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

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ABSTRACT

An experiment was conducted during 2014 and 2015 at Solan, Himachal Pradesh to study the effect of elevated CO_2 (eCO_2) and temperature (eT) on growth and yield contributing parameters of pea (*Pisum sativum* L.) crop under four conditions of CO_2 and temperature in open top chambers and open natural condition. The study revealed that pea plants performed better under eCO_2, with slight changes in development and yield attributing traits, depending on the cultivars. However, the beneficial direct impact of elevated CO_2 (eCO_2) on crop yield can counteract by elevated temperature (*e*T). Pooled data for two years indicated that growth and yield attributing traits like plant height, days to first harvest of pods, harvest duration, fresh weight and biomass, number of pods per plant, pod length, pod girth, pod yield were improved under eCO_2. However, responses of these attributes were negated with *e*T. Pea cultivars PB-89 performed well under eCO_2 and *e*T conditions as compared to Azad P-1.

Key words: Elevated CO_2, elevated temperature, pea, yield, vegetables, OTC.

Agricultural production system is largely affected due to variability and change in climatic parameters viz. temperatures, rainfall, changes in atmospheric carbon dioxide concentrations as induced by global warming. Carbon dioxide is fundamental for plant production and its rising concentrations have the potential to enhance of agro-ecosystem's productivity and it is estimated that vegetable crop yield increase to 10 per cent for every 100 ppm increase in CO_2 concentration (Miglietta *et al.*, 1998). The rise in carbon dioxide levels is associated with an increase in average global temperature. The availability of suitable growing period in India is likely to be impacted seriously by climate change and global warming.

Vegetable cultivation in Himachal Pradesh has gained significant importance on account of favorable agro-climatic conditions for growing quality off-season vegetables. 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. During 2015, pea was grown in an area of 23623 hectares with annual production of about 277718 metric tones respectively (DOA, 2016). However increasing level of CO_2 and temperature is affecting the growth and development of pea in the region and these events can cause drastic reductions in commercial yield and affect the livelihood of farmers.

A large number of studies have been conducted on responses of various types of crop systems to elevated CO_2 and temperature (Jyothilakshmi *et al.* 2017; Singh *et al.* 2013; Mukherjee *et al.* 2015; Kumari *et al.* 2019). The quantification of impact of elevated CO_2 and temperature on growth and yield attributes of pea in Himachal Pradesh has not been investigated. Therefore, the present investigation was carried out to study the effects of increasing CO_2 concentration and temperature on growth and yield contributing parameters of vegetable crop pea.

MATERIALS AND METHODS

The present investigations was conducted at experimental farm of Department of Environmental Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India in year 2014-2015 and 2015-16. Farm is situated at 30°5' N latitude and about 77°11' E longitudes and 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 elevated carbon dioxide (eCO_2), elevated carbon dioxide (eCO_2) + elevated temperature (*e*T) and ambient CO_2 (aCO_2) and temperature (*a*T). An automatic CO_2 enrichment and

temperature technology was developed by adapting software Supervisory Control And Data Acquisition (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). The concentration of CO_2 in the chamber was monitored by a non-dispersive infrared (NDIR) gas analyser. 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 (381±10 ppm) and aT (23.55 °C) (reference) and

T_4: natural air (CO_2 355±10 ppm) and temperature (21.6 °C).

In each treatment there were two varieties of pea which were replicated thrice. Pea cultivar Azad P-1 and Pb-89 were sown following recommended package of practices of vegetable crops.

For recording data five plants were selected randomly from each treatment in each replication. Significance (P=0.05) of each treatment was calculated. The observations were recorded on plant height, days to first picking pods, harvest duration, plant fresh weight, biomass, number of pods per plant, pod length, pod girth, number of grains per pod, average pod weight and pod yield. The pooled analysis was done 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

Growth parameters and phenology

Analysis of data revealed that the growth parameters and phenology of pea were significantly (P=0.05) influenced by eCO_2 and eT (Table 1). Higher plant height of pea (97.8 cm) was recorded under eCO_2 which differed statistically with eCO_2 and eT (91.7cm), aCO_2 and aT (85.9 cm) and natural condition (82.4 cm). Azad P - 1 cultivar recorded higher plant height (94.2 cm) at maturity which differed significantly with PB - 89 (84.7cm) cultivar. The maximum plant height recorded under eCO_2 as compared to aCO_2 and aT 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 eCO_2 resulted greater plant height in mung bean at different growth stages.

The lowest number of days to first picking of pods (92.7 days) were recorded under eCO_2 and eT and maximum days were recorded under open natural condition. Days to first picking of pods under eCO_2 were 97.1 days, while under aCO_2 and aT were 102.9 days and natural condition took 114.9 days (Table 1). In case of varieties, PB - 89 recorded significantly lower days to first picking of pods (95.9 days) compared to Azad P - 1 (107.9 days). In the present study, lower days to first picking of pods were recorded under eCO_2 and eT which may be due to the effect of higher temperature and CO_2 that might hasten the reproductive development of plants and ultimately shortened the fruit maturation time which leads to early maturity of fruits. The present findings are in confirmation with the findings of Rao *et al.* (2010) who reported that due to eCO_2 and temperature rate of reproductive development got accelerated which shortened the fruit maturation period and also resulted in rapid maturation of fruits.

Similarly, harvest duration was recorded lowest (22.2 days) under eCO_2 and eT which differed statistically from rest of the treatments. Maximum harvest duration (42.5 days) was recorded under natural condition followed by aCO_2 and aT (39.3 days) and eCO_2 (28.0 days). In case of varieties, significantly higher harvest duration (7 days) was recorded in PB - 89 i.e. 36.6 days as compared to Azad P - 1 (29.5 days). As longest harvest duration was recorded under natural condition which may be due to long duration of crop growth while duration got reduced under eCO_2 and eT which may be due to early maturity under the influence of higher temperature and CO_2. Wheeler *et al.* (1996) also reported that increased in temperature reduced the duration of crop growth.

Plant fresh weight was found significantly higher (72.8 g plant^{-1}) under eCO_2 followed by eCO_2 and eT (67.4 g plant^{-1}), aCO_2 and aT (61.0 g plant^{-1}) and natural condition (56.3 g plant^{-1}) (Table 1). Natural condition recorded lowest plant fresh weight. Azad P-1 cultivar recorded significantly (P=0.05) higher plant fresh weight (67.8 g plant^{-1}) as compared to PB - 89 (60.9 g plant^{-1}) cultivar. The results in present investigations revealed that pea plants grown under eCO_2 as well as eCO_2 and eT produced significantly higher plant fresh weight as compared to aCO_2 and aT and natural condition. Similarly, plant dry weight or biomass (36.2 g

Table 1: Effect of elevated CO_2 and temperature on plant height (cm), days taken to first picking of pods, harvest duration, plant fresh weight (g), dry weight (g/plant) and number of pods per plant of pea (two years pooled data).

Treatment	Plant height (cm)			Days to first picking (days)			Harvest duration (days)			Fresh weight of plant (g)			Dry weight (biomass) (g plant^{-1})			Number of pods per plant		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 :	102.4	93.2	97.8	103.5	90.6	97.1	25.5	30.5	28.0	75.6	69.9	72.8	40.7	31.6	36.2	41.1	49.9	45.5
T_2 :	98.7	84.8	91.7	99.5	85.9	92.7	19.4	24.9	22.2	70.7	64.1	67.4	36.9	26.9	31.9	37.6	45.8	41.7
T_3 :	90.0	81.7	85.9	108.2	97.6	102.9	34.5	44.2	39.3	63.6	58.4	61.0	29.5	23.8	26.6	34.9	41.7	38.3
T_4 :	85.7	79.2	82.4	120.3	109.6	114.9	38.4	46.7	42.5	61.4	51.2	56.3	26.2	21.1	23.6	29.8	37.3	33.5
Mean	94.2	84.7	89.5	107.9	95.9	101.9	29.5	36.6	33.0	67.8	60.9	64.4	33.3	25.8	29.6	35.8	43.7	39.8
CD (p =0.05)																		
Treatment (T) :			5.0			2.0			1.7			3.5			2.0			1.9
Variety (V) :			3.6			1.4			1.2			2.5			4.0			3.8
Treatment x Variety (Txv):			NS			NS			NS			NS			NS			NS

V_1 = Azad P-1, V_2 = PB-89; T_1 = eCO_2, T_2 = eCO_2+eT, T_3 = aCO_2 + aT, T_4 = natural condition

plant^{-1}) was higher in pea plants grown under *e*CO_2 followed by *e*CO_2 and *e*T (31.9 g plant^{-1}), *a*CO_2 and *a*T (26.6 g plant^{-1}) and natural condition (23.6 g plant^{-1}). Lowest plant dry weight was obtained under natural condition (i.e. control). In case of varieties, Azad P-1 recorded significantly (P=0.05) higher plant dry weight (33.3 g plant^{-1}) as compared to PB -89 (25.8 g plant^{-1}). In present study highest dry weight was recorded in plants grown under *e*CO_2 followed by *e*CO_2 and *e*T which may be due to effect of higher CO_2 and temperature which stimulated higher vegetative growth of plant and resulted increased total fresh weight as well as biomass accumulation under enriched carbon and *e*T.

Yield and yield attributes

The number of pods (45.5 pods plant^{-1}) were higher in pea plants grown under *e*CO_2 which differed statistically with rest of treatments (Table 1). Under *e*CO_2 and *e*T number of pods were 41.7 pods plant^{-1}, followed by *a*CO_2 and temperature (38.3 pods plant^{-1}) and natural condition (33.5 pods plant^{-1}). PB – 89 cultivar produced higher number of pods per plant (43.7 pods plant^{-1}) as compared to Azad P - 1(35.8 pods plant^{-1}). In our findings, maximum number of pods were produced in pea plants grown under *e*CO_2 which may be due to higher photosynthetic rate under enriched CO_2 which resulted more production of soluble proteins, sugars like carbohydrates and amino acids. These compounds are then used as building blocks and form the main structural component of the plant which ultimately affect yield in the form of increased number of pods per plant. Similarly Ackerson *et al.* (1984) reported more number of pods and seeds per plant under CO_2 enrichment which attributed the high seed yield.

Higher pod length (10.1 cm) was recorded in pea plants grown under *e*CO_2 which was statistically at par with *e*CO_2 and *e*T (9.7 cm) and differed statistically from *a*CO_2 and temperature (9.1 cm) and natural condition (8.4 cm) (Table 2). Comparatively higher pod length was recorded in PB – 89 (10.4 cm) variety as compared to Azad P - 1(8.3 cm). Similarly maximum pod girth (13.7 mm) recorded under *e*CO_2 was significantly different from *e*CO_2 and temperature (12.7 mm), *a*CO_2 and *a*T (11.9 mm) and natural condition (11.8 mm). Lowest pod girth (11.8 mm) was recorded under natural condition i.e. control. Significantly (P=0.05) higher pod girth was recorded in PB - 89 (13.4 mm) as compared to Azad P - 1 (11.7 mm). Higher pod size i.e. pod length and pod girth was recorded under *e*CO_2 in comparison to *a*CO_2 and *a*T which may be due to carbon enrichment/fertilization effect which caused higher photosynthesis and resulted more

Table 2: Effect of elevated CO_2 and temperature on pod length (cm), pod girth (mm), number of grains/pod, average pod weight, pod yield per plant (g) and total pod yield (kg ha^{-1}) in pea (two years pooled data).

Treatment	Pod length			Pod girth			Number of grains/pod			Average pod weight(g)			Pod yield per plant (g)			Total pod yield (kg ha-1)		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1 :	9.1	11.2	10.1	12.8	14.7	13.7	8.8	9.7	9.2	7.8	9.5	8.6	132.9	171.6	152.3	26587	34320	30453
T_2 :	8.3	11.0	9.7	12.1	13.4	12.7	7.5	8.2	7.8	7.6	8.6	8.1	108.2	145.4	126.8	21639	29073	25356
T_3 :	8.1	10.1	9.1	10.6	13.1	11.9	6.9	7.5	7.2	5.7	6.5	6.1	97.6	130.8	114.2	19515	26153	22834
T_4 :	7.7	9.2	8.4	11.3	12.3	11.8	6.4	7.2	6.8	4.7	5.9	5.3	66.1	98.1	82.1	13213	19620	16417
Mean	8.3	10.4	9.3	11.7	13.4	12.5	7.4	8.1	7.8	6.5	7.6	7.0	101.2	136.5	118.8	20238	27292	23765
CD (p =0.05)																		
Treatment:			0.8			0.8			0.6			0.7			12.4			2479
Variety:			0.6			0.4			0.4			0.5			8.8			1753
Treatment × Variety:			NS			NS			NS			NS			NS			NS

V_1 = Azad P-1, V_2 = PB-89; T_1 = eCO_2, T_2 = eCO_2+eT, T_3 = aCO_2 + aT, T_4 = natural condition

production of carbohydrates, proteins and amino acids. The abundance of these structural compounds in plant system lead to better growth of pods and affect size positively. The results are in consonance with findings of Hartz *et al*. (1991) who reported that carbon dioxide enrichment significantly increased fruit size in vegetable crops.

Pea plants grown under *e*CO_2 resulted maximum number of grains per pod (9.2) which was statistically different with *e*CO_2 and *e*T (7.8), *a*CO_2 and *a*T (7.2) and natural condition (6.8) (Table 2). Lowest number of grains per pod was recorded under natural condition. PB - 89 recorded significantly higher number of grains per pod (8.1) as compared with Azad P - 1 (7.4). Average pod weight (8.6 g pod^{-1}) was higher in plants grown under *e*CO_2 which was statistically at par with *e*CO_2 and *e*T (8.1 g pod^{-1}) and differed significantly from *a*CO_2 and *a*T (6.1 g pod^{-1}) and natural condition (5.3 g pod^{-1}). Significantly higher average pod weight was recorded in PB - 89 (7.6 g pod^{-1}) as compared with Azad P - 1(6.4 g pod^{-1}) (Table 2). Higher average pod weight obtained in plants grown under *e*CO_2 may be due to higher photosynthetic rate under enriched CO_2 which resulted formation of structural compounds in abundance like soluble proteins, amino acids and sugars. The present results are in line with the findings of Stanciel *et al.* (2000) who reported that pod weight of peanut was significantly higher at 1200 mmol.mol^{-1} CO_2 than ambient, reflecting both an increase in pod number as well as assimilate partitioning to the pods.

Pod yield per plant (152.3 g plant^{-1}) was highest under *e*CO_2 which was significantly (P=0.05) superior over *e*CO_2 and *e*T (126.8 g plant^{-1}) and *a*CO_2 and *a*T (114.2 g plant^{-1}) and lowest yield per plant (82.1 g plant^{-1}) was obtained in natural condition (Table 2). All the treatments were significantly different from each other. Significantly maximum pod yield was recorded in PB – 89 (136.5 g plant^{-1}) cultivar as compared with Azad P - 1 (101.2 g plant^{-1}). Similarly highest pod yield (30453 kg ha^{-1}) was recorded under *e*CO_2 which was significantly superior over *e*CO_2 and *e*T (25356 kg ha^{-1}), *a*CO_2 and *a*T (22834 kg ha^{-1}) and lowest pod yield (16417 kg ha^{-1}) was obtained in natural condition. PB - 89 recorded significantly higher pod yield (27292 kg ha^{-1}) as compared to Azad P - 1 (20238 kg ha^{-1}). In present findings, increases in pod yield at *e*CO_2 were mainly attributed to increases in number of pods and grains from improved branching and greater number of pods on branches. The present results are in agreement with the findings of Ainsworth *et al*. (2002) who reported that yield of soybean

increased by 24 per cent due to effects of doubled CO_2 over ambient CO_2.

CONCLUSION

Present study revealed that eCO_2 has positive effect on plant growth, phenolgy, yield and yield attributes of pea crop. However, under interactive effect of eCO_2 and eT, rising temperature negated the positive effects of eCO_2 in crop. While it is observed that with increase in temperature along with increasing CO_2 does not harm that much extent if compared with ambient and natural open conditions in cool season crop. Similarly, plant growth parameters, yield and yield attributes under study were higher and better in pea cultivar PB-89 as compared to Azad P-1 under the influence of eCO_2 and interactive effect of eCO_2 and eT. Hence, Pea cultivar PB-89 was more adaptable to climate change as compared with Azad P- 1 under the influence of eCO_2 and interaction effect of eCO_2 and temperature. Though, there is a significant effect of climate change on pea crop, yet the tested cultivars of crop showed differential reaction to climate change.

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