



Impact of elevated CO₂ and temperature on quality and biochemical parameters of pea (*Pisum sativum*)

MEENA KUMARI¹, S C VERMA² and S K BHARDWAJ³

Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh 173 230

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ABSTRACT

Global climate change, i.e. increase in carbon dioxide concentration in atmosphere and the associated increase in temperature result significant positive and negative impacts on the vegetable crop production. The field experiment was conducted during 2014 and 2015 which aimed to study effect of elevated CO₂ and temperature on quality and biochemical parameters of pea (*Pisum sativum* L.) and experiment was carried out under four combinations of CO₂ and temperature. Pooled data for two years indicated that pod length, pod girth, leaf chlorophyll content of pea showed significant differences between all four combinations. Higher total phenols (0.55 g/100g), ascorbic acid content in pods (46.24 mg/100g) were found under elevated CO₂ and least under natural condition (total phenols: 0.37 g/100g) (ascorbic acid: 28.44 mg/100g). Total soluble solids (20.81 °B) and nitrogen content (2.34%) were higher under natural condition and lowest under elevated CO₂ (TSS: 12.47 °B) (N: 1.97%). Higher P (0.29%), K (1.11%) and Mg (1.28%) content was recorded under natural condition as compared to other treatments. Elevated CO₂ recorded significantly higher Ca content (0.56 %) and least under natural condition (0.46 %). Both elevated CO₂ and temperature had significant negative effects on quality and biochemical parameters in pea crop as compared to elevated CO₂ and natural conditions. So changing climate can alter the composition of these important elements in pea crop and degrade the overall quality.

Key words: Elevated CO₂, Elevated temperature, Open top chamber, Pea, Vegetables

The global annual mean concentration of CO₂ in the atmosphere has increased markedly from 280 ppm to 400 ppm since the industrial revolution during 18th century. Atmospheric CO₂ 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) in which scenarios are of a more integrated world and rapid economic growth. Vegetable cultivation in Himachal Pradesh has gained significant importance due to 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. In Himachal Pradesh, pea was grown in an area of 23 623 ha with annual production of about 277 718 metric tonnes respectively, in 2015 (DOA 2016) and at this place 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).

Increasing level of CO₂ 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). The positive effect of elevated CO₂ 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 crops to elevated CO₂ (Ainsworth and Long 2005). Fewer studies have been conducted on responses of crops to both high CO₂ and temperature (Prasad *et al.* 2003) and the quantification of impact of elevated CO₂ and temperature on vegetable quality and biochemical parameters 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 effects of increasing CO₂ concentration and temperature on quality and biochemical

¹Ph D (Environmental Science) (meena.sankhyan@gmail.com), ³Professor and Head (sbhardwajswm@rediffmail.com), Department of Environmental Science, College of Forestry; ²Principal Scientist (svermaento@gmail.com), Department of Entomology, College of Horticulture

parameters in important commercial vegetable crop pea.

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 2013-2014 and 2014-15. 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 × 4 m² dimension were used to raise the crop under elevated and ambient CO₂ and temperature conditions. An automatic CO₂ enrichment and temperature technology was developed by adapting software SCADA to automatically maintain the desired and accurate levels of CO₂ 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, CO₂ analyzer, PC linked Program Logic Control (PLC) and Supervisory Control and Data Acquisition (SCADA). The concentration of CO₂ in the chamber was monitored by a non dispersive infrared (NDIR) gas analyser. There were four treatments, i.e. T₁: elevated CO₂(550 ±10 ppm), T₂:elevated CO₂ and temperature (CO₂:550 ±10 ppm, temperature: 1°C elevated than T₁), T₃: ambient temperature condition (reference) and T₄: 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 2013-2014 and 2014-15 under all the four conditions by following recommended package of practices of vegetable crops (YSPUHF 2009). For recording data five plants (plot size: 3m × 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 various quality and biochemical parameters like pod length, pod girth, 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 H₂SO₄ 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 help of Statistical Product and Service Solutions (SPSS-21) Statistics 21.

RESULTS AND DISCUSSION

Plant quality and biochemical parameters were significantly influenced in pea grown under different conditions of CO₂ and temperature. It is evident from Table 1 that irrespective of varieties pea plants were found to obtain significantly (P=0.05) higher pod length (10.14 cm) when exposed to elevated CO₂, which was statistically at par with elevated CO₂ and temperature (9.67 cm) and differed statistically from ambient CO₂ and temperature (9.12 cm) and natural condition (8.42 cm). Comparatively higher pod length (10.38 cm) was recorded in PB – 89 as compared to Azad P – 1(8.29 cm). Similarly pod girth under elevated

Table 1 Effect of elevated CO₂ and temperature on pod length (cm), pod girth (mm), ash content (%) in pea plants (two years pooled data)

Treatment	Pod length			Pod girth			Ash content		
				Variety					
	Azad P – 1	PB - 89	Mean	Azad P - 1	PB - 89	Mean	Azad P - 1	PB - 89	Mean
T ₁ : Elevated CO ₂ (550±10 PPM)	9.06	11.21	10.14	12.80	14.70	13.75	11.90	11.18	11.54
T ₂ : Elevated CO ₂ and elevated temp (550±10 PPM & 1°C)	8.34	11.00	9.67	12.09	13.40	12.75	9.89	9.75	9.82
T ₃ : Ambient CO ₂ and temperature	8.10	10.14	9.12	10.65	13.06	11.86	8.65	8.09	8.37
T ₄ : Natural condition (control)	7.67	9.17	8.42	11.35	12.27	11.81	8.27	7.77	8.01
Mean	8.29	10.38	9.34	11.72	13.36	12.54	9.68	9.20	9.44
CD (P =0.05)	Treatment: 0.80			Treatment:0.80			Treatment:1.42		
	Variety: 0.57			Variety: 0.45			Variety: NS		
	Treatment × Variety: NS			Treatment × Variety: NS			Treatment × Variety: NS		

CO₂ (13.75 mm) was higher and significantly different from elevated CO₂ and temperature (12.75 mm), ambient CO₂ and temperature (11.86 mm) and natural condition (11.81 mm). Lowest pod girth (11.81 mm) was recorded under natural condition, i.e. control. Significantly higher pod girth was recorded in PB - 89 (13.36 mm) as compared to Azad P - 1 (11.72 mm).

Higher pod size, i.e. pod length and pod girth was recorded under elevated CO₂ in comparison to ambient CO₂ and temperature which may be due to carbon enrichment/fertilization effect which caused higher photosynthesis and resulted more production of carbohydrates, proteins and amino acids. The abundance of these structural compounds in plant system leads 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.

Elevated CO₂ produced significantly (P=0.05) higher ash content (11.54%) which was statistically different from elevated CO₂ and elevated temperature (9.82%), ambient CO₂ and temperature (8.37%) and natural condition (8.01%). Ash content in natural condition was statistically at par with ambient CO₂ and temperature. Elevated CO₂ levels increased ash content as compared to ambient CO₂ and temperature which may be attributed to higher C/N ratio and increased carbon under influence of more photosynthetic activity due to elevated level of CO₂. Similar to present findings, Sreedevi *et al.* (2015) observed in maize genotypes, viz. DHM 117, Harsha and Varun contained significantly higher ash content under elevated CO₂ as compared to ambient CO₂.

Data revealed significant (P=0.05) differences among treatments for total leaf chlorophyll content in leaves of pea. Natural condition recorded higher total leaf chlorophyll (2509.84 mg/kg) content followed by ambient CO₂ and temperature (2472.92 mg/kg), elevated CO₂ (2186.51 mg/kg) and elevated CO₂ and elevated temperature (2090.05 mg/kg), the last two were statistically at par with each other. In response to CO₂ enrichment it results in decline in leaf chlorophyll per unit area due to dilution effect (Epron *et*

al. 1996). The results are in agreement with the findings of Gosavi *et al.* (2014) who reported significant decline in total chlorophyll content under high temperature, suggesting structural damage to chloroplast in sorghum seedlings.

Higher total phenols were recorded under elevated CO₂ (0.55 g/100g) which differed statistically from elevated CO₂ and temperature (0.46 g/100g), ambient CO₂ and temperature (0.40 g/100g) and natural condition (0.37 g/100g). The polyphenol content was much higher at elevated CO₂ which may be due to higher CO₂ favours photosynthetic activity in plant species favouring higher C:N ratio which may have positive impact in the carbon based photo-chemicals such as phenolic compounds and their derivatives in plants. The present results are also supported by findings of Saxon *et al.* (2004) who reported decrease in leaf nitrogen and increase total phenolics in plants grown under elevated CO₂.

A perusal of data presented in Table 2 revealed that significantly (P=0.05) higher ascorbic acid content in pods (46.24 mg/100g) was recorded under elevated CO₂ and temperature followed by elevated CO₂ (42.23 mg/100g), ambient CO₂ and temperature (33.73 mg/100g) and natural condition (28.44 mg/100g), the last two were statistically at par with each other. In present investigations, high ascorbic acid content was found to be in elevated CO₂ and temperature which may be due to cumulative enhancing effect of elevated temperature and elevated CO₂ which caused elevation in levels of ascorbic acid in plants. Carbon based defensive compounds like ascorbic acid, phenolics in cotton plants increased under elevated CO₂ (Coviella *et al.* 2002).

There were significant differences among treatments for the total soluble solids in pea. Higher total soluble solids (20.81 °B) were recorded under natural condition followed by ambient CO₂ and temperature (19.30 °B), elevated CO₂ and temperature (15.04 °B) and elevated CO₂ (12.47 °B). In case of varieties, significantly higher total soluble solids (17.59°B) were recorded in PB - 89 as compared to Azad P - 1 (16.22 °B). Lower total soluble solids were recorded under elevated CO₂ which may be due to production of sugars, organic acids and other substances which contributed to total soluble solids. Total soluble solids levels of the tomato

Table 2 Effect of elevated CO₂ and temperature on total chlorophyll (mg/kg) in fresh weight, polyphenols (g/100g), ascorbic acid (mg/100g) in pea (two years pooled data)

Treatment	Total chlorophyll			Polyphenols (g/100g)			Ascorbic acid		
				Variety					
	Azad P - 1	PB - 89	Mean	Azad P - 1	PB - 89	Mean	Azad P - 1	PB - 89	Mean
T ₁ : Elevated CO ₂ (550±10 PPM)	2145.92	2227.11	2186.51	0.52	0.58	0.55	42.85	41.61	42.23
T ₂ : Elevated CO ₂ and elevated temp (550±10 PPM & 1°C)	2096.15	2083.95	2090.05	0.43	0.49	0.46	46.83	45.67	46.24
T ₃ : Ambient CO ₂ and temperature	2453.43	2492.40	2472.92	0.40	0.41	0.40	35.18	32.28	33.73
T ₄ : Natural condition (control)	2490.11	2529.57	2509.84	0.34	0.39	0.37	29.32	27.56	28.44
Mean	2296.40	2333.26	2314.83	0.42	0.47	0.45	38.54	36.78	37.66
CD (P =0.05)	Treatment: 178.19			Treatment: 0.02			Treatment: 7.04		
	Variety: NS			Variety: 0.01			Variety: NS		
	Treatment × Variety: NS			Treatment × Variety: NS			Treatment × Variety: NS		

Table 3 Effect of elevated CO₂ and temperature on total soluble solids (°B), nitrogen (%), phosphorus (%) in pea (two years pooled data)

Treatment	TSS			Nitrogen			Phosphorus		
				Variety					
	Azad P - 1	PB - 89	Mean	Azad P - 1	PB - 89	Mean	Azad P - 1	PB - 89	Mean
T ₁ : Elevated CO ₂ (550±10 PPM)	11.26	13.68	12.47	1.89	2.06	1.97	0.18	0.22	0.20
T ₂ : Elevated CO ₂ and elevated temp (550±10 PPM and 1°C)	14.50	15.58	15.04	1.92	2.09	2.01	0.15	0.21	0.18
T ₃ : Ambient CO ₂ and temperature	19.20	19.40	19.30	2.21	2.38	2.29	0.21	0.29	0.25
T ₄ : Natural condition (control)	19.94	21.68	20.81	2.27	2.42	2.34	0.24	0.35	0.29
Mean	16.22	17.59	16.91	2.07	2.24	2.16	0.19	0.27	0.23
CD (P =0.05)	Treatment: 1.01			Treatment: 0.06			Treatment:0.03		
	Variety: 0.72			Variety: 0.04			Variety: 0.02		
	Treatment × Variety: NS			Treatment × Variety: NS			Treatment × Variety: 0.04		

fruits exposed to 40 per cent CO₂ tended to decrease with the increasing exposure period and it caused considerably lower total soluble solids values than the treatments lower than 40% CO₂ (Batu and Thompson 1998). Higher CO₂ prevented the production of sugars, organic acids and other chemicals which are the main substance of total soluble solids and ultimately decrease total soluble solids (Hobson and Davies 1971).

Pea plants grown under natural condition (Table 3) recorded higher nitrogen content (2.34 %) which was statistically at par with ambient CO₂ and temperature (2.29 %) and differed statistically with elevated CO₂ and elevated temperature (2.01 %) and elevated CO₂ (1.97 %). Lowest nitrogen content was observed under elevated CO₂. Significantly higher nitrogen content (2.24 %) was recorded in PB – 89 as compared to Azad P - 1 (2.07 %). Nitrogen concentration in pea plants decreased under elevated CO₂ and elevated temperature which may be due to dilution of nitrogen under elevated CO₂ due to higher vegetative growth and more biomass production as compared to ambient CO₂. The present findings are in line with Rao *et al.* (2012) who found that nitrogen concentration in peanut leaves decreased by about 7-8 % and carbon concentration increased by 2.5 to 6 % in plants grown under elevated CO₂.

Higher phosphorus (0.29%) content was recorded under natural condition which differed statistically with rest of treatments and followed by ambient CO₂ and temperature (0.25%), elevated CO₂ (0.20%) and elevated CO₂ and temperature (0.18%). Lower phosphorus concentration was recorded in pea plants grown under elevated CO₂ and temperature. PB - 89 recorded significantly (P=0.05) higher phosphorus content (0.27%) as compared to Azad P - 1 (0.19%). Azad P - 1 recorded 0.21 % phosphorus content under ambient CO₂ and temperature which was statistically at par with same variety under natural condition (0.24%) and PB - 89 under elevated CO₂ (0.22%) and elevated CO₂ and elevated temperature (0.21 %), respectively. In the present study phosphorus content in pea leaves at elevated CO₂ was less as compared to ambient CO₂ and temperature as well as elevated CO₂ and elevated temperature, which indicated that phosphorus is highly mobile within plants and leaves

tended to accumulate phosphorus. Due to more biomass production and higher vegetative growth under influence of elevated CO₂ and temperature in limited soil nutrients the foliar concentration of phosphorus got decreased. The results are in line with the findings of Abdelgawad *et al.* (2014) who reported that in the legumes, elevated CO₂ in combination with high temperature reduced phosphorus (P) contents. A similar trend of decreased nutrient concentration in leaves of lettuce at elevated CO₂ was observed by Giri *et al.* (2016).

Higher potassium content was recorded in plants grown under natural condition (1.11%) which was statistically different from ambient CO₂ and temperature (1.07%), elevated CO₂ (0.93%) and elevated CO₂ and temperature (0.92%). Least potassium content was recorded under elevated CO₂ and temperature. Azad P - 1 recorded higher potassium content (1.09%) as compared to PB - 89 (0.94%), both differed significantly (P=0.05) with each other. Elevated CO₂ recorded less potassium content in leaves of pea as compared to ambient CO₂ and temperature. At elevated CO₂, the concentration of potassium in lettuce and spinach reduced as compared to ambient CO₂ and temperature (Giri *et al.* 2016).

Elevated CO₂ recorded significantly (P=0.05) higher Ca content (0.56%) followed by elevated CO₂ and temperature (0.52%), ambient CO₂ and temperature (0.49%) and natural condition (0.46%). Natural condition was found to be statistically at par with ambient CO₂ and temperature. Significantly higher Ca content was recorded under Azad P - 1 (0.53%) as compared to PB - 89 (0.48%). In the present investigations, it has been observed that calcium content under elevated CO₂ was higher than ambient CO₂ and temperature as well as from elevated CO₂ and temperature. Similar to present investigations, Giri *et al.* (2016) reported that elevated CO₂ increased 17 % higher calcium concentration in spinach shoots than in those grown at ambient CO₂ level.

Plants grown under natural condition of CO₂ and temperature recorded significantly higher magnesium content (1.28%) (Table 4) followed by ambient CO₂ and temperature (1.18%), elevated CO₂ (1.09%) and elevated

Table 4 Effect of elevated CO₂ and temperature on potassium (%), calcium (%), magnesium (%) in pea (two years pooled data)

Treatment	Potassium			Calcium			Magnesium		
	Variety								
	Azad P - 1	PB - 89	Mean	Azad P - 1	PB - 89	Mean	Azad P - 1	PB - 89	Mean
T ₁ : Elevated CO ₂ (550±10 PPM)	1.03	0.84	0.93	0.59	0.53	0.56	1.06	1.14	1.09
T ₂ : Elevated CO ₂ and elevated temp (550±10 PPM & 1°C)	1.01	0.85	0.92	0.55	0.49	0.52	0.94	1.02	0.98
T ₃ : Ambient CO ₂ and temperature	1.14	1.00	1.07	0.51	0.47	0.49	1.17	1.21	1.18
T ₄ : Natural condition (control)	1.18	1.06	1.11	0.48	0.44	0.46	1.27	1.29	1.28
Mean	1.09	0.94	1.01	0.53	0.48	0.51	1.11	1.16	1.14
CD (P =0.05)	Treatment: 0.03 Variety: 0.02 Treatment × Variety: NS			Treatment: 0.04 Variety: 0.03 Treatment × Variety: NS			Treatment: 0.12 Variety: NS Treatment × Variety: NS		

CO₂ and temperature (0.98%). Lowest magnesium content was recorded under elevated CO₂ and temperature. In present investigations, lowest magnesium content was recorded under elevated CO₂ and temperature which may be attributed to low mineral accumulation which was affected by high temperature and high CO₂. Abdelgawad *et al.* (2014) also reported that in the legumes, elevated CO₂ in combination with high temperature reduced magnesium (Mg) contents.

The present studies in this research article indicated that elevated CO₂ has positive effect on plant quality and biochemical parameters of pea crop. However, under interactive effect of elevated CO₂ and elevated temperature, rising temperature negated the positive effects of elevated CO₂ in crop. Similarly, plant quality characters, and biochemical parameters under study were higher and more satisfactory in PB - 89 as compared to Azad P - 1 of pea under the influence of elevated CO₂ and interactive effect of elevated CO₂ and temperature. Pea cultivar PB-89 was more adaptable to climate change (elevated CO₂ and interaction effect of elevated CO₂ and temperature) as compared with Azad P = 1.

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