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Impact of elevated CO_2 and temperature on quality and biochemical parameters of bell pepper (*Capsicum annuum*) crop

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ABSTRACT

Experiment was conducted during 2014 and 2015 to study effect of elevated CO_2 and temperature on quality and biochemical parameters of bell pepper (*Capsicum annuum* L.) crop. To carry out experiment there were four conditions, i.e. in three Open Top Chambers, (T_1: OTC with elevated $CO_2$550±10 ppm; T_2: OTC with elevated temperature 1°C and elevated $CO_2$550±10 ppm; T_3: OTC with ambient temperature and CO_2(reference) and T_4: natural air and temperature). Pooled data for two years indicated that higher fruit size (40.19 cm^2) and average fruit weight (63.06 g/ fruit) was obtained in plants grown under elevated CO_2. Elevated CO_2 and temperature treatment resulted lower leaf chlorophyll (1 708.71 mg/kg). Higher ascorbic acid content in fruits (159.12 mg/100g) was recorded under elevated CO_2 and temperature. Lower total soluble solids were observed under elevated CO_2 (4.02°B) while higher under elevated CO_2 and temperature (5.39°B). Higher N content (5.73%) was recorded under natural condition and lower under elevated CO_2 (4.08%). Higher P (0.39%), K (5.21%) and Mg (0.49%) content was recorded under natural condition and lower values were recorded under elevated CO_2 and temperature. Significantly higher Ca content (0.46%) was recorded in elevated CO_2 and lowest in natural condition (0.35%). Both elevated temperature and CO_2 had significant effects on quality and biochemical parameters in vegetables**.** These parameters of bell pepper crop were affected negatively by changing climatic conditions, i.e. elevated CO_2 and temperature where positive effect of CO_2 offset by elevated temperature effect.

Key words: Bell pepper, *Capsicum annuum.,*Elevated CO_2, Open top chamber, Temperature, Vegetables,

Earth climate has changed many times during the existence of our planet, ranging from the ice ages to periods of warmth. According to Inter-governmental Panel on Climate Change (IPCC) Report (2007) the global atmospheric concentration of carbon dioxide (CO_2) has increased from pre-industrial level of 280 ppm to the level of 401.62 ppm (NOAA/ESRL, 2016) and is increasing at the rate of 2 ppm per annum and atmospheric CO_2 is expected to reach 700 ppm by the end of 21st century. The rise in carbon dioxide levels is associated with an increase in average global temperature. Himachal Pradesh climate has changed in last few decades and maximum temperature has increased in all the seasons, however highest increase of temperature 3.11°C was noticed in winter season during 2001-2011 over base period of 1971-90 which has affected the crops (Bhardwaj and Sharma 2013). Vegetable cultivation in Himachal Pradesh has gained significant importance on account of favorable agro-climatic conditions for growing quality off-season vegetables. In Himachal Pradesh, bell pepper (*Capsicum annuum* L.) is the most widely produced and consumed vegetable. In Himachal Pradesh, bell pepper was grown in an area of 2 408 ha with annual production of about 55 252 metric tonnes respectively, during 2015 (DOA 2016). The mid-hill zone of Himachal Pradesh is endowed with highly congenial climatic conditions for vegetable production. This produce fetches high price in plain markets and thus encourages Himachal growers to take up vegetable cultivation as a profession.

Increasing level of CO_2 and temperature is affecting the growth and development of bell pepper in this region and these events can cause drastic reductions in commercial yield and affect the livelihood of farmers. Increased concentration of atmospheric carbon dioxide stimulates crop growth by the carbon fertilization effect (Rogers and Dahlman 1993). 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 plants

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to elevated CO_2 (Ainsworth *et al*. 2002, Ainsworth and Long 2005). The quantification of impact of elevated CO_2 and temperature on vegetable 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 vegetable crops under influence of climate change. The objective of this study was to investigate the quality and biochemical parameters of bell pepper under the effect of increasing CO_2 concentration and temperature.

MATERIALS AND METHODS

The present investigation was conducted at experimental farm of Department of Environmental Science, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan India, in year 2014 and 2015. Farm is situated at 30°5'N latitude and about 77°11'E longitudes and at an elevation of 1 260 m above mean sea level. Circular type natural ambient air and temperature condition top chambers (OTC) of 4 × 4 m^2dimension were used to raise the crop under elevated and ambient CO_2 and temperature conditions. 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: elevated CO_2 (550 ±10 ppm), T_2: elevated CO_2 and temperature (CO_2:550 ±10 ppm, temperature: 1°C), T_3: ambient temperature (reference) and T_4: natural air and temperature (control). Each replication was replicated thrice. Two bell pepper cultivar, viz. California Wonderand Solan Bharpur 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.

For recording data five plants (plot size: 3 × 2m) were selected randomly from each treatment in each replication. Significance (P=0.05) of each treatment was calculated as suggested by Cochran and Cox (1964). The observations were recorded on quality and biochemical parameters like fruit size, average fruit weight, ash content, chlorophyll content, polyphenols, ascorbic acid, TSS, N, P, K, Ca and Mg in plant. The total soluble solids values in bell pepper were obtained by placing on prism a droplet of juice squeezed from five mature fruits of bell pepper, picked randomly from each treatment, using digital hand refractometer. The results were reported as °Brix. For estimation of N, 0.5 g of plant material was digested in concentrated H_2SO_4 in the presence of a digestion mixture. After digestion, the N was determined by micro-kjeldahl method. Leaf nitrogen content was measured by adopting the standard procedure given by Jackson (1973). The concentration of each macro and micro-mineral nutrients was determined using ground dry leaf/fruits samples. Concentration of phosphorus, potassium, calcium and magnesium was determined by per-chloric digest method as outlined by Gieseking *et al*. (1935). The nutrient concentration of phosphorus and magnesium was then quantified by using an Inductively Coupled Plasma (ICP) Spectrometer. Potassium and calcium were estimated with the help of flame photometer. The results were reported as per cent (%).

Data on these various parameters was recorded by following stranded procedures in Factorial Randomized Block Design 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 helpSPSS (Statistical Product and Service Solutions) Statistics 21 .

RESULTS AND DISCUSSION

Important quality characteristics, such as fruit size, fruit weight, soluble solids and biochemical attributes of bell pepper were significantly influenced by elevated CO_2 and temperature. Larger fruit size (40.19 cm^2) was recorded in bell pepper plants grown under elevated CO_2 followed by elevated CO_2 and temperature (38.36 cm^2), ambient CO_2 and temperature (38.12 cm^2) and natural (33.74 cm^2) condition (Table 1). In case of cultivars, comparatively larger fruit size (39.64 cm^2) was recorded in California Wonder as compared to Solan Bharpur (35.57 cm^2). Higher fruit size under elevated CO_2 in comparison to elevated CO_2 and temperature 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.

Data analysis indicated that maximum average fruit weight (63.06 g/fruit) was obtained in plants grown under elevated CO_2 which was statistically at par with elevated CO_2 and temperature (58.33 g/fruit) and differed significantly from ambient CO_2 and temperature (52.56 g/fruit) and natural (42.59 g/fruit) condition (Table 1). Significantly higher average fruit weight was recorded in Solan Bharpur (59.60 g/fruit) compared with California Wonder (48.64 g/fruit). Similarly elevated CO_2 produced significantly higher ash content (23.68%) followed by elevated CO_2 and temperature (21.17%), ambient CO_2 and temperature (18.91%) and natural condition (16.75%). Solan Bharpur produced significantly higher ash content (20.85%) as compared with California Wonder (19.40 %). The average fruit weight and ash content were higher under elevated CO_2 as compared to elevated CO_2 and temperature which may be ascribed to increased CO_2 levels, increased synthetic compounds and dry matter content in fruit weight. The present findings are in confirmation with the findings of Sun *et al.* (2012) who reported that at low temperature

Table 1 Effect of elevated CO_2 and temperature on fruit size (cm^2), average fruit weight (g), ash content (%) in bell pepper (two years pooled data)

Treatment	Fruit Size			Average fruit weight			Ash content		
	Variety			Variety			Variety		
	California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean
T_1 : Elevated CO_2 (550±10 PPM)	42.33	38.07	40.19	56.17	69.96	63.06	24.08	23.27	23.68
T_2 : Elevated CO_2 and elevated temp (550±10 PPM & 1°C)	41.04	35.69	38.36	51.89	64.78	58.33	20.62	21.73	21.17
T_3 : Ambient CO_2 and temperature	39.91	36.34	38.12	48.53	56.58	52.56	17.91	19.90	18.91
T_4 : Natural condition (control)	35.30	32.18	33.74	38.11	47.09	42.59	15.00	18.50	16.75
Mean	39.64	35.57	37.61	48.67	59.60	54.14	19.40	20.85	20.13
CD (P =0.05)	Treatment: 2.85 Variety: 2.02 Treatment × Variety: NS			Treatment: 5.59 Variety: 3.96 Treatment × Variety: NS			Treatment: 2.23 Variety: 1.57 Treatment × Variety: NS		

elevated CO_2 improved the fruit yield by increasing fruit number and weight. However, at high temperature, elevated CO_2 decreased fruit yield which may be due to fewer induced inflorescence and smaller induced umbel size which caused reduced fruit number and weight, respectively, in strawberry. Increased ash content under elevated CO_2 as compared to ambient CO_2 and temperature may be ascribed to increase in carbon based compounds under high photosynthetic rate in elevated CO_2 which resulted accumulation of carbohydrates and other carbonaceous compounds in plant parts. Ash content in maize under elevated CO_2 contained significantly higher ash content as compared to ambient CO_2 (Sreedevi *et al.,* 2015).

Total leaf chlorophyll was significantly higher (2 000.68 mg/kg) in plants grown undernatural condition followed by ambient CO_2 and temperature (1 955.21 mg/kg), elevated CO_2 (1 864.62 mg/kg) and elevated CO_2 and elevated temperature (1 708.71 mg/kg), the last two were statistically (P=0.05) at par with each other. Low chlorophyll content was observed under elevated CO_2 and temperature which may be due to dilution of chlorophyll content as well as degradation of content by excess utilization under high photosynthetic rate in elevated CO_2. These results are also in agreement with the findings of Epron *et al*. (1996), they reported decline in leaf chlorophyll per unit area in response to CO_2 enrichment and further reported that it may be only due to dilution effect. Plants grown under elevated temperature conditions showed decline in chlorophyll content by around 16 and 15% (Dwivedi *et al*. 2015).

Higher ascorbic acid content in fruits (159.12 mg/100g) was recorded (Table 2) under elevated CO_2 and temperature followed by elevated CO_2 (152.44 mg/100g), ambient CO_2 and temperature (148.72 mg/100g) and natural condition (147.59 mg/100g), the last two were statistically at par with each other. Higher ascorbic acid content was recorded in elevated CO_2 and temperature which may be due to cumulative enhancing effect of elevated temperature and elevated CO_2 which caused stress to plants and increased carbon based compounds under accelerated photosynthesis (Table 1). Carbon based defensive compounds like ascorbic

Table 2 Effect of elevated CO_2 and temperature on total chlorophyll (mg/kg) in fresh weight , polyphenols (g/100g), ascorbic acid (mg/100g) in bell pepper (two years pooled data)

Treatment	Total chlorophyll			Polyphenols (g/100g)			Ascorbic acid		
	Variety			Variety			Variety		
	California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean
T_1 : Elevated CO_2 (550±10 PPM)	1806.50	1922.74	1864.62	39.07	38.95	39.00	153.09	151.79	152.44
T_2 : Elevated CO_2 and elevated temp (550±10 PPM and 1°C)	1717.94	1699.49	1708.71	31.47	32.55	32.01	159.62	158.62	159.12
T_3 : Ambient CO_2 and temperature	1930.63	1979.80	1955.21	29.50	30.78	30.14	148.52	148.93	148.72
T_4 : Natural condition (control)	1941.23	2060.14	2000.68	27.45	26.37	26.91	150.19	144.99	147.59
Mean	1849.07	1915.54	1882.31	31.87	32.16	32.02	152.86	151.08	151.97
CD (P =0.05)	Treatment: 76.32 Variety: NS Treatment × Variety: NS			Treatment: 3.22 Variety: NS Treatment × Variety: NS			Treatment: 3.37 Variety: NS Treatment × Variety: NS		

acid, phenolics in cotton plants increased under elevated CO_2 (Coviella *et al*. 2002). Similarly Hamner *et al*. (1944) also reported higher ascorbic acid content in tomato fruits produced at a temperature of 78° F (26°C) than fruits produced at 63° F (17°C).

Total soluble solids recorded under natural condition (4.52°B) was statistically at par with ambient CO_2 and temperature (4.43°B). Lower total soluble solids were observed under elevated CO_2 (4.02°B) while higher under elevated CO_2 and temperature (5.39°B). Lower total soluble solids were recorded under elevated CO_2 which may be due to lower production of sugars, organic acids and other substances which contributed to TSS while increased under elevated CO_2 and temperature may be due to TSS condenses under effect of raised temperature. Plants grown at doubled CO_2 and high temperature were up to two fold greater in total soluble solids than those grown at ambient CO_2 and ambient temperature (Vu and Allen 2009).

Bell pepper plants grown under natural condition recorded higher nitrogen content (5.73%) which was statistically at par with ambient CO_2 and temperature (5.16%) and differed statistically with elevated CO_2 and temperature (4.39%) and elevated CO_2 (4.08%) (Table 3). In this investigations, lowest nitrogen content was recorded in plant under elevated CO_2 and temperature which may be due to dilution of nitrogen in foliage under more vegetative growth due to high photosynthetic activity under enriched carbon dioxide, due to which less nitrogen is distributed to more biomass of plant which resulted decrease in nitrogen content. The present results are supported by findings of Zvereva and Kozlov (2006) who reported that nitrogen content in plants decreased under elevated CO_2 and temperature. The results are in consonance with findings of Cong *et al.* (2009) who found that leaf samples collected from the elevated CO_2 had significantly lower nitrogen concentrations compared with the control in peanut and further observed that foliar nitrogen concentrations decreased with increased CO_2 concentrations, from 34±1 g/kg in the control to 27±1 and 23±1 g/kg in the elevated CO_2 of 550 and 730 ppm, respectively.

Higher phosphorus (0.39 %) content was recorded under natural condition which differed statistically with rest of the treatments. The treatment ambient CO_2 and temperature (0.30%) followed by elevated CO_2 (0.27%) and elevated CO_2 and temperature (0.25%) (Table 3). Lower phosphorus concentration was recorded in bell pepper plants grown under elevated CO_2 and temperature. Phosphorous content in bell pepper leaves at elevated CO_2 was less as compared to ambient CO_2 and temperature as well as elevated CO_2 and temperature, which indicated that phosphorous is highly mobile within plants and leaves try to accumulate phosphorous. A similar trend of depressed nutrient concentration in leaves of lettuce at elevated CO_2 was observed by Giri *et al.* (2016).

Higher potassium content was recorded in plants grown under natural condition (5.21%) which was statistically at par with ambient CO_2 and temperature (5.08%) and different significantly with elevated CO_2 (4.83%), elevated CO_2 and temperature (4.48%), last two were statistically at par with each other (Table 4). Lower potassium content was recorded under elevated CO_2 and temperature. Solan Bharpur (5.12%) recorded higher potassium content as compared to California Wonder (4.68%). Elevated CO_2 recorded less potassium content in leaves of bell pepper as compared to ambient CO_2 and temperature. At elevated CO_2, the concentration of potassium in lettuce and spinach reduced as compared to ambient CO_2 and temperature (Giri *et al.* 2016).

Plants grown under elevated CO_2 resulted significantly higher calcium content (0.46 %) followed by elevated CO_2 and temperature (0.39 %), ambient CO_2 and temperature (0.36 %) and natural condition (0.35%). Natural condition, i.e. ambient air and temperature condition was statistically at par with ambient CO_2 and temperature and elevated CO_2 and temperature. It has been observed that under elevated CO_2 the calcium content in bell pepper fruits was higher than ambient CO_2 and temperature as well as

Table 3 Effect of elevated CO_2 and temperature on total soluble solids (°B), nitrogen (%), phosphorus (%) in bell pepper (two years pooled data)

Treatment	TSS			Nitrogen			Phosphorus		
				Variety					
	California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean
T_1 : Elevated CO_2 (550±10 PPM)	3.98	4.07	4.02	3.89	4.26	4.08	0.27	0.27	0.27
T_2 : Elevated CO_2 and elevated temp (550±10 PPM and 1°C)	5.47	5.31	5.39	4.46	4.31	4.39	0.29	0.21	0.25
T_3 : Ambient CO_2 and temperature	4.53	4.33	4.43	5.09	5.23	5.16	0.31	0.30	0.30
T_4 : Natural condition (control)	4.62	4.42	4.52	5.86	5.61	5.73	0.39	0.39	0.39
Mean	4.65	4.53	4.59	4.83	4.85	4.84	0.31	0.29	0.30
CD (P =0.05)	Treatment: 0.21 Variety: NS Treatment × Variety: NS			Treatment: 0.66 Variety: NS Treatment × Variety: NS			Treatment: 0.03 Variety: NS Treatment × Variety: NS		

Table 4 Effect of elevated CO_2 and temperature on potassium (%), calcium (%), magnesium (%) in bell pepper (two years pooled data)

Treatment	Potassium			Calcium			Magnesium		
	Variety								
	California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean
T_1 : Elevated CO_2 (550±10 PPM)	4.58	5.08	4.83	0.45	0.47	0.46	0.44	0.41	0.42
T_2 : Elevated CO_2 and elevated temp (550±10 PPM and 1°C)	4.29	4.68	4.48	0.38	0.40	0.39	0.37	0.34	0.36
T_3 : Ambient CO_2 and temperature	4.88	5.29	5.08	0.36	0.36	0.36	0.45	0.41	0.43
T_4 : Natural condition (control)	4.98	5.43	5.21	0.35	0.35	0.35	0.50	0.49	0.49
Mean	4.68	5.12	4.90	0.39	0.39	0.39	0.44	0.42	0.43
CD (P =0.05)	Treatment: 0.30 Variety: 0.22 Treatment × Variety: NS			Treatment: 0.05 Variety: NS Treatment × Variety: NS			Treatment: 0.04 Variety: NS Treatment × Variety: NS		

elevated CO_2 and temperature which may be attributed to the higher photosynthate availability, as a consequence of more accumulation of calcium in fruits under the influence of enriched CO_2 environment (Giri *et al.* 2016).

Plants grown under natural condition (0.49%) recorded significantly higher magnesium content followed by ambient CO_2 and temperature (0.43%), elevated CO_2 (0.42%) and temperature (0.36%) (Table 4). Lowest magnesium content was recorded under elevated CO_2 and temperature. Lowest magnesium content was observed under elevated CO_2 and temperature. The present results are in line with the findings of Abdelgawad *et al*. (2014) who reported that in legumes, elevated CO_2 in combination with climate extreme like high temperature reduced protein, phosphorus and magnesium contents.

From study, it may be concluded that under interactive effect of elevated CO_2 and temperature, rising temperature negated the positive effects of elevated CO_2 in the crop and affect the crop quality and biochemical attributes negatively leading to decline in overall value to vegetable crop. Thus, under changing climate scenario bell pepper crop proved to be less adaptation under mid hill conditions of Himachal Pradesh whereas in case of varieties Solan Bharpur performed well as compared to California wonder which implies it is more adaptable to climate change compared to other one.

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