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Effect of elevated CO_2 and temperature on incidence of diseases in bell pepper (*Capsicum annuum* L.) crop

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Abstract
The present investigations were conducted during 2014 and 2015 to study the effect of elevated CO_2 and temperature on diseases viz. *Phytopthora* blight and *Cercospora* leaf spot infestation and severity on bell pepper (*Capsicum annuum* L.), respectively. The experiment was carried out under four conditions, i.e. 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). The present study reveal that the maximum *Phytophthora* blight incidence was under elevated CO_2 and temperature (22.71%) which differed statistically with elevated CO_2 (16.29%), ambient CO_2 and temperature (11.09%) and natural condition (9.24%). California Wonder recorded significantly higher *Phytophthora* blight incidence (17.81%) as compared to Solan Bharpur (11.87%). Amongst all treatments, higher *Cercospora* leaf spot severity was under elevated CO_2 and temperature (7%) which was statistically at par with elevated CO_2 (5.82%) and differed statistically from ambient CO_2 and temperature (5.22%) and natural condition (3.86%). *Cercospora* leaf spot severity was significantly higher (6.11%) in California Wonder as compared to Solan Bharpur (4.84%). Both elevated temperature and CO_2 had significant effects on diseases infestation and severity of *Phytopthora* blight and *Cercospora* leaf spot, respectively. The crop productivity of bell pepper was affected due to the increase incidence and severity of diseases under changing climatic conditions, i.e. elevated CO_2 and temperature.

Keywords: *Phytophthora nicotianae* var. nicotianae, *Cercospora capisici*, *Capsicum annuum* L., elevated temperature and CO_2, open top chamber, disease incidence, severity

1. Introduction
Climate on Earth has changed many times during the existence of our planet, ranging from the ice ages to periods of warmth. According to Intergovernmental Panel on Climate Change (IPCC) Report [1] the global atmospheric concentration of carbon dioxide (CO_2) has increased from pre-industrial level of 280 ppm to the level of 403.96 ppm [2] and is rising 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. Climate change is predicted to cause an increase in average air temperature, increases in atmospheric CO_2 concentration and significant changes in rainfall pattern [3]. The interaction of elevated CO_2 and warming would determine the extent of impact of climate change on vegetable production over an agro-ecological region.

Vegetables play a pivotal role in Indian agriculture by providing food, nutritional and economic security to the people of India with higher returns per unit area to the producers. The mid hill zone of Himachal Pradesh is endowed with highly congenial climatic conditions for vegetable production. In the mid hill region of 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 a base period of 1971-90 and sub temperate region as a whole experienced scanty rains during winter, summer and spring months resulting water scarcity which has affected the crops [4]. In the state of Himachal Pradesh, this vegetable is grown as off- season vegetable, it brings lucrative price to the farmers and increase the economy of the state. Bell pepper is considered as money-spinner to the hill farmers as they fetch high remuneration due to off-season cultivation [5, 6]. Climate changes may influence the interactions of plant-pathogen and their impact on production is largely debated and represents a challenge for future disease management

programmes under global changing conditions [7]. A large number of multidisciplinary approaches have reported the effects of rising temperature and CO_2 levels on crop productions and physiological changes [8]. Elevated CO_2 influences the pathogenicity, host-pathogen interaction and epidemiology of fungal diseases [9, 10, 11]. Considering that the rising concentrations of CO_2 and other greenhouse gases will lead to an increase in global temperature and longer seasons, we can assume that this will allow more time for pathogens evolution and could increase pathogen survival, indirectly affecting downy and powdery mildews of grapevine [12]. Increased CO_2 concentrations results in enlarged canopy which coupled with a favorable microclimate offers more sites for infection and increases fungal pathogen fecundity, which has been shown to lead to twice the number of lesions for [13, 14]. However, the quantification of impact of elevated CO_2 and temperature on vegetable disease infestations in Himachal Pradesh had not been investigated. So, there was 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 and to screen out the commercial varieties of vegetables resistant to interactive effect of elevated CO_2 and temperature. So the aim of this work was to study the disease infestations like *Phytopthora* blight (%) incidence and *Cercospora* leaf spot severity (%) on commercial varieties of bell pepper under conditions with rising CO_2 concentrations and temperatures in Open Top chambers.

2. Materials and methods

The present investigation was conducted on experimental farm of the Department of Environmental Science, Dr. YS Parmar UHF, Nauni, Solan India in the year 2014 and 2015. Experimental 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 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 the 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 (reference) and T_4: natural air and temperature condition (control).The bell pepper crop was transplanted during crop growing season in 2014 and 2015 under all the four conditions by following recommended package of practices of vegetable crops [15].

2.1 *Phytophthora* leaf blight (*Phytophthora nicotianae* var. nicotianae) incidence (%)

The incidence of *phytophthora* leaf blight caused by *Phytophthora nicotianae* var. nicotianae was assessed by recording the number of plants killed to the total number of plants per plot. Per cent incidence was worked out from the formula:

$$\textit{Phytopthora}\text{ blight incidence (\%)} = \frac{\text{Number of diseased plants}}{\text{Total number of plants/plot}} \times 100$$

2.2 *Cercospora* leaf spot (*Cercospora capisici*) severity (%)

The assessment of severity of *cercospora* leaf spot in the bell pepper crop was done on visual observation and categorized into four grades according to McKinney scale:

Scale	Symptom
0	No visible disease damage
1	0- 25% leaf area is damaged
2	25-50% leaf area damaged
3	50-75% leaf area is damaged, few leaves wilted
4	75-100% Severe defoliation, only new leaves remaining

The per cent severity index was calculated by the formula [16] as under:

$$\text{Disease severity (\%)} = \frac{\text{Sum of all disease ratings}}{\text{Total number of ratings} \times \text{Maximum disease grade}} \times 100$$

Disease rating = Grade × Leaflets in a grade

The data emanating from the above experiments were subjected to statistical analysis through Factorial Randomized Block Design (RBD) and significance of each treatment was calculated as suggested by Cochran and Cox [17]. SPSS-21 software was used for analysis of data.

3. Results and discussion

Bell pepper crop exhibited significant variation in disease incidences like *Phytopthora* blight (%) and *Cercospora* leaf spot severity (%) under elevated CO_2, elevated CO_2 and elevated temperature, ambient CO_2 and temperature as well as under natural condition during the year 2014 and 2015.

3.1 *Phytophthora* leaf blight (*Phytophthora nicotianae* var. nicotianae) incidence

It is evident from Table 1 that during 2014, the incidence of *Phytophthora* blight was recorded maximum under elevated CO_2 and temperature (22.49%) which differed statistically with elevated CO_2 (16.08 %), ambient CO_2 and temperature (11.16%) and natural condition (9.33%), the last two treatments were statistically at par with each other. California Wonder recorded significantly higher *Phytophthora* incidence (17.64%) as compared to Solan Bharpur (11.89%).

Similarly, during 2015, Table 1 depicts that elevated CO_2 and temperature recorded significantly higher *Phytophthora* blight incidence (22.94%) followed by elevated CO_2 (16.51%), ambient CO_2 and temperature (11.04%) and natural condition (9.14%). California Wonder recorded significantly higher *Phytophthora* blight incidence (17.98%) as compared to Solan Bharpur (11.84%). Irrespective of years, maximum *Phytophthora* blight incidence was recorded under elevated CO_2 and temperature (22.71%) which differed statistically with elevated CO_2 (16.29 %), ambient CO_2 and temperature (11.09%) and natural condition (9.24%), the last two treatments were statistically at par with each other. California Wonder recorded significantly higher *Phytophthora* blight incidence (17.81%) as compared to Solan Bharpur (11.87%).

Table 1: Effect of elevated CO_2 and temperature on *Phytopthora* blight incidence (%) in bell pepper

Treatment			*Phytopthora* blight incidence								
			2014			2015			Pooled		
			Variety								
			California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean
T_1	:	Elevated CO_2 (550±10 PPM)	18.96 (4.35)	13.19 (3.58)	16.08 (3.97)	18.88 (4.34)	14.15 (3.74)	16.51 (4.04)	18.92 (4.34)	13.67 (3.66)	16.29 (4.00)
T_2	:	Elevated CO_2 and elevated temp (550±10 PPM & 1°C)	25.67 (5.06)	19.31 (4.37)	22.49 (4.71)	27.07 (5.19)	18.81 (4.33)	22.94 (4.76)	26.37 (5.12)	19.06 (4.35)	22.71 (4.74)
T_3	:	Ambient CO_2 and temperature	14.12 (3.75)	8.19 (2.85)	11.16 (3.30)	14.05 (3.74)	8.03 (2.82)	11.04 (3.28)	14.09 (3.74)	8.11 (2.84)	11.09 (3.29)
T_4	:	Natural condition (control)	11.80 (3.43)	6.86 (2.61)	9.33 (3.02)	11.92 (3.45)	6.37 (2.52)	9.14 (2.98)	11.86 (3.44)	6.62 (2.56)	9.24 (3.00)
Mean			17.64 (4.15)	11.89 (3.35)	14.76 (3.75)	17.98 (4.18)	11.84 (3.35)	14.90 (3.76)	17.81 (4.16)	11.87 (3.35)	14.84 (3.76)
CD (p =0.05)			Treatment: 0.48 Variety: 0.34 Treatment × Variety: NS			Treatment: 0.31 Variety: 0.22 Treatment × Variety: NS			Treatment:0.27 Variety: 0.19 Treatment × Variety: NS		

*Figures in parenthesis are square root transformed values

In the present findings, *Phytophthora* blight incidence was higher under elevated CO_2 and temperature than ambient CO_2 and temperature which may be attributed to elevated CO_2 and temperature which provide a conducive and favourable environment for fungal growth by changing host chemistry. These results are in agreement with the findings [18] who reported that elevated CO_2 and temperature increased the incidence of *Phytophthora* blight in chilli pepper under elevated CO_2 and temperature than ambient condition.

3.2 *Cercospora* leaf spot (*Cercospora capisici*) severity

Data presented in Table 2 revealed that during 2014, amongst all treatments higher *Cercospora* leaf spot severity was recorded under elevated CO_2 and temperature (7.27%), which was statistically at par with elevated CO_2 (5.68%) and differed significantly from ambient CO_2 and temperature (5.21%) and natural condition (3.87%). California Wonder recorded significantly higher (6.21%) *Cercospora* leaf spot severity as compared with Solan Bharpur (4.80%).

Similar trend was observed during 2015, where data in Table 2 revealed that *Cercospora* leaf spot severity was recorded higher under elevated CO_2 and temperature (6.74%), which was statistically at par with elevated CO_2 (5.97%), ambient CO_2 and temperature (5.22%) and differed significantly from the natural condition (3.86%). California Wonder recorded higher *Cercospora* leaf spot severity (6.02%) as compared with Solan Bharpur (4.87%). Irrespective of years, amongst all treatments, higher *Cercospora* leaf spot severity was recorded under elevated CO_2 and temperature (7%) which was statistically art par with elevated CO_2 (5.82%) and differed statistically from ambient CO_2 and temperature (5.22%) and natural condition (3.86%). *Cercospora* leaf spot severity was significantly higher (6.11%) in California Wonder as compared with Solan Bharpur (4.84%).

Table 2: Effect of elevated CO_2 and temperature on *Cercospora* leaf spot severity (%) in bell pepper

Treatment			*Cercospora* leaf spot severity								
			2014			2015			Pooled		
			Variety								
			California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean	California Wonder	Solan Bharpur	Mean
T_1	:	Elevated CO_2 (550±10 PPM)	6.83 (2.61)	4.53 (2.12)	5.68 (2.36)	6.67 (2.58)	5.27 (2.28)	5.97 (2.43)	6.75 (2.59)	4.90 (2.20)	5.82 (2.40)
T_2	:	Elevated CO_2 and elevated temp (550±10 PPM & 1°C)	8.27 (2.87)	6.27 (2.49)	7.27 (2.68)	7.25 (2.67)	6.22 (2.49)	6.74 (2.58)	7.76 (2.77)	6.24 (2.49)	7.00 (2.63)
T_3	:	Ambient CO_2 and temperature	5.70 (2.30)	4.72 (2.16)	5.21 (2.23)	5.67 (2.37)	4.79 (2.16)	5.22 (2.26)	5.68 (2.33)	4.75 (2.16)	5.22 (2.25)
T_4	:	Natural condition (control)	4.03 (1.99)	3.70 (1.92)	3.87 (1.95)	4.50 (2.09)	3.22 (1.77)	3.86 (1.93)	4.27 (2.04)	3.46 (1.84)	3.86 (1.94)
Mean			6.21 (2.44)	4.80 (2.17)	5.51 (2.31)	6.02 (2.43)	4.87 (2.17)	5.44 (2.30)	6.11 (2.43)	4.84 (2.17)	5.48 (2.30)
CD (p =0.05)			Treatment: 0.39 Variety: NS Treatment × Variety: NS			Treatment: 0.35 Variety: 0.25 Treatment × Variety: NS			Treatment: 0.25 Variety: 0.17 Treatment × Variety: NS		

*Figures in parenthesis are square root transformed values

In the present findings, maximum *Cercospora* leaf spot severity was observed under elevated CO_2 and temperature which may be ascribed to cumulative effect of elevated CO_2 and elevated temperature which caused higher growth rates of leaves and stems as well as plant growth thereby resulting denser canopies with higher humidity which favoured the growth of pathogens more rapidly. The present results are in consonance with findings [19] who reported that incidence and severity of *cercospora* leaf spot disease increased under elevated CO_2. Disease severity was increased in plants by

23.5 per cent and by 28 per cent under elevated CO_2 in 2003 and 2000, respectively. Wolf and Verreet [20] reported more incidences of *Cercospora* leaf spot in sugar beet under warm and humid conditions.

4. Conclusion

From this study, it may be concluded that under interactive effect of elevated CO_2 and temperature, disease infestation as well as incidence like *Phytophthora* blight incidence and *Cercospora* leaf spot severity was higher and maximum. Under these scenarios there is an enhancement of the growth of pathogens under favourable environmental conditions and this ultimately results in a high loss of crop productivity. Ultimately, it may be found that increasing CO_2 along with increasing temperature is harmful to crop productivity by hampering its growth and development by more proliferations of diseases.

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