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Effect of elevated CO_2 and temperature on crop growth and yield attributes of bell pepper (*Capsicum annuum* L.)

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ABSTRACT

Investigations were carried out during 2014 and 2015 to study the effect of elevated CO_2 and temperature on growth and yield contributing parameters of bell pepper (*Capsicum annuum* L.) under open top chamber (OTC) at research farm of Department of Environmental Science, Dr Y.S. Parmar UHF, Nauni, Solan, Himachal Pradesh with four treatments [T_1(*e*CO_2): OTC with elevated CO_2 550±10 ppm; T_2(*e*T & *e*CO_2): elevated temperature by 1°C and elevated CO_2 550±10 ppm; T_3(*a*T & *a*CO_2): ambient temperature and CO_2 and T_4: natural condition] and each treatment had two varieties (California Wonder and Solan Bharpur) of bell pepper which were replicated thrice. Results revealed that bell pepper recorded maximum plant height, leaf area, yield attributes under *e*CO_2 which were significantly higher than all other treatments. However, the harvest duration and days to first harvest was lowest under *e*CO_2. Higher fruit size as well as fruit weight was recorded with *e*CO_2 followed by *e*T and *e*CO_2, *a*T and *a*CO_2 and open natural condition. But maximum number of fruits and highest fruit yield was obtained with natural condition which was significantly superior over *e*CO_2 as well as over *e*T and *e*CO_2 because increase in temperature negated fruit set due to less pollen viability under *e*CO_2 and *e*T & *e*CO_2 as compared to open. In open natural conditions due to higher pollen viability and more fruit setting as compared to higher CO_2 and temperature conditions, it resulted more yield. Solan Bharpur recorded higher total fruit yield (800.2 g plant^{-1}) than California Wonder (399.1 g plant^{-1}). Elevated CO_2 has positive effect on plant growth and yield attributes in both cultivars of bell pepper. However, under interactive effect of elevated CO_2 and elevated temperature, rising temperature negated the positive effects of elevated CO_2 on crop production.

Key Words: Bell pepper, elevated CO_2, elevated temperature, open top chamber, vegetables

The global atmospheric concentration of carbon dioxide (CO_2) has increased from pre-industrial (before 1750) level of 280 ppm to the level of 408.71 ppm (NOAA/ESRL, 2018) and is rising at the rate of 2 ppm per annum which is expected to reach 700 ppm by the end of 21st century. The rise in carbon dioxide level is associated with an increase in average global temperature. Global studies projected a 10-40 per cent loss in crop production in India by 2080-2100 due to climate change unless farmers adapt to climate change (IPCC, 2007). Assessment of many studies on crops shows that the negative impacts of climate change on crop yields at worldwide level, have been more common than positive impacts (IPCC, 2014). Food production in India is also sensitive to climate changes such as variability in monsoon rainfall and temperature changes within a season. Small changes in temperature and rainfall have significant effects on the quality of vegetables, tea and medicinal plants. With increasing temperatures, it is anticipated that there may be an all-round decrease in horticultural- agricultural production in the Himachal Pradesh in long-term. Temperature humidity index (THI) is projected to rise in many parts of state during March–September with a maximum rise during April–July in 2030s with respect to 1970s which can affect negatively the agriculture productivity (Annon, 2012.)

Climate of Himachal Pradesh, India has changed in last few decades and maximum temperature has increased in all the seasons, particularly in winter season and which has affected the crops and their suitabiligy area, as a result apple suitability area are shifting towards higher latitudes (Rana *et al.* 2011, 2012; Singh and Patel 2017; Bhardwaj and Sharma, 2013). In the state, bell pepper (*Capsicum annuum* L.) is the most widely produced and consumed vegetable. It is grown in an area of 2,408 hectares with annual production of about 55,252 metric tonnes respectively (Annon. 2016). The mid hill zone of Himachal Pradesh is endowed with highly congenial climatic conditions of meteorological parameters.

Increased concentration of atmospheric carbon dioxide stimulates crop growth by the carbon fertilization effect. However, the positive effect of elevated CO_2 might be offset by the adverse effect of associated global warming particularly excessive heat and drought. A large number of studies have been conducted on responses of various types of crop systems to elevated CO_2 (Mukherjee *et al.* 2015; Singh *et al.* 2013; Kumari *et al.* 2019) . However, the quantification of influence of elevated CO_2 and temperature on bell pepper production in Himachal Pradesh has not been investigated. So, there is an urgent need to record more information in order to develop effective and sustainable approaches to manage production of bell pepper under influence of climate change. Therefore, objective of this study was to investigate the growth and yield parameters of bell pepper under the effect of increasing CO_2 concentration and temperature.

MATERIALS AND METHODS

The present investigation was conducted at Research farm of Department of Environmental Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan India in year 2014 and 2015 situated at 30°05' N latitude and about 77°11' E longitude at an elevation of 1260 m above mean sea level. Circular type Open top chambers (OTC) of 4 m diameter were used to raise the crop under conditions of elevated carbon dioxide (eCO_2), elevated carbon dioxide (eCO_2) + elevated temperature (eT) and ambient CO_2 (aCO_2) and temperature (aT). An automatic CO_2 enrichment and temperature technology was developed by adapting software SCADA to automatically maintain the desired and accurate levels of CO_2 and temperature around crop canopy inside OTCs. Carbon dioxide gas was supplied to the chambers and maintained at set levels using manifold gas regulators, pressure pipelines, solenoid valves, rotameters, sampler, pump, CO_2 analyzer, PC linked Program Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA). There were four treatments i.e.

T_1: eCO_2 (550 ±10 ppm),

T_2: eCO_2 and eT (CO_2: 550±10 ppm, temperature: ambient +1°C),

T_3: aCO_2 (387±10 ppm) and aT (30.76°C) (reference) and

T_4: natural air (CO_2 350±10 ppm) and temperature (28.73 °C).

In each treatment there were two varieties of crop which were replicated thrice. These cultivars were transplanted during crop growing season in 2014 and 2015 under all the four conditions. The standard cultural practices recommended in the package of practices for vegetable crops were followed to ensure a healthy crop stand. Data were recorded randomly on five plants in each replication in each treatment. The observations were recorded on various growth and yield contributing attributes like plant height, leaf area, harvest duration, days to first harvest of fruits, plant fresh weight, biomass, fruit size, fruit pericarp thickness, number of fruits per plant, average fruit weight and fruit yield in plant. Data on these various parameters was recorded by following standard procedures in factorial randomized block design (FRBD) and their means values were utilized for statistical analysis as per the method described by Gomez and Gomez (1984). The pooled analysis was made from two years data to assess the effect. The data recorded on different parameters were analyzed statistically with the help IBM SPSS Statistics 21.

RESULTS AND DISCUSSION

Phenology and growth attributes

Maximum plant height of bell pepper (111.0 cm) was with eCO_2 which differed significantly with aCO_2 and aT (100.9 cm) followed by eCO_2 and eT (97.5 cm) and natural condition (74.7 cm) (Table 1). California Wonder recorded higher plant height (98.4 cm) which differed significantly with Solan Bharpur (93.6 cm). In the present study, the maximum plant height was with eCO_2 as compared to aCO_2 and aT which may be due to increased cell division, cell expansion, cell differentiation under the influence of increased CO_2 concentration. The present results are in conformity with the findings of Rao *et al.* (2010) who reported that among all growth parameters plant height was significantly higher in tomato at eCO_2 as compared to aCO_2. Plant height with eCO_2 and eT was comparatively lower than eCO_2 and aCO_2 and aT which may be due to effect of higher temperature which offsets the positive effect of eCO_2 and reduced the overall height of plants by hampering growth of plants.

Bell pepper plants grown under eCO_2 recorded higher (123.3 cm^2) leaf area. Leaf area under eCO_2 and eT was 117.0 cm^2, aCO_2 and aT (115.6 cm^2) as well as natural condition (87.4 cm^2) as described in Table 1. California Wonder recorded higher leaf area (112.7 cm^2) as compared to Solan Bharpur (109.0 cm^2). Solan Bharpur recorded leaf area of 114.7 cm^2 with eCO_2 and eT which was statistically at par with same variety with aCO_2 and aT (116.2 cm^2), California wonder with aCO_2 and aT (115.0 cm^2) and eCO_2 and eT (119.4 cm^2). In the

Table 1: Effect of elevated CO_2 and temperature on phenology and growth attributes viz. plant height (cm), leaf area (cm^2), days to first harvest of fruits, harvest duration (days), plant fresh weight (g) and dry weight (g plant^{-1}) of bell pepper (pooled data of two years).

Treatment	Plant height (cm)			Leaf area (cm^2)			Days to first harvest of fruits (day)			Harvest duration (day)			Fresh weight of plant (g)			Dry weight (biomass) (g plant^{-1})		
	CW	SB	Mean	CW	SB	Mean	CW	SB	Mean	CW	SB	Mean	CW	SB	Mean	CW	SB	Mean
T_1 :	113.2	108.8	111.0	121.4	125.1	123.3	104.9	107.4	106.1	50.6	52.2	51.4	442.1	478.2	460.2	103.6	110.8	107.2
T_2 :	101.3	93.6	97.5	119.4	114.7	117.0	103.7	104.6	104.2	47.9	48.5	48.2	415.2	391.1	403.2	82.7	98.6	90.6
T_3 :	101.7	100.1	100.9	115.0	116.2	115.6	110.2	113.7	111.9	54.2	55.4	54.8	360.9	368.9	364.9	75.3	83.2	79.3
T_4 :	77.3	71.9	74.6	94.8	80.1	87.4	115.9	117.0	116.5	60.7	60.5	60.6	333.4	365.2	349.3	74.4	80.9	77.6
Mean	98.4	93.6	96.0	112.6	109.0	110.8	108.7	110.7	109.7	53.3	54.1	53.7	387.9	400.9	394.4	83.9	93.4	88.7
CD ($p = 0.05$)																		
Treatment:			2.3			3.2			1.6			1.2			48.8			9.7
Variety:			1.6			2.2			1.1			NS			NS			6.8
Treatment × Variety: NS			4.5			NS			NS			NS			NS			

CW: California Wonder; SB: Solan Bharpur, T_1 : eCO_2, T_2 : eCO_2+eT, T_3 : aCO_2+aT, T_4 : Natural condition

present findings, maximum leaf area of bell pepper plants recorded with *e*CO_2 while lowest was under natural condition which may be due to carbon fertilization effect in *e*CO_2 which resulted production of more structural compounds like carbohydrates, amino acids and proteins under high rate of photosynthesis. The present results corroborate the findings of Tremblay *et al.* (1987) who reported that carbon dioxide enrichment increased plant leaf area of celery (*Apium graveolens* L.).

As depicted in Table 1, least number of days (104.2 days) to first harvest of fruits was recorded with *e*CO_2 and *e*T. Whereas, in case of *e*CO_2 days to first harvest were 106.2 days, and under *a*CO_2 and *a*T were 111.9 days. Minimum days (108.7 days) to first picking of fruits were recorded with California Wonder than Solan Bharpur (110.7 days). In present studies, minimum days to first harvest of fruits were recorded with *e*CO_2 and temperature which may be due to the effect of raised temperature and CO_2 which might hasten the reproductive development of plants and ultimately shortened the fruit maturation time which leads to early maturity of fruits. These findings are in confirmation with the findings of Rao *et al.* (2010) who reported that due to *e*CO_2 and *e*T rate of reproductive development got accelerated which shortened the fruit maturation period and also resulted in lower fruit weight.

Minimum harvest duration (48.2 days) was recorded with *e*CO_2 and *e*T which differed statistically from rest of the treatments (Table 1). Maximum harvest duration (60.6 days) was recorded under natural condition followed by *a*CO_2 and *a*T (54.8 days) and *e*CO_2 (51.4 days). In the present study, maximum harvest duration recorded with natural condition might be due to long duration of crop growth while crop duration got reduced under *e*CO_2 and *e*T.

Elevated CO_2 produced significantly higher plant fresh weight (460.1 g plant^{-1}) followed by *e*CO_2 and *e*T (403.2 g plant^{-1}), *a*CO_2 and *a*T (364.9 g plant^{-1}) and natural condition (349.3 g plant^{-1}) (Table 2). In the present investigations, plant fresh weight was higher with *e*CO_2 which may be due to carbon fertilization effect which resulted in high rate of photosynthesis and resulted in higher vegetative growth. Elevated CO_2 produced highest plant biomass (107.2 g plant^{-1}) and plant biomass under *e*CO_2 and *e*T was 90.6 g plant^{-1}, *a*CO_2 and *a*T (79.3 g plant^{-1}) and natural condition (77.6 g plant^{-1}). Solan Bharpur recorded significantly higher plant dry weight (93.4 g plant^{-1}) as compared to California Wonder (83.9 g plant^{-1}) (Table 1). Plant dry weight was higher with *e*CO_2.

Table 2: Effect of elevated CO_2 and temperature on yield and yield attributes viz. number of fruits per plant, fruits size (cm^2), average fruit weight (g), pericarp thickness (mm), fruit yield per plant (g) and total fruit yield ($t\ ha^{-1}$) in bell pepper (pooled data of two years).

Treatment	No. of fruits plant			Fruits size (cm^2)			Average fruit weight (g)			Pericarp thickness (mm)			Fruit yield plant (g)			Total fruit yield ($t\ ha^{-1}$)		
	CW	SB	Mean	CW	SB	Mean	CW	SB	Mean	CW	SB	Mean	CW	SB	Mean	CW	SB	Mean
T_1:	10.7	17.0	13.9	42.3	38.1	40.2	56.2	69.9	63.1	5.7	5.2	5.4	418.3	840.1	629.2	13.9	28.0	20.9
T_2:	9.2	14.9	12.0	41.0	35.7	38.4	51.9	64.8	58.3	4.6	5.2	4.9	328.2	665.9	497.1	10.9	22.2	16.6
T_3:	7.9	13.9	10.9	39.9	36.3	38.1	48.5	56.6	52.6	4.7	4.6	4.7	373.5	717.9	545.7	12.4	23.9	18.2
T_4:	18.2	24.4	21.3	35.3	32.2	33.7	38.1	47.1	42.6	3.8	4.4	4.1	476.3	976.8	726.5	15.9	32.5	24.2
Mean	11.5	17.6	14.5	39.6	35.6	37.6	48.7	59.6	54.1	4.7	4.8	4.8	399.1	800.2	599.6	13.3	26.7	19.9
CD ($p = 0.05$)																		
Treatment:			2.6			2.8			5.6			0.5			39.4			3.9
Variety:			1.8			2.0			3.9			NS			27.8			2.7
Treatment × Variety:			NS			NS			NS			NS			55.3			5.5

CW: California Wonder; SB: Solan Bharpur, , T_1: eCO_2, T_2: eCO_2+eT, T_3: aCO_2+aT, T_4: Natural condition

Yield and yield attributes

Higher number of fruits (21.3 fruits $plant^{-1}$) of bell pepper were found under natural condition followed by eCO_2 (13.9 fruits $plant^{-1}$), eCO_2 and *e*T (12.05 fruits $plant^{-1}$) and aCO_2 and *a*T (10.9 fruits $plant^{-1}$). Solan Bharpur (17.6 fruits $plant^{-1}$) produced higher number of fruits than California Wonder (11.5 fruits $plant^{-1}$) (Table 2). Higher number of fruits/plant recorded with eCO_2 in comparison to eCO_2 and *e*T may be due to higher photosynthesis rate and carbon fertilization effect. Elevated CO_2 caused high growth and development in tomato whereas, elevated CO_2 and *e*T reduced reproductive growth of plants (Rao *et al.,* 2010). Poor fruit-set was believed to be one of the major barriers to the tropical adaptation of bell pepper. Fruit set in bell pepper was sensitive to high temperatures and reduced under increasing temperature (Erickson and Markhart, 2002).

Significantly higher fruit size (40.2 cm^2) (Table 2) of bell pepper was under eCO_2 followed by eCO_2 and *e*T (38.4 cm^2), aCO_2 and *a*T (38.1 cm^2) and natural condition (33.7 cm^2). California wonder recorded larger fruit size (39.6 cm^2) than Solan Bharpur (35.6 cm^2). Higher fruit size with eCO_2 may be due to carbon enrichment/fertilization effect, which leads to higher photosynthesis and resulted in more synthesis of carbohydrates and other important structural component which resulted better growth of fruits. The results are in consonance with findings of Hartz *et al.* (1991) who reported carbon dioxide enrichment significantly increase fruit size of tomato. Fruit size of bell pepper got decreased with eCO_2 and temperature due to negative impact of temperature which act opposite to CO_2 effect and ultimately reduced the size of fruits.

Higher average fruit weight (63.1 g $fruit^{-1}$) was obtained with eCO_2 which was statistically at par with eCO_2 and *e*T (58.3 g $fruit^{-1}$) and differed significantly from aCO_2 and *a*T (52.6 g $fruit^{-1}$) and natural condition (42.6 g $fruit^{-1}$) (Table 2). Significantly, higher average fruit weight was recorded in Solan Bharpur (59.6 g $fruit^{-1}$) compared to California wonder (48.6 g $fruit^{-1}$). The present study revealed that average fruit weight was higher with eCO_2 compared to eCO_2 and *e*T which may be ascribed to increased CO_2 levels, increased synthetic compounds and dry matter content in fruit weight.

Maximum pericarp thickness (5.4 mm) recorded with eCO_2. Pericarp thickness under eCO_2 and *e*T was 4.9 mm, as well as under aCO_2 and *a*T was 4.7 mm and under natural condition was 4.1 mm (Table 2). In the present study, higher pericarp thickness of bell pepper fruits (5.4 mm) with eCO_2

may be due to enhanced dimensions of fruits with CO_2 enriched atmosphere. The present results corroborate the findings of Hernandez *et al*. (2013) who also recorded increased pericarp thickness of habanero peppers (*Capsicum chinense* Jacq.) with increased level of CO_2 compared to ambient CO_2.

Highest fruit yield per plant (726.5 g plant^{-1}) was obtained under natural condition which was significantly superior over eCO_2 (629.2 g plant^{-1}), aCO_2 and aT (545.7 g plant^{-1}) (Table 2). Lowest yield per plant was obtained with eCO_2 and eT (497.1 g plant^{-1}). Significantly maximum total fruit yield was recorded with Solan Bharpur (800.2 g plant^{-1}) compared to California wonder (399.1 g plant^{-1}). Solan Bharpur recorded fruit yield of 665.9 g plant^{-1}with eCO_2 and eT which was statistically at par with aCO_2 and aT (717.9 g plant^{-1}) and differed significantly with rest of the treatments. California Wonder recorded fruit yield of 328.2 g plant^{-1} with eCO_2 and eT which was statistically at par with aCO_2 and aT (373.5 g plant^{-1}) and differed significantly from rest of the conditions of same variety. So in both varieties of crop, Solan Bharpur performed well and seem it can produce better in climate changing scenario while California Wonder produce less under changed conditions. In present investigations, fruit yield per plant of bell pepper with eCO_2 was higher than eCO_2 and eT as well as from aCO_2 and aT which may be due to higher photosynthetic activity which leads to more carbohydrates and other synthetic products accumulation in fruits and resulted increased individual fruit mass with CO_2 enriched environment. Similar to present investigations but in another crop Rao *et al*. (2010) found that eCO_2 (550 ppm) influenced growth and development in tomato cv. Arka Ashish and which increased yield by 24.4 per cent, while eCO_2 along with high temperature reduced the yield which can be due to effect of high temperature on reproductive growth of plant which offsets the positive effects of eCO_2. The fruit yield per plant was also higher (3.4 kg plant^{-1}) at 550 ppm compared to 2.7 kg plant^{-1} under ambient conditions

Significantly higher fruit yield per hectare (24.2 t ha^{-1}) (Table 2) was produced with natural condition. Fruit yield per hectare under eCO_2 was 20.9 t ha^{-1}, for aCO_2 and aT was 18.2 t ha^{-1} and for eCO_2 and eT was 16.6 t ha^{-1}. Solan Bharpur produced significantly higher fruit yield (26.7 t ha^{-1}) compared to California Wonder (13.3 t ha^{-1}). California Wonder recorded maximum fruit yield (12.4 t ha^{-1}) with aCO_2 and aT which was statistically at par with eCO_2 (13.9 t ha^{-1}) and different statistically with rest of the treatments. Highest fruit yield recorded with eCO_2 compared to aCO_2 and aT may be due to CO_2 enrichment effect. In the present study, lower yield was recorded eCO_2 and eT which may be due to adverse effect of increased temperature which resulted low fruit set, more flower abortion and reduced pollen viability.

CONCLUSION

The present investigations indicated that elevated CO_2 has positive effect on plant growth and yield parameters of bell pepper. However, under interactive effect of elevated CO_2 and elevated temperature, rising temperature negated the positive effects of eCO_2. Most of the plant growth parameters and yield attributes under study were higher and performed best in Solan Bharpur cultivar than California Wonder cultivar of bell pepper under the influence of eCO_2 and interactive effect of eCO_2 and eT. Hence, Solan Bharpur cultivar of bell pepper was more adaptable to climate change compared to California wonder which can sustain better under adverse effects of climate change i.e. eCO_2 and eT and give better production.

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