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Radiation use efficiency and yield of wheat grown under elevated CO_2 and temperature in open top chamber at Patna, Bihar

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ABSTRACT

Elevated CO_2 increases the C3 photosynthetic rate at the cellular level through increased carboxylation and decreased oxygenation, both of which are catalyzed by Rubisco. The study was conducted in the experimental farm of ICAR Research Complex for Eastern Region, Patna (Lat. 25°35'37" N, Long. 85°05' E and altitude 51.8 m amsl) under open top chamber (OTC). The circular structure of OTCs were made with an aluminum frame covered with UV-treated poly carbonate sheet, which transmits 85% of natural sunlight. The higher grain yields in wheat crop under elevated CO_2 were primarily due to their greater biomass production capacity and not due to a greater fraction of total biomass being partitioned to grains. The percentage of filled grains also was significantly greater in the elevated treatment. Harvest index (HI) differed significantly between the elevated and ambient treatments in both the years. However, HI of the open treatment was significantly lower than the other two. Seed yields under elevated CO_2 were greater than the ambient and open field treatment.

Key words: GHG, OTC, elevated CO_2, wheat, climate change and RUE

Fossil fuel combustion and deforestation have resulted in a rapid increase in atmospheric carbon dioxide concentration CO_2 since the 1950s. It is predicted that the concentration will reach about 550 ppm in 2050. Numerous studies have been conducted to examine the response of agricultural food production to elevated CO_2. Elevated CO_2 generally stimulates plant photosynthetic processes, thereby increasing crop growth and yield (Drake *et al*, 1997, Kimball *et al*, 2002 and Singh, *et al,* 2013). Rising CO_2 can be sensed by plant tissues, which are directly in contact with the atmosphere IPCC, 2007). Several reviews have shown that the above increase in photosynthetic rates is translated to increases in biomass production and yield of agricultural crops and natural plant species (Kimball *et al*, 2002).

Globally, wheat is a major staple crop and it is also significant for India. Because of wheat's importance, effects of ongoing regional and global environmental changes on wheat yield need to be better understood. Warming generally reduces wheat yield (van Oijen *et al*, 1999), probably because of a shorter grain filling period caused by more rapid development. On the other hand, beneficial effects of elevated (CO_2) on photosynthesis and growth are sometimes thought to increase with warming (Monteith 1977 and Moiser *et al*, 1998). A complication is that elevated CO_2 reduces stomatal conductance and increases water-use efficiency in C3 crops (Erice *et al*, 2007, Qiu *et al,* 2008, Pritchard *et al.,* 2000 and Lawlor and Mitchel, 1991), so beneficial effects of elevated CO_2 on yield may be due to changes in photosynthesis, changes in water use or water-use efficiency or both.

Keeping in view the importance of global climate change, this study was undertaken with the objective to study the yield and physiological behavior of wheat under elevated CO_2.

MATERIALS AND METHODS

Field experiment

This study was conducted in the experimental farm of ICAR Research Complex for Eastern Region, Patna located at 25°35'37" N latitude and85°05' E longitude and at an altitude of 51.8 m above mean sea level during 2011-12 and 2012-13. The land area of open-top chambers (OTCs) had a fairly level topography.

The climate of the experimental site is semi-arid with dry hot summer and mild winters. The soil at the experimental site belongs to the major group of Indo-Gangetic alluvium (Table 1).

Table 1: Soil characteristic of experimental site.

Year	Sand (%)	Silt (%)	Clay (%)	Organic carbon (%)	Soil pH	Bulk density (mg m^3)	Electrical conductivity (dSm^{-1})	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
2011-12	26.2	42.5	31.3	0.62	7.5	1.46	0.29	224	32.2	219
2012 -13	29.5	41.5	28.0	0.67	7.3	1.45	0.26	237	27.0	203.2

Table 2: Variation of leaf area index (LAI) (average of all varieties) of wheat grown in OTC (under elevated CO_2 concentration), control and open field.

Days after sowing	Open Top Chamber (OTC)		Field condition	LSD $_{0.05}$
	Elevated CO_2 (480 ppm)	Control (380 ppm)		
Rabi 2011-12				
30	0.32	0.16	0.22	0.14
45	1.12	0.55	0.65	0.23
60	2.44	2.13	2.37	0.36
75	3.74	3.23	3.29	0.34
90	4.60	3.82	4.39	0.41
110	4.13	3.45	3.82	0.32
Rabi 2012-13				
30	0.39	0.21	0.37	0.13
45	1.24	0.62	1.05	0.25
60	2.65	2.34	2.54	0.39
75	3.86	3.56	3.63	0.31
90	4.76	3.93	4.49	0.48
110	3.84	3.14	3.56	0.33

LSD0.05, least significant difference at p = 0.05

Crop management

Four wheat genotypes (Local/Indigenous: C306, Promising HYV of State: HD 2967, Promising HYV of Eastern region: PBW 550 and Ruling variety in state: HD 2733) were used for the study. Sowing of treated seed was done manually in OTCs with seed rate of 100 kgha^{-1}. The experimental plots were fertilized @ 120-60-40 kg NPK ha^{-1}. Four irrigations were applied at CRI stage, tillering, heading and milking stage, respectively. The observations were recorded on ten randomly selected plants per genotype per replication for all the traits in all the phonological stages, plant height (cm), harvest index, biomass (dry basis), straw yield (ha^{-1}) as well as grain yield (tha^{-1}).

Weather during crop season: Daily maximum and minimum temperatures, maximum and minimum relative humidity, total radiation, daily rainfall were recorded from the meteorological observatory of the ICAR Research Complex, Patna. Mean daily maximum and minimum temperatures and relative humidity (RH) inside the OTC were recorded using data-logger.

Leaf area index (LAI): Leaf-area index was measured at weekly intervals with a plant canopy analyzer (LAI-2000, LI-COR, Lincoln, NE, USA). The LAI was measured at four random locations within each plot .

Photosynthetically active radiation (PAR)

Incident,transmitted and reflected photosynthetically active radiation(PAR) were measured periodically at the top, middle and bottom of rice crop throughout the season using line quantum sensorLI-191SA (LICOR Inc., Lincoln, NE, USA). These measurements were used to derive fraction intercepted PAR (fIPAR).

The canopy fIPAR and LAI were related using following equation:

$$fIPAR = 1 - \exp(-k \times LAI)$$

where, k is the canopy radiation extinction coefficient and LAI is the leaf area index.

Radiation use efficiency (RUE) was estimated as the slope of the linear regression between total biomass accumulation and cumulative radiation interception (Monteith, 1977).

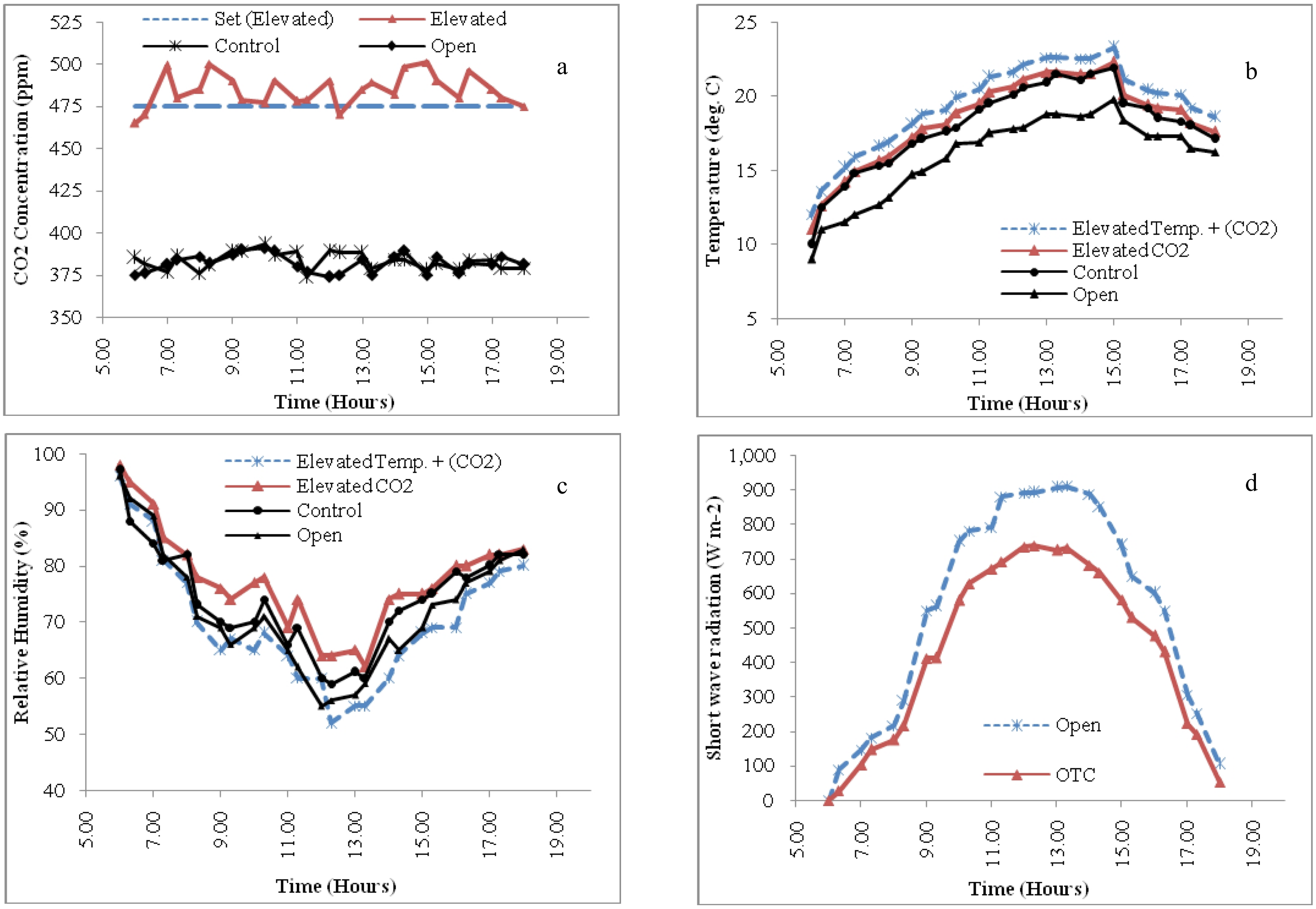

Fig. 1: Weather conditions (in 45 DAS at the tillering stage of the crop) within the OTCs and open field (a) CO_2 concentration; (b) air temperature; (c) relative humidity and (d) shortwave radiation.

Table 3: Seasonal total PAR and mean seasonal fraction of PAR interception (fIPAR) by wheat crop grown under different treatments.

Treatments	*rabi* 2011-12		*rabi* 2012-13	
	PAR (MJ m^{-2})	fIPAR	PAR (MJ m^{-2})	fIPAR
Elevated CO_2 OTC	612	0.534	627	0.549
Control OTC(ambient)	615	0.483	623	0.479
Open field	727	0.489	752	0.493
LSD0.05	34	0.016	44	0.019
CV (%)	5.36	4.92	7.12	4.56

Plant sampling and harvest

Crop biomass was measured by samplings of ten randomly selected plants at 25, 40, 60, 77, 90 and 105 DAS. Dry weights of leaves, stems, roots and grains were determined by oven drying at 80°C until a constant weight was attained. Total biomass was computed as the sum of dry weights of different plant parts. Grain yield was measured by harvesting the central 1 m^2 of each plot at final harvest. Yield components were measured on a sub-sample of 10 plants from the final harvest. Harvest index was calculated as the ratio between grain yield and total biomass at harvest.

Statistical analysis

Significance of treatment differences in growth and yield measurements were tested by analysis of variance and means were separated by least significant difference. Significance of treatment differences in radiation use

Table 4: Variation of the total dry biomass of wheat cultivars.

Cultivar	Treatment	Days after sowing (DAS)		
		52	74	110
C-306	Elevated CO_2	0.41	2.62	3.92
	Ambient CO_2(Control)	0.36	2.43	5.18
	Open	0.39	2.61	5.71
	LSD 0.05	0.06	0.29	0.34
HD2967	Elevated CO_2	0.59	3.56	6.92
	Ambient CO_2(Control)	0.49	2.92	6.03
	Open	0.51	3.23	6.44
	LSD 0.05	0.06	0.39	0.40
PBW550	Elevated CO_2	0.49	2.67	5.81
	Ambient CO_2(Control)	0.40	2.18	5.72
	Open	0.41	2.56	5.86
	LSD 0.05	0.07	0.34	0.61
HD2733	Elevated CO_2	0.53	3.71	7.16
	Ambient CO_2(Control)	0.45	3.19	6.10
	Open	0.48	3.49	6.83
	LSD 0.05	0.04	0.41	0.65

LSD0.05, least significant difference at p = 0.05

Table 5: Radiation use efficiency (RUE in g MJ^{-1}) different cvlfivars wheat.

Cultivar	Treatment	RUE ± SE	R^2	RUE ± SE	R^2
		During heading stage		Total crop duration	
C-306	Elevated CO_2	1.99 ± 0.36	0.87	1.95 ± 0.29	0.86
	Ambient CO_2	1.83 ± 0.20	0.84	1.86 ± 0.13	0.85
	Open	1.99 ± 0.24	0.82	1.76 ± 0.30	0.81
HD2967	Elevated CO_2	2.13 ± 0.14	0.86	1.98 ± 0.31	0.88
	Ambient CO_2	1.79 ± 0.22	0.83	1.75 ± 0.36	0.87
	Open	1.89 ± 0.21	0.78	1.84 ± 0.33	0.82
PBW550	Elevated CO_2	2.06 ± 0.16	0.89	2.07 ± 0.18	0.89
	Ambient CO_2	1.86 ± 0.14	0.88	1.89 ± 0.29	0.82
	Open	1.98 ± 0.10	0.80	1.99± 0.23	0.89
HD2733	Elevated CO_2	2.19 ± 0.15	0.89	2.18 ± 0.25	0.89
	Ambient CO_2	1.98 ± 0.09	0.83	1.99 ± 0.22	0.87
	Open	1.99 ± 0.25	0.87	1.83 ± 0.31	0.90

efficiency was tested by comparing the 95% confidence intervals of slopes in the regressions of biomass accumulation against cumulative intercepted radiation using SAS software.

RESULTS AND DISCUSSION

Weather outside and within open top chambers

Variation of meteorological parameters within OTCs and open field conditions during the daytime on a sunny day are shown in Fig. 1. The 1 h averages of CO_2 in the elevated CO_2 OTC ranged between 455 and 510 ppm with a mean of 485ppm and a standard deviation (S.D.) of 11.7 ppm (Fig. 1a). The corresponding means and ranges for control (ambient) OTC and the open field were 382 (374-393) ppm and 380 (370-390) ppm with S.D. of 4.2 and 5.5 ppm,

Table 6: Yield and yield contributing traits of wheat culfivars.

Cultivar	Treatment	Height (cm)	Duration (days)	Panicle length (cm)	Grains / panicle	1000 grain weight (g)	Spikelet sterility	Grain yield (t ha $^{-1}$)
C-306	Elevated CO_2	92	127	13.5	51	37.8	6.8	3.9
	Ambient CO_2	85	124	10.5	46	35.2	6.5	2.9
	Open	88	121	11.2	48	36.9	6.2	3.1
	LSD 0.05	2.1	2.5	1.8	1.9	1.3	0.4	0.5
HD 2967	Elevated CO_2	96	132	14.6	51	51.6	5.4	4.2
	Ambient CO_2	88	127	11.1	44	42.7	4.9	2.9
	Open	91	126	12.4	46	45.3	4.7	3.3
	LSD 0.05	2.3	1.5	1.3	1.7	1.8	1.5	0.9
PBW550	Elevated CO_2	90	127	12.6	49	43.8	6.2	4.1
	Ambient CO_2	83	128	10.5	44	40.1	6.5	2.8
	Open	85	124	11.7	46	41.4	5.8	3.2
	LSD 0.05	1.4	1.5	1.2	2.5	2.6	0.7	0.6
HD2733	Elevated CO_2	83	136	14.5	60	51.2	3.2	5.1
	Ambient CO_2	77	133	12.8	52	47.1	3.9	3.9
	Open	79	132	13.6	57	48.6	3.5	4.5
	LSD 0.05	1.3	1.6	1.1	2.4	2.0	0.8	0.6

respectively. In all OTCs and open field, CO_2 showed a reduction during a 2-h period around midday and an increase towards the end of the day. Air temperature (Ta) was more inside the OTCs than open field (Fig. 1b) condition. Air temperature of the elevated CO_2 OTC was consistently greater than that of the ambient OTC. This temperature difference ranged from 0.07 to 4.3°C with a mean and S.D. of 1.4 and 0.61°C.

The relative humidity (RH) within the OTCs was higher than in the open field (Fig. 1c). In general CO_2 elevated OTC is having more RH followed by control and open field. As the CO_2 elevated OTC is having more biomass and having more transpiration compare to other treatments, the OTC is having more relative humidity.

Incident shortwave radiation on the crop canopy was lower in the OTCs (Fig. 1d) because of partial interception by the polythene of OTC walls. Maximum incident on top of canopy was in open field (910 W m^{-2}) compared to all OTCS (737 W m^{-2}).

Crop growth and radiation interception

LAI of wheat crop in elevated CO_2 treatment was significantly ($p< 0.05$) greater than the control OTC and open field at all times in both *rabi* seasons (Table 2). However, the maximum LAI achieved by OTC with elevated CO_2 during *rabi* 2012-13 (i.e. 4.76) than *rabi* 2011-12 (i.e. 4.60). In both the growing season the maximum LAI levels were achieved around 90-92 DAS (heading stage). LAI under ambient CO_2 was significantly ($p< 0.05$) lower than that in the open treatment.

The OTC with elevated CO_2 showed higher levels of fIPAR than the open field at all times (Table 3). The lower fPAR of the open field was partly because of its lower LAI. Crops of elevated CO_2 OTC showed a higher fPAR than open field and the control OTC. Over the crop growing season, there was no significant ($p< 0.05$) difference between the fIPAR levels of the elevated and ambient CO_2 treatments growing within OTCs. However, in both seasons, elevated CO_2 treatment had significantly greater fIPAR than the open treatment. Therefore, the total PAR was 18% lower in the treatments within OTCs, the fraction PAR interception was more (12.9%) than open field condition.

Radiation use efficiency (RUE)

The greater biomass under elevated CO_2 was brought about by an increase in RUE, during both pre- and post-anthesis periods (Table 4) and not by an increase in radiation interception. Results have shown that this increase in light use efficiency at the cellular level is reflected at the crop level also as an increase in radiation use efficiency. The average (*rabi* 2011-12 and 2012-13) radiation use efficiency (RUE) of the elevated CO_2 treatment was significantly ($p< 0.05$) greater than the ambient CO_2 treatment (Table 5). There was no significant difference between the RUE of ambient and open field conditions. In contrast, both the elevated and ambient treatments had appreciably greater post-heading RUE. RUE of the open treatment did not differ in both seasons. In both the years, wheat growing under elevated CO_2 had significantly greater grain numbers and grain yields than under ambient CO_2 and open field conditions (Table 6), which did not differ significantly. The percentage of filled grains also was significantly greater in the elevated treatment. Harvest index (HI) differ significantly between the elevated and ambient treatments in both the years. However, HI of the open treatment was significantly lower than the other two. Seed yields under elevated CO_2 were greater than the ambient and open field treatment. The higher grain yields in wheat crop under elevated CO_2 were primarily due to their greater biomass production capacity and not due to a greater fraction of total biomass being partitioned to grains.

CONCLUSIONS

The present experiment used open top chambers (OTCs) to grow crops under elevated CO_2. Literature raised doubts about the results obtained using OTCs (Foyer and Harbinson, 1994 and Schneider., 1989) because of the changed environmental conditions within them as compared to open field conditions. However, in a comprehensive review of results from OTCs and Free-Air CO_2 enrichment (FACE) facilities, Kimball *et al.* (2002) concluded that although absolute growth cannot be determined with a high degree of confidence using OTCs, the relative growth responses to elevated CO_2 in wheat and cotton were not significantly different between the two methods. In fact, even the absolute growth of wheat did not differ between OTCs and FACE conditions. Furthermore, in another extensive review, Kimball *et al*. (2002) concluded that results on crop responses to CO_2 enrichment in FACE were consistent with those obtained in chamber studies and that conclusions based on data from both types of methodology were accurate.

In this regard, there are not many FACE studies done on wheat to compare our results, especially in the higher range of temperatures experienced by crops in the present study.

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