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GROWTH RESPONSES OF HOT CHILLI (*Capsicum chinense* JACQ.) TO ELEVATED CARBON DIOXIDE AND TEMPERATURE

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KEYWORDS

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Leaf area index

Leaf area duration

Specific leaf weight

Root: Shoot

ABSTRACT

The current study was carried out to evaluate the response of hot chilli (*Capsicum chinense* Jacq.) to elevated CO₂ and temperature for two consecutive years by using CTGT (Carbon dioxide Temperature Gradient Tunnel) technology at Assam Agricultural University, Jorhat. Hot chilli plants were grown at different conditions viz. ambient (open condition); CTGT I (380 ppm CO₂ and ambient temperature); CTGT II (550 ppm CO₂ + 2°C temperature elevation from CTGT I) and CTGT III (750 ppm CO₂ + 4°C elevation from CTGT I). Results of the study revealed that plants grown at CTGT II and CTGT III recorded a significant increase in root: shoot ratio, leaf area index (LAI), leaf area duration (LAD) in both the year of experimentation. An increase in specific leaf weight (SLW) and a decrease in specific leaf area (SLA) was observed due to the elevation of CO₂ and temperature at CTGT II. A highly significant positive correlation ($r = 0.997$) was obtained between SLW and LAI. Further, LAD showed a significant positive correlation ($r = 0.968$) to fruit yield per plant. Regression analysis revealed 79.1 % contribution of LAD to the fruit yield. Amongst the two cultivars (cv. Manipur and cv. Assam), cv. Manipur performed better in terms of morphological and growth parameters under elevated carbon dioxide and temperature conditions. This indicates the differential responses of hot chilli genotypes under future climate change conditions. Thus, the current study documented that elevated CO₂ @ 550 ppm and 2°C temperature may favor the production of Bhut Jolokia due to enhanced assimilation of CO₂.

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1 Introduction

Carbon dioxide is a potent greenhouse gas that plays a vital role in regulating the earth's surface temperature through the greenhouse effect (Petty, 2004). High CO₂ concentrations, plus water vapor would increase the global mean surface temperature by 3–5°C in 2100 (IPCC, 2014). With the beginning of the industrial era, a rise of 100 µmol mol⁻¹ CO₂ has been recorded and it has been predicted that the rise in the rate will be approximately 2 µmol mol⁻¹ per year. Due to this, warming of more than 6°C is expected in the 21st century under some scenarios. The increase in temperature is related to elevation in CO₂ (ACIA, 2004; Solomon et al., 2007). In the global climate change situation, the associated elevation in the temperature is a significant abiotic stress. A change in carbon dioxide concentration in the atmosphere might have a significant effect on photosynthesis (Van der Kooi, 2016).

The crop used in the current study was hot chilli or bhut jolokia or king chilli (*Capsicum chinense* Jacq.), which is an important medicinal and spice crop (Rudrapal & Sarwa, 2020). India is the biggest producer and exporter of chilli and annually India produced around 35000 tons of chilies worth Rs. 80 corer in every year (Tiwari et al., 2005). The NE region of India has a unique high humidity environment and is considered a 'hot spot' of biodiversity. It has given rise to the world's hottest chilli, 'Bhut Jolokia' (Guinness Book of World Records, 2006). *Capsicum* plant growth depends on the soil temperature and it ranges from 20–22°C. Moreover, a night temperature of 18–27°C is crucial for its fruit development (Purkayastha et al., 2012). The reproductive stage is more sensitive to heat stress, causing impaired fertilization, as a result, abortion of flowers occur (Bhattacharya, 2019). Similar to bell pepper, bhut jolokia is very much sensitive to high temperature and reduced fruit set with an increase in temperature (Erickson & Markhart, 2002) which leads to lower yield and less return. Thus it is important to study the interactive effect of the elevated CO₂ and high-temperature stress, on the morphology and growth parameters of *Capsicum* species collected from Assam and Manipur in the present investigation and to identify a suitable cultivar for growing under the present scenario of climate change.

2 Materials and Methods

2.1 Experimental Setup

The study was conducted under field and Carbon dioxide Temperature Gradient Tunnels (CTGTs) at Assam Agricultural University, Jorhat, Assam from 2012 to 2014. Two locally grown genotypes of *Capsicum chinense* Jacq. were collected from Manipur (viz. cv 1) and Assam (viz. cv 2) for studying the effect of high carbondioxide and temperature on various morphological and growth parameters. Four different treatments i.e. Field

(Ambient CO₂ condition and temperature condition); CTGT I (380 ppm CO₂ + ambient temperature); CTGT II (550 ppm CO₂ + 2°C higher than ambient) and CTGT III (750 ppm CO₂ + 4°C higher than ambient) were given to *Capsicum* plants. CTGT I was treated as a control. The carbon dioxide was maintained throughout the entire crop growth period from 9 a.m. to 2 p.m. regularly. At CTGT II and CTGT III, a temperature elevation of 2°C and 4°C was imposed from flower bud initiation up to maturity. The elevated temperature was provided by the InfraRed Gas Analyzer which was regulated by SCADA software. The carbon dioxide temperature gradient tunnel (CTGT), (Make: Genesis Technologies, Maharashtra, India) was used for creating a controlled environment for the experiment. The CTGTs were covered by poly carbonated sheet of 100-micron gauge showing greater than 85 % light transmission. Recording of data viz. temperature, relative humidity in CTGTs, and ambient conditions were done by using temperature sensors, humidity transmitters etc. CO₂ gas cylinders supplied the CO₂ gas. The entire system was automated to obtain the desired CO₂ level. The monitoring and controlling of CO₂ levels in all the chambers were done by Datalogger, SCADA software, and PC.

Capsicum seeds, previously treated with Captan @ 2.5g/Kg were germinated. Earthen pots were filled with fertilized soil @ 120: 60: 60:: N: P: K kg/ha. In each treatment, five pots were kept per cultivar. The experimental design was CRD with factorial treatment combination and data were collected during the flowering stage. The experiment was repeated next year and data were analyzed.

2.2 Parameters recorded

2.2.1 Leaf area Index

For calculation of leaf area index, the leaf area was measured using a portable leaf area meter (model LI 3000). LAI was calculated using the method of Evans (1972) using the following formula.

$$LAI = \frac{\text{Total leaf area}}{\text{Ground area}}$$

2.2.2 Leaf area duration

For calculating LAD, the LAI was calculated twice at an interval of 15 days and was expressed in days. LAD was calculated using the method of Power et al. (1967) using the following formula

$$LAD = \frac{L_1 + L_2}{2} \times (t_2 - t_1)$$

Where, L₁ = LAI at the first stage; L₂ = LAI at the second stage; (t₂ - t₁) = Time interval in days

2.2.3 Root: shoot ratio

Roots were dug out by the method of Sirohi et al. (1978). Roots were washed gently to separate soils from the roots. The ratio of root growth to the top growth was expressed by root: shoot ratio.

2.2.4 Specific leaf area (SLA)

The specific leaf area (SLA) was calculated according to the method of Das (2003). The specific leaf area was calculated as leaf area per unit of dry matter and was expressed as cm^2g^{-1} . The following formula was used for calculating Specific leaf area

$$\text{SLA} = \{ (A_2/LW_2) + (A_1/LW_1) \} / 2$$

Where A_1 and A_2 were leaf area and LW_1 and LW_2 were the dry weight of leaf for time t_1 and t_2 respectively.

2.2.5 Specific leaf weight (SLW)

Specific leaf weight (SLW) was calculated according to the method of Das (2003). Specific leaf weight denoted leaf dry weight per unit leaf area and was expressed as g cm^{-2} . Specific leaf weight was calculated using the following formula.

$$\text{SLW} = \{ (LW_2/A_2) + (LW_1/A_1) \} / 2$$

Where A_1 and A_2 were leaf area and LW_1 and LW_2 were the dry weight of leaf for time t_1 and t_2 respectively.

2.2.6 Yield Parameter

Mature and ripe fruits were harvested at the time interval and fresh weights were calculated. At the end of the crop period, the total fruit yield/ plant was calculated and expressed as g plant^{-1} .

3. Results and Discussion

A significant difference in LAI was noted among the tested cultivars. An increase in LAI (7% and 11 %) was recorded in cv.

Manipur over cv. Assam in the first and second year respectively. Elevated CO_2 and temperature brought an increase of 56% and 74% in CTGT III and CTGT II treatment respectively over the ambient condition in the first year. In the second year of the experiment, an increase of 14 % and 42 % was reported in CTGT III and CTGT II respectively (Figure 1). A significant difference in LAD was recorded amongst the genotypes. Chilli cultivar cv. Manipur has 16 and 17% higher LAD in the first and second year respectively (Figure 2). A significant difference in LAD was also recorded amongst the treatments and cultivars. Further, CO_2 enrichment enhanced the LAI and LAD in the selected cultivars. As compared to CTGT II, a reduction in these growth parameters was observed at CTGT III.

In the current study, the effect of high temperature at CTGT II and CTGT III could be ameliorated due to the CO_2 elevation. As evidenced by the present study, the enhanced LAI and LAD could maintain the photosynthesizing capacity for a longer period. Hence the newly produced leaves and branches at CTGT II might have acted as a temporary sink for utilizing the photoassimilates. Such leaves acted as a source of assimilation for reproductive organs; the ultimate sink for utilizing the photoassimilates. Thus the demand for photoassimilates by the fruit might have been catered by the photosynthates in both the cultivars. Thus the process of feedback inhibition might have been eliminated due to elevated CO_2 . High temperatures can cause loss of cell water content, cell size, and eventually reduced growth. Such a reduction in growth due to elevated temperature has been observed in maize and pearl millet (Ashraf & Hafeez., 2004).

The current study showed a significant increase in the specific leaf weight (SLW) and decreased the specific leaf area due to CO_2 elevation. Similar findings were reported by Mailliard et al. (2001), those who have reported a decrease in specific leaf area under elevated CO_2 . The primary photosynthetic organelle in the plants which influences the plants' growth and development are the chloroplasts (Sharma et al., 2014). Chinese Yam grown under

Figure 1 Interactive effect of elevated carbon dioxide and temperature on leaf area index in *C. chinense*

Figure 2 Interactive effect of elevated carbon dioxide and temperature on leaf area duration in *C. chinense*

elevated CO₂ showed thicker palisade layer than those grown under ambient conditions resulting in a thicker leaf blade (Thinh et al., 2018). Moreover, Teng et al. (2006) reported an increase in the number of chloroplasts per mesophyll cell in leaves of *A. thaliana* when grown under elevated CO₂. According to them the increase in SLW, may be due to anticlinal divisions of mesophyll cells. Thus additional palisade layers were produced which were the resource utilization sites for higher CO₂. In *Capsicum* species too, a marked increase in specific leaf weight was recorded. At CTGT III, the high-temperature stress significantly decreased the SLW as compared to CTGT II. Bray & Reid (2002) also reported an increase in leaf area, LAI, LAD, SLW in *Phaseolus sp.* when grown under elevated CO₂ concentration. While Jumrani et al. (2017) reported that an elevation in temperature brought a negative effect on SLW and leaf thickness in soybean.

The current study showed an increase in leaf area duration at CTGT II. This indicated that the plants grown at CTGT II conditions got more time for the production of photosynthates, which was ultimately used for fruit development. Canopy assimilation and plant growth are affected by LAI when grown

under elevated CO₂ (Li et al., 2018). In an ecosystem modeling study from 1981 to 2016, the increase in LAI accounted for 12.4% of the accumulated terrestrial carbon sink (Chen et al., 2019). Whereas in a study on some forest species indicated that LAI was not affected by the elevation of CO₂ levels, but CO₂ enrichment could stimulate leaf-area expansion in field experiments in some other ecosystems. Leaf expansion of *Populus* was sensitive to atmospheric carbon dioxide (Ferris et al., 2001). In the birch forest, an increase in CO₂ and O₃ caused a 40% increase above ambient values which affected tree water use. The 1 sap flux was not affected by elevated [O₃], but an increase of 18% was recorded by elevated [CO₂] and O₃ regimes (Uddling et al., 2008).

A significant difference in SLA and SLW was recorded amongst the cultivars and treatments for both the years (Table 1). Correlation studies between LAD and yield revealed a significant positive *r* value (*r* = 0.968) which indicates that LAD and yield/ plant are highly associated with one another in a linear way (Table 2). The SLW showed a negative correlation (*r* = -0.996) with SLA. A highly significant positive correlation (*r* = 0.997) between SLW and LAI was obtained from the data analyzed.

Table 1 Interactive effect of elevated carbon dioxide and high temperature on specific leaf area and specific leaf weight in *C. chinense*

Treatments	Specific leaf area (cm ² g ⁻¹)		Specific leaf weight (g cm ⁻²)	
	1 st year	2 nd year	1 st year	2 nd year
Field	338.16	310.4	0.0031	0.0033
CTGT-I	323.74	340.22	0.0030	0.0031
CTGT-II	259.30	246.01	0.0039	0.0041
CTGT-III	268.14	283.45	0.0037	0.0037
SEd	6.47	9.97	0.00003	0.015
P (0.05%)	14.29	2.13	0.000065	0.032
cv. Manipur	283.88	284.03	0.0036	0.0036
cv. Assam	310.80	306.01	0.0033	0.0034
SEd	4.57	7.05	0.00006	0.00009
P (0.05%)	10.11	14.94	0.0001	0.0002
Treatment X Cultivar				
Treatments	1 st year		2 nd year	
	cv. Manipur	cv. Assam	cv. Manipur	cv. Assam
Field	311.87	364.46	291.86	328.93
CTGT-I	310.99	336.49	321.76	358.68
CTGT-II	250.81	267.8	245.45	246.57
CTGT-III	261.84	274.45	277.04	
SEd	9.15		3.09	
P (0.05%)	20.13		NS	

Table 2 Correlation study of some growth parameters in *C. chinense*

Parameters	Leaf area index	Specific leaf area	Specific leaf weight	Leaf Area Duration
Yield	0.715	-0.651	0.664	0.968*
Leaf area index		-0.991	0.997**	0.542
Specific leaf area			-0.996	-0.454
Specific leaf weight				0.479

* Significance at 5 % level; ** Significance at 1% level

Figure 3 Interactive effect of elevated carbon dioxide and temperature on root: shoot ratio in *C. chinense*

Figure 4 Interactive effect of elevated carbon dioxide and temperature on fruit yields/plant in *C. chinense*

Results of two years data revealed a significant difference in root: shoot ratio between the cultivars while interaction effect was reported between the treatments and cultivars for both the years of experimentation (Figure 3). A significantly higher root: shoot ratio was observed in CTGT II and CTGT III for both the years. Among the tested cultivars, cv. Manipur recorded a significantly higher root: shoot over cv. Assam for both the years of experimentation. A significantly higher root: shoot ratio ranging from 0.66 to 0.78 and 0.68 to 0.78 was reported for the treatment CTGT II and CTGT III for the first and second year respectively.

Elevated CO₂ enhanced the growth of root and shoot which resulted in higher root: shoot ratio (Liu et al., 2002). In the present study, the elevated CO₂ helped in sequestration of carbon by the capsicum plants and this resulted in higher root: shoot ratio probably due to more root growth in terms of root volume and secondary root number. The allocation of biomass in plant parts plays an important role in the adaptation of stress conditions (Ge et al., 2012). The current study depicts the enhanced rate of root growth as compared to shoot under elevated CO₂. The better root growth might have facilitated the uptake of nutrients and water for supporting plant growth and adaptation under high temperatures. Similarly, Arnone et al. (2000) reported that crop grown under elevated CO₂ will have a larger and highly branched root system which would increase the capacity for resource acquisition. Similarly, as compared to plants with a smaller and fibrous root system, tuberous and woody root system tends to respond more to elevated CO₂ (Runion et al., 2010).

In the yield/plant, a significant difference was noted amongst the different treatments and amongst the cultivars. CTGT II recorded significantly higher yield/ plant as compared to CTGT III and ambient conditions (Figure 4). Similarly, cv. Manipur recorded a significantly higher yield/ plant as compared to cv. Assam.

In the current study, the crop *C. chinense* is an indeterminate type of plant, hence flower and fruit development took place for a longer growth period. This was evident from higher LAI and LAD. The potentiality of the crop to experience higher leaf area duration with a higher rate of photosynthesis has to lead better yield. The increased LAD along with the indeterminate growth pattern resulted in greater productivity under the CTGT II. The contribution of leaf area duration to the fruit yield has also been estimated and results have been presented in Figure 5. The coefficient of estimated regression is 0.791 level. The computed R² value indicates that 79.1 percent of the total yield being attributed to leaf area duration.

From the present study, it can be concluded that under the present scenario of climate change, the elevation of climatic factors viz. CO₂ (550 ppm) and temperature (2°C) is beneficial for higher production of hot chilli crop under farmers' field. Cultivar Manipur could resist the high carbon dioxide and temperature stress, thereby indicating its adaptability for growing in the future years.

Figure 5 Scatter Plot of Correlation between leaf area duration and yield/plant

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Conflict Of Interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

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