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Effect of elevated CO_2 and temperature on growth parameters of pea (*Pisum sativum* L.) crop

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Abstract: Global warming is predicted to have negative effect on plant growth due to the damaging effect of high temperature on plant development. The field experiment was conducted during 2014-15 to study effect of elevated CO_2 and temperature on growth parameters of pea (*Pisum sativum* L.) crop in order to check the effect of climate change on vegetable crops. Effect was studied under four conditions i.e. Open Top Chambers, T_1: OTC - elevated $CO_2$550±10 ppm; T_2: OTC -elevated CO_2 550±10 ppm and temperature 1°C; T_3: OTC - ambient CO_2 and temperature (reference) and T_4: natural condition. Maximum plant height at 50 % flowering was recorded in T_1 (84.29cm) at elevated CO_2 which differed significantly with T_2 (79.47cm) at elevated CO_2 and temperature, T_3 (73.60cm) at ambient CO_2 and temperature and natural condition (70.73cm). Minimum days to 50 per cent flowering were recorded in plants growing under T_2 (68.56 days). Maximum pollen viability was recorded in T_1 (77.42%) followed by T_3 (76.36%), T_4 (74.65%) and T_2 (69.97%). Internode length of plants grown under T_1 was maximum (7.01cm) followed by T_2 (6.68cm), T_3 (6.00cm) and T_4 (5.05cm). Elevated temperature and CO_2 had significant effects on growth and development in vegetables. Overall, growth parameters of pea crop were affected positively by elevated CO_2 whereas under interaction effect of elevated CO_2 and temperature these positive effects of CO_2 were offset by elevated temperature effect and hampered the growth of pea crop which interns can affect the yield and quality of crop under changing climate scenario.

Keywords: CO_2, Open top chamber, Pea, Temperature, Vegetables

INTRODUCTION

The global annual mean concentration of CO_2 in the atmosphere has increased markedly from 280 ppm to 400 ppm since the industrial revolution during 18th century. Atmospheric CO_2 is expected to reach 700 ppm by the end of the century according to the Intergovernmental Panel on Climate Change (IPCC) under emission Scenario A1B (Carter *et al*., 2007). 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, pea (*Pisum sativum* L.) is the most widely produced and consumed vegetable. 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 (Shukla *et al.,* 2011).

However increasing level of CO_2 and temperature is affecting the growth and development of pea 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). 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

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crop systems to elevated CO_2 (Ainsworth *et al*., 2002; Ainsworth and Long, 2005). However, fewer studies have been conducted on responses of crops to both high CO_2 and temperature (Prasad *et al.,* 2002, 2003) and no such study has been conducted in Himachal Pradesh on vegetables. Hence there is urgent need to understand the effects of changing climate on growth and development of pea under elevated CO_2 and temperature conditions. The objective of this study was to investigate the effects of increasing CO_2 concentration and temperature on growth and development in pea, *P. sativum.*

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 2014-15. Farm is situated at 30˚5'N latitude and about 77˚11'E longitudes and at an elevation of1260 m above mean sea level. Circular type open top chambers (OTC) of 4 x 4 m^2 dimension 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 toautomatically 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). The concentration of CO_2 in the chamber was monitored by a non dispersive infrared (NDIR) gas analyser. There were four treatmentsi.e.T_1: elevated CO_2 (550 ±10 ppm), T_2: elevated CO_2 and temperature (CO_2:550 ±10 ppm, temperature: 1°C elevated than T_1), T_3: ambient temperature condition (reference) and T_4: natural air and temperature condition (control). Each replication was replicated thrice. Two pea cultivar Azad P-1 and Pb-89 were sown during crop growing season in 2014-15 under all the four conditions by following recommended package of practices of vegetable crops (YSPUHF, 2009).

For recording data five plants were selected randomly from each treatment in each replication.The observations were recorded on growth parameters like plant height at 50 per cent flowering, plant height at maturity, days to 50 per cent flowering, pollen viability, inter -node length, leaf area, leaf water content and days to first picking of fruits. The height of the plant was measured in centimeters from the soil line to highest tip of the plant at 50 % flowering and at maturity. For days to 50 % flowering the numbers of days were counted from date of sowing to when 50 % out of total plants got flowering. Leaf area (cm^2) at peak vegetative stage was recorded on automatic leaf area meter available at the department. Leaf water content was measured as per method of Barr and Weatherley (1962). The data recorded on different parameters were analyzed statistically with the help SPSS Statistics 21 as per the method described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

It is evident from Table 1 that irrespective of varieties pea plants were found to obtain significantly (P=0.05) higher height of 84.29 cm at the stage of 50 % flowering when exposed to elevated CO_2, which differed significantly with height of plants in rest of treatments. It was followed by elevated CO_2 and temperature (79.47 cm), ambient CO_2 and temperature (73.60 cm), natural condition (70.73 cm) and lowest plant height was recorded under natural condition. Plant height (79.68 cm) recorded at 50 % flowering with Azad P-1 differed significantly (P=0.05) with Pb – 89 (74.37cm). In the interaction effect of verities and treatments it was revealed from the data that Azad P-1exhibited higher plant height of 88.80 cm under elevated CO_2 which differed statistically from rest while Pb - 89 exhibited lowest height of 69.40 cm under natural condition.

There was 14.52 % increase in plant height under elevated CO_2 as compared to ambient CO_2 and temperature while this increase reduced to 3.14 % in plant height under elevated CO_2 and temperature. Whereas plants grown under natural condition showed 3.89 % decrease in plant height as compared to ambient CO_2 and temperature.

Similarly, irrespective of varieties maximum plant height at maturity was recorded in elevated CO_2 (97.02 cm) which was statistically at par with plant height under elevated CO_2 and temperature (91.88 cm) and differed significantly (P=0.05%) with plants height under ambient CO_2 and temperature (85.20 cm) and natural condition (82.52 cm). Minimum plant height was recorded under natural condition. Maximum plant height of Azad P - 1 recorded (93.33 cm) at maturity differed significantly with Pb - 89 (84.97 cm). There was 13.87 % increase in plant height under elevated CO_2 as compared to ambient CO_2 and temperature while it reduced to 7.84 % in plant height under elevated CO_2 and temperature. Whereas plant height under natural condition showed 3.15 % decrease as compared to ambient CO_2 and temperature.

In the present investigation, the maximum plant height at 50 per cent flowering as well as at maturity was recorded under elevated CO_2 as compared to ambient CO_2 and temperature which may be due to increased cell division, cell expansion, cell differentiation and high vegetative growth which resulted in stimulation of internode elongation under the influence of increased CO_2. Similar to present investigations Pilumwong *et al.* (2007) reported that elevated CO_2 resulted greater plant height in mung bean at different growth stages.

Data on days to 50 % flowering of pea revealed that amongst all treatments, minimum days to 50 % flowering were recorded under elevated CO_2 and temperature (68.56 days) followed by plants grown under elevated CO_2 (74.31 days), ambient CO_2 and temperature (84.81 days) and natural condition (94.10 days). Highest days to 50% flowering were recorded in plants growing under natural ambient air and temperature (94.10 days). Pb - 89 recorded minimum days to 50% flowering (76.11 days) as compared with Azad P-1 (84.79 days, both differed significantly with each other. There was 12.38 % decrease in days to 50 % flowering in plants grown under elevated CO_2 condition as compared to ambient CO_2 and temperature while 19.16 % decrease in days to 50 % flowering in plants grown under elevated CO_2 and temperature. Pea plants grown under natural condition showed 10.95 % increase over ambient CO_2 and temperature.

In the present investigation pea plant grown under elevated CO_2 and temperature took less days to 50 % flowering than elevated CO_2 and it took maximum days to 50 % flowering in natural ambient air and temperature condition. This may be due to the effect of elevated temperature in T_2 (elevated CO_2 and temperature) which caused earlier flowering by accelerating flower development while delayed 50 % flowering under natural ambient air and temperature which may be due to low temperature condition. The present findings corroborate the findings of Rani and Maragatham (2013) who reported that 50 % flowering and harvest for the rice crop raised under elevated temperature was

Table 1: Effect of elevated CO_2 and temperature on plant height, flowering and pollen viability of pea.

				Per cent increase/decrease (%)		
Treatment	**Azad P – 1**	**Pb - 89**	**Mean**	**Azad P - 1**	**Pb - 89**	**Mean**
1. Plant height At 50 % flowering						
T_1 : elevated CO_2 550±10PPM	88.80	79.78	84.29	19.68	9.29	14.52
T_2 : elevated CO_2 550±10PPM and elevated temperature 1˚C	83.66	75.29	79.47	12.75	3.14	7.98
T_3 : ambient CO_2 and temperature	74.20	73.00	73.60	-	-	-
T_4 : natural ambient air and temperature condition (control)	72.07	69.40	70.73	- 2.87	- 4.93	- 3.89
Mean	**79.68**	**74.37**	**77.02**	**7.39**	**1.87**	**4.65**
CD (p = 0.05) : Treatment : 3.99; Variety : 0.13; Interaction : 0.26;						
2. Plant Height at maturity						
T_1 : elevated CO_2 550±10PPM	101.47	92.57	97.02	14.88	12.79	13.87
T_2 : elevated CO_2 550±10PPM and elevated temperature 1˚C	98.33	85.44	91.88	11.32	4.11	7.84
T_3 : ambient CO_2 and temperature	88.33	82.07	85.20	-	-	-
T_4 : natural ambient air and temperature condition(control)	85.20	79.83	82.52	- 3.54	- 2.73	-3.15
Mean	**93.33**	**84.97**	**89.16**	**5.66**	**3.53**	**4.65**
CD (p = 0.05) : Treatment :8.12; Variety :5.74; Interaction : NS;						
3. Days to 50 % flowering						
T_1 : elevated CO_2 550±10PPM	78.46	70.17	74.31	- 13.30	- 11.32	- 12.38
T_2 : elevated CO_2 550±10PPM and elevated temperature 1˚C	70.06	67.07	68.56	- 22.59	- 15.24	- 19.16
T_3 : ambient CO_2 and temperature	90.50	79.13	84.81	-	-	-
T_4 : natural ambient air and temperature condition(control)	100.13	88.06	94.10	10.64	11.29	10.95
Mean	**84.79**	**76.11**	**80.45**	**- 6.31**	**- 3.82**	**- 5.15**
CD (p = 0.05) : Treatment :4.52; Variety :3.19; Interaction : NS;						
4. Pollen Viability (%)						
T_1 : elevated CO_2 550±10PPM	76.27	78.57	77.42	0.74	2.03	1.39
T_2 : elevated CO_2 550±10PPM and elevated temperature 1˚C	69.31	70.62	69.97	- 8.45	- 8.30	- 8.37
T_3 : ambient CO_2 and temperature	75.71	77.01	76.36	-	-	-
T_4 : natural ambient air and temperature condition (control)	74.00	75.30	74.65	- 2.26	- 2.22	- 2.24
Mean	**73.82**	**75.37**	**74.60**	**- 2.50**	**- 2.13**	**- 2.30**
CD (p = 0.05) : Treatment :1.81; Variety :1.28; Interaction :NS;						

*Values in table are mean of three replications, each replication contain five plants

Table 2. Effect of elevated CO_2 and temperature on internodes length, leaf water content, leaf area, days to first picking of fruits and harvest duration of pea.

				Per cent increase/decrease (%)		
Treatment	**Azad P – 1**	**Pb - 89**	**Mean**	**Azad P - 1**	**Pb - 89**	**Mean**
1. Internode length (cm)						
T_1 : elevated CO_2 550±10PPM	7.76	6.27	7.01	21.25	11.96	16.92
T_2 : elevated CO_2 550±10PPM and elevated temperature 1˚C	7.53	5.83	6.68	17.66	4.11	11.33
T_3 : ambient CO_2 and temperature	6.40	5.60	6.00	-	-	-
T_4 : natural ambient air and temperature condition (control)	5.40	4.70	5.05	- 15.63	- 16.07	- 15.83
Mean	**6.77**	**5.60**	**6.19**	**5.82**	**0.00**	**3.10**
CD (p = 0.05) : Treatment :0.74; Variety :0.52; Interaction : NS;						
2. Leaf Water Content (%)						
T_1 : elevated CO_2 550±10PPM	89.62	87.94	88.78	4.72	6.45	5.58
T_2 : elevated CO_2 550±10PPM and elevated temperature 1˚C	83.52	81.74	82.63	- 2.41	- 1.05	- 1.74
T_3 : ambient CO_2 and temperature	85.58	82.61	84.09	-	-	-
T_4 : natural ambient air and temperature condition(control)	80.53	77.24	78.88	- 5.90	- 6.50	- 6.20
Mean	**84.81**	**82.38**	**83.59**	**- 0.90**	**- 0.28**	**- 0.59**
CD (p = 0.05) : Treatment : 4.21; Variety : NS; Interaction : NS;						
3. Leaf Area (cm^2)						
T_1 : elevated CO_2 550±10PPM	68.57	74.44	71.51	4.30	9.89	7.15
T_2 : elevated CO_2 550±10PPM and elevated temperature 1˚C	66.37	68.71	67.54	0.96	1.43	1.20
T_3 : ambient CO_2 and temperature	65.74	67.74	66.74	-	-	-
T_4 : natural ambient air and temperature condition(control)	62.68	65.30	63.98	- 4.65	- 3.60	- 4.14
Mean	**65.84**	**69.05**	**67.45**	**0.15**	**1.93**	**1.06**
CD (p = 0.05) : Treatment : 4.23; Variety : 2.99; Interaction : NS;						
4. Days to first picking of pods						
T_1 : elevated CO_2 550±10PPM	104.17	88.97	96.57	- 3.61	- 9.79	- 6.56
T_2 : elevated CO_2 550±10PPM and elevated temperature 1˚C	100.07	85.20	92.63	- 7.40	- 13.62	- 10.37
T_3 : ambient CO_2 and temperature	108.07	98.63	103.35	-	-	-
T_4 : natural ambient air and temperature condition (control)	121.10	109.10	115.10	12.06	10.62	11.37
Mean	**108.35**	**95.47**	**101.91**	**0.26**	**3.20**	**1.39**
CD (p = 0.05) : Treatment : 2.08; Variety : 1.47; Interaction : 2.94;						

*Values in table are mean of three replications, each replication contain five plants

found to be shorter than ambient temperature.

In the present investigation, maximum pollen viability (77.42 %) was recorded in elevated CO_2 condition which is statistically (P=0.05) at par with ambient CO_2 and temperature condition (76.36 %) and differed from natural air and temperature condition (74.65 %) and elevated CO_2 and temperature (69.97 %). Maximum pollen viability of 75.37 % was recorded in PB - 89 which differed significantly with Azad P-1(73.82 %).

There was 1.39 % increase in pollen viability of pea grown under elevated CO_2as compared to ambient CO_2 and temperature while 8.37 % decrease in pollen viability under elevated CO_2 and temperature. While plants grown under natural condition showed 2.24 % decrease over ambient CO_2 and temperature.

Pollen viability was found to be minimum in elevated CO_2 and temperature which can be due to high temperature stress on pollen development while maximum in elevated carbon dioxide condition which can be due to carbon fertilization effect.The direct temperature effects on plants are important and there were negative interactions between temperature and CO_2 on pollen viability as similar reported by Suzuki *et al*. (2001) that lower pollen viability of green bean (*Phaseolus vulgaris* L.) at high temperatures could be related to degeneration of tapetum layer and also findings of Harsant *et al.* (2013) support the present findings that increased temperature declines in pollen viabilityin C_3 model grass *Brachypodium distachyon*.

Plants grown under elevated CO_2 attained maximum (7.01 cm) internode length which was statistically at par with elevated CO_2 and temperature (6.68 cm) and differed significantly (P=0.05) from ambient CO_2 and temperature (6.00 cm), and natural air and temperature (5.05 cm) (Table 2). Lowest internode length (5.05 cm) was recorded under natural condition i.e. control. Higher internode length of 6.77cm was recorded inAzad P - 1 which differed significantly with Pb - 89 (5.60 cm).

Plants grown under elevated CO_2 showed 16.92 % increase in internode length whereas plants grown under elevated CO_2 and temperature showed 11.33 % increase over ambient CO_2 and temperature while plants under natural condition showed 15.83 % decrease over ambient CO_2 and temperature.

In the present study, higher internode length was observed under elevated CO_2 which may be due to higher photosynthetic response to enriched CO_2 which resulted in increased cell division, cell expansion, cell differentiation. Similar to present findings, Prasad *et al.* (2005) found that elevated CO_2 resulted increase in internode length in grain legumes. Similarly Mendes *et al.* (2014) also reported that the exposure of *B. dracunculifolia* to elevated CO_2 resulted in a significant increase length of internodes (increase of 17%) than plants grown in ambient CO_2. While internode length were found to be decreased under elevated CO_2 and temperature as compared to plants grown under elevated CO_2 condition which may be due to effect of elevated CO_2 might be offset by the adverse effect of elevated temperature as found by Wang *et al.* (2008).

Elevated CO_2 treatment recorded maximum (88.78 %) leaf water content which differs significantly (P=0.05) with plants grown under ambient CO_2 and temperature (84.09 %) and elevated CO_2 and temperature (82.63 %) and natural condition (78.88 %). Minimum leaf water content was recorded in natural condition (78.88 %) which was statistically at par with elevated CO_2 and temperature (82.63 %). Pea plants grown under elevated CO_2 recorded 5.58 % increase for leaf water content and plants under elevated CO_2 and temperature recorded 1.74 % decrease over ambient CO_2 and temperature while pea plants grown under natural condition had 6.20 % decrease overambient CO_2 and temperature.

In the present findings, leaf water content was minimum under elevated CO_2 and temperature which may be due to increase in overall temperature which caused reduction in water content more rapidly by more evapotranspiration as compared to other conditions. The results are in conformity with findings of Omae *et al.* (2005) who also reported that reduction in relative leaf water content became faster with the increase in temperature in snap bean (*Phaseolus vulgaris* L.).

Plants grown under elevated CO_2 condition revealed maximum (71.51 cm^2) leaf area which was statistically at par with plants grown under elevated CO_2 and temperature (67.54 cm^2) and significantly different from ambient CO_2 and temperature (66.74 cm^2) as well as from natural ambient air and temperature. Lowest leaf area (63.98 cm^2) was recorded under natural condition *i.e.* control. Plants grown under elevated CO_2 recorded 7.15 % increase, while 1.20 % increases in leaf area for plants grown under elevated CO_2 and temperature over ambient CO_2 and temperature and there was 4.41 % decrease for leaf area of pea plants under natural condition.

Leaf area 69.05 cm^2 of Pb - 89 recorded differed statistically (P=0.05) with Azad P - 1 (65.84 cm^2). Maximum leaf area was recorded in plants under elevated CO_2 while lowest was found in natural ambient air and temperature which may be due to carbon fertilization effect in elevated CO_2 condition. The present finding corroborate the findings of Zhao *et al.* (2013) who reported that cotton (*Gossypium hirsutum* L.) plants grown in elevated CO_2 had significantly greater leaf area and higher leaf photosynthesis than plants in ambient CO_2.

Minimum days to first picking of pods were recorded in pea plants grown under elevated CO_2 and temperature (92.63 days) followed by plants grown under elevated CO_2 (96.57 days), ambient CO_2 and temperature (103.35 days) and natural ambient air and temperature. Maximum days to first picking of fruits were recorded under natural ambient air and temperature (115.10 days). Minimum days to first picking of fruits were taken by Pb - 89 (95.47 days) which was statistically different (P=0.05) from Azad P - 1 (108.35days). Maximum days to first picking were taken by Azad P - 1 (121.10 days) under open natural conditions which differed statistically from rest of treatments. Lowest days were taken by Pb - 89 (85.20days) under elevated CO_2 and temperature. There was 6.56 % decrease for days to first picking of pods under elevated CO_2 and 10.37 % decrease under elevated CO_2 and temperature as compared to ambient CO_2 and temperature while 11.37 % increase over reference for plants grown under natural condition.

In present investigations, minimum days to first picking of fruits recorded under elevated CO_2 and temperature may be due to the effect of elevated temperature and CO_2 which might hasten the reproductive development of plants and ultimately short 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 elevated CO_2 and temperature rate of reproductive development got accelerated which shortened the fruit maturation period and also resulted in lower fruit weight in tomato crop.

Conclusion

The present investigation indicated that elevated CO_2 has positive effect on plant growth and development of pea crop. However, under interactive effect of elevated CO_2 and elevated temperature, rising temperature negated the positive effects of elevated CO_2 in pea crop. Most of plant growth and development characters under study were higher in Pb - 89 as compared to Azad P - 1 of pea under the influence of elevated CO_2 and interactive effect of elevated CO_2 and temperature. Hence, pea cultivar Pb–89 was more adaptable to climate change as compared with Azad P - 1 under the influence of elevated CO_2 and interaction effect of elevated CO_2 and temperature.

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