in the fecundity was noticed under eCO_2 treatments. The lowest fecundity (484.94eggs/female) was recorded in eCO_2 +eTemperature (550 ppm + 2ºC) (Table 2). Alteration in phytochemistry of plants under the elevated CO2 concentrations is well documented (Hunter, 2001). Elevated CO_2 increases biomass, reduces foliar nitrogen and increases C: N ratio for most plants, especially C_3 crops (Chen *et al.,* 2005). Likewise, eCO_2 generally decreases nitrogen concentrations and increases phenolic and carbohydrate concentration and C: N ratios (Lindroth, 2010) but decline in leaf nutritional quality (especially N). Similar change was observed in the present study also wherein, biochemical analysis of groundnut foliage, a C_3 plant revealed a significant reduction in leaf nitrogen, protein when grown under eCO_2 (550 ppm) compared to reference plot.

Carbon, C: N ratio, phenol and tannin was significantly highest in eCO_2 (550 ppm) and least in aCO_2 + eTemperature (390 ppm + 2 ºC) treatment. Similar result was observed by Abdul *et al.,* (2014) in chickpea.

Leaf nitrogen concentration is the key factor that affects the consumption, digestion, growth, development and the reproduction of herbivorous insects (Williams *et al.,* 1994 and Saxon *et al.,* 2004). Most of chewing insects exhibit compensatory increase in food consumption (Lee *et al.,* 2002). Insects, when fed on plants grown under elevated CO_2, were shown to increase their individual consumption due to poor food quality of plants (Coviella *et al.,* 2002; Hunter, 2001).

Since nitrogen is the chief constituent of proteins and is evident that groundnut plants grown under elevated CO_2 concentrations have lower protein content in their tissues, which might result in poor nutritional quality of food. If the nutritional quality of the food is low, it would try to compensate through higher consumption and intake.

In the present study, due to poor quality of the food increased food consumption by the larvae when fed on groundnut leaves grown under elevated CO_2 condition compared to ambient.

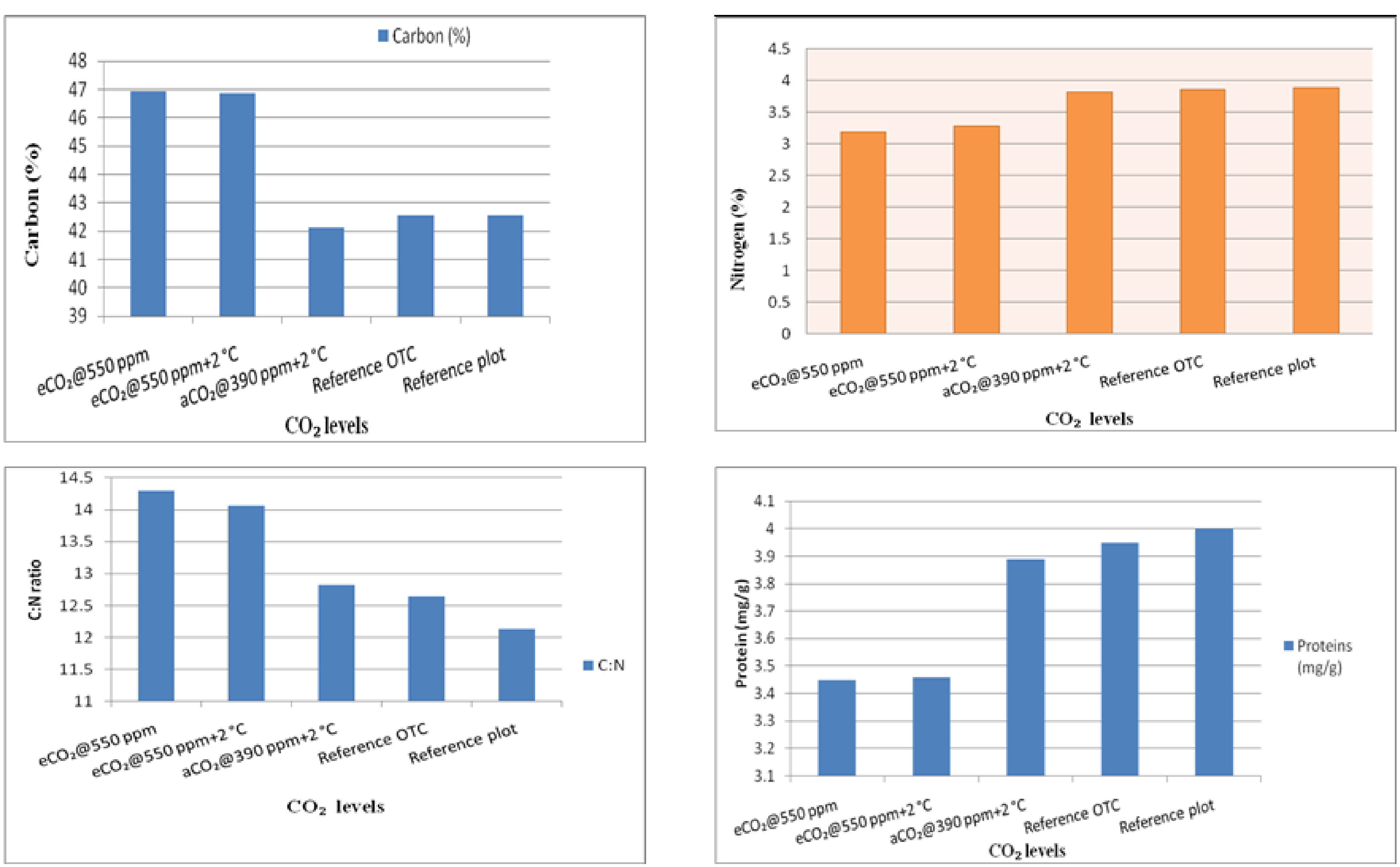
Table.1 Groundnut mediated effect of eCO_2 and temperature on growth performance or indices of *S. litura*

Treatment	Approximate digestibility (%)			Efficiency of conversion of ingested food (%)			Efficiency of conversion of digested food (%)			Relative growth rate (mg g^{-1} day^{-1})			Relative consumption rate (mg g^{-1} day^{-1})		
	Sept.	Oct.	Mean	Sept.	Oct.	Mean	Sept.	Oct.	Mean	Sept.	Oct.	Mean	Sept.	Oct.	Mean
eCO_2 (550ppm)	76.51	76.10	76.31	41.34	44.67	43.01	54.10	58.69	56.40	114.18	125.94	120.06	277.11	281.83	279.47
eCO_2+eTemp.(550ppm+2^0C)	77.31	76.95	77.13	39.94	43.35	41.65	51.73	56.34	54.04	113.14	124.38	118.76	284.34	286.83	285.59
aCO_2+eTemp.(390ppm+2^0C)	75.78	74.89	75.34	42.50	46.62	44.56	56.03	62.04	59.04	115.28	128.59	121.94	272.00	275.75	273.88
Reference OTC	75.09	74.00	74.55	44.04	48.55	46.30	58.71	65.60	62.16	119.13	132.76	125.95	271.30	273.44	272.37
Reference plot	74.42	73.24	73.83	45.20	49.98	47.59	60.79	68.26	64.53	122.00	135.00	128.50	270.57	270.12	270.35
CV (%)	2.33	2.66	2.50	3.76	3.30	3.53	2.26	2.95	2.61	2.73	2.39	2.56	2.35	2.56	2.46
S.Em±	0.40	0.31	0.36	0.80	0.77	0.79	0.64	0.56	0.60	1.59	1.55	1.57	2.54	2.98	2.76
CD(P=0.01)	1.66	1.29	1.48	3.34	3.21	3.28	2.65	2.35	2.50	6.64	6.45	6.55	10.56	12.42	11.49

Table.2 Groundnut mediated effect of elevated CO_2 and temperature on growth parameters of *Spodoptera litura*

Treatment	Total consumption (mg)	Fecal matter (mg)	Larval weight (mg)	Larval duration (d)	Pupal weight (g)	Fecundity (No.)
eCO_2 (550ppm)	3606.47	891.74	2656.98	22.38	0.66	498.25
eCO_2+eTemp.(550ppm+2°C)	3758.07	893.72	2678.01	22.80	0.52	484.94
aCO_2+eTemp.(390ppm+2°C)	3521.08	889.78	2645.53	21.95	0.56	487.35
Reference OTC	3365.47	885.27	2617.28	21.03	0.76	510.25
Reference plot	3341.28	884.38	2613.95	20.58	0.81	520.67
C V (%)	3.53	2.86	2.38	3.16	2.86	2.72
S.Em±	3.05	1.28	2.73	0.34	0.01	2.17
CD(P=0.01)	12.7	5.33	11.38	1.43	0.04	9.04

Fig.1 Effect of eCO_2 and temperature on biochemical constituents of groundnut



Further in spite of increased food consumption, relative consumption and AD, the gain in larval weight more compared to ambient. This could be attributed to lower protein content and higher C and C: N ratio in the plant tissues resulting in reduced efficiency in the conversion of ingested and digested food by the larvae fed on leaves of groundnut grown under elevated CO_2 compared to ambient.

Due to poor efficiency of both ingested and digested food, much of the food consumed was resulted in higher quantity release of fecal matter under elevated CO_2 compared to rest of treatments. Similar observations were made by Srinivasa *et al.*, (2014) in *S. litura*.

In the present study, an increase in developmental time with decreased pupal duration and pupal weight was observed when larvae of *S. litura* were reared from hatching to pupation on elevated CO_2 grown groundnut crop, similar trend of results recorded by Srinivasa *et al.,* (2014) in *S. litura*. Hence, alteration in plant phytochemistry due to change in CO_2 and temperature have been shown to have lower growth rate, slow larval developmental time and increase compensatory feeding for herbivorous insects (Fajer *et al.,* 1989; Lincoln *et al.,* 1993).

There is general prediction that the fecundity is the most common parameter for determining the larval food quality on performance of the insect. A significant reduction of fecundity was recorded under elevated CO_2 treatment compared to ambient. Similar observations made by Srinivasa *et al.*, (2014) who have reported that, reduced fecundity of *S. litura* fed on groundnut leaves grown under elevated CO_2 compared to ambient CO_2 which is mainly due to dilution of biochemical constituents especially nitrogen which is mainly responsible for reproduction. Succinctly, if we put together the above results, it is understood that the dilution of bio chemical constituents of groundnut caused poor growth, development and fecundity of *S. litura* under elevated CO_2 conditions. Based on the present study, it can be speculated that, the growth performance of *S. litura* under elevated CO_2 conditions, affects badly resulting in poor perpetuation of the population which may reduce its fitness in subsequent generation.

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