

Effect of elevated CO₂ and temperature on growth and yield of wheat grown in sub-humid climate of eastern Indo-Gangetic Plain (IGP)

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सार – वर्तमान की तुलना में 21^{वीं} सदी के अंत तक वायुमंडलीय कार्बनडाइऑक्साइड (CO₂) की सांद्रता 510 से 760 माइक्रो लीटर प्रति लीटर व औसत वैश्विक तापमान के 1.5 से 4.5° सेल्सियस तक बढ़ने की संभावना है जो कृषि को प्रत्यक्ष व अप्रत्यक्ष रूप से प्रभावित करेगा। भारत जलवायु परिवर्तन की चपेट में आने वाला एक प्रमुख वैश्विक क्षेत्र है, हालांकि, सीमित अध्ययनों ने उप-आर्द्र जलवायु वाले पूर्वी गंगा के मैदानी इलाकों में गेहूँ उत्पादन पर कार्बनडाइऑक्साइड (CO₂) व तापमान के संयुक्त प्रभाव पर ध्यान आकर्षित किया है। इस मुद्दे का समाधान करने के लिए एक खुला शीर्ष कक्ष (OTC) प्रयोग किया गया जिसमें हमने उच्च वातावरणीय कार्बनडाइऑक्साइड (CO₂) व तापमान का गेहूँ की प्रजातियों के विकास व उपज पर प्रभाव का अध्ययन किया। रबी के दौरान गेहूँ की फसल (DBW 14 और HD 2967) कार्बनडाइऑक्साइड (CO₂) और OTC में तापमान के चार उपचार संयुक्तों के साथ उगाई गई। अध्ययन से पता चला है कि गेहूँ की प्रजातियां उच्च कार्बनडाइऑक्साइड (CO₂) के तहत बेहतर प्रदर्शन करती हैं तथा सामान्य परिवेश की तुलना में अधिक दानों की संख्या, परीक्षण वजन और उपज देती हैं वरन उच्च तापमान में उपज एवं उपज विशेषताएं कम पाई गई हैं। सामान्य परिवेश की तुलना में उच्च तापमान वाले परिवेश में पौधों की शारीरिक परिपक्वता 4 से 7 दिन तक कम तथा उच्च कार्बनडाइऑक्साइड (CO₂) की परिस्थिति में परिपक्वता 3 से 4 दिन तक बढ़ जाती है। ये सभी परिणाम इंगित करते हैं कि उच्च कार्बनडाइऑक्साइड (CO₂) वाला परिवेश गेहूँ की वृद्धि एवं पैदावार पर सकारात्मक प्रभाव व उच्च तापमान नकारात्मक प्रभाव डालता है।

ABSTRACT. The atmospheric CO₂ will be in the range of 510 to 760 $\mu\text{L L}^{-1}$ by the end of 21st century and mean global temperature will be 1.5 to 4.5 °C higher than the present day which has a direct and indirect effect on agriculture. India is a key global region vulnerable to climate change; however, limited studies have focused on the combine effect of CO₂ enrichment and temperature on wheat production in Sub-humid climate of eastern IGP in India. To address this issue, an Open top chamber (OTCs) experiment was conducted during 2013-14, to determine the effects of elevated atmospheric carbon dioxide (CO₂) and temperature on growth, yield attributes and yield of wheat. Wheat cultivars (DBW 14 and HD 2967) were grown with four treatment combination of CO₂ and temperature in OTCs, during the *rabi* season. The study revealed that wheat genotypes performed better under elevated CO₂ condition in term of grain number, test weight and grain yield than an ambient condition. The greater biomass under elevated CO₂ was brought about by an increase in radiation use efficiency (RUE) during both heading and physiological maturity periods. Elevated temperature decreased the grain yield but increase plant height compared to ambient temperature. Days to physiological maturity was reduced by 4 to 7 days in both the cultivars under elevated temperature condition and increased by 3 to 4 days under the elevated CO₂ condition with respect to ambient condition. The elevated CO₂ had positive effects whereas elevated temperature had negative effects on growth, yield attributes and yield of wheat. With elevation of both CO₂ and temperature, elevated CO₂ compensate the negative effects of elevated temperature on growth, yield attributes and yield of wheat.

Key words – OTCs, Elevated CO₂, Elevated temperature, RUE, Wheat and climate change.

1. Introduction

Climate change associated with rise in the concentration of green house gases (GHG) is likely to affect crop production and thus human food supplies. Increasing carbon dioxide (CO₂) concentration in the atmosphere together with rising temperature and changes in rainfall amount and patterns are current concerns for

agricultural crop production and crop quality in the near future (Miraglia *et al.*, 2009). Current atmospheric CO₂ is expected to increase to 550 $\mu\text{mol mol}^{-1}$ by 2050 under most emission scenarios which have the direct and indirect effect on rainfed agriculture (Carter *et al.*, 2007). This increase is likely to affect the global and regional climates and weather patterns. Crop production will be affected by global warming. Elevated atmospheric CO₂

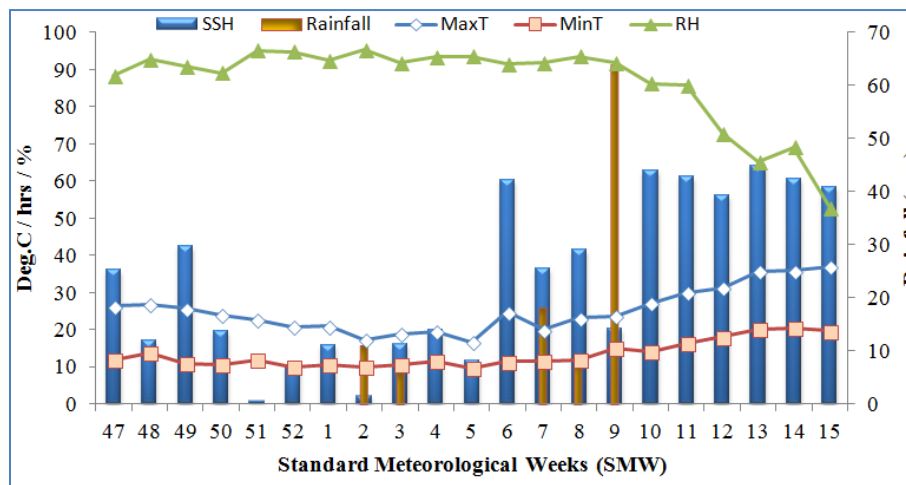


Fig. 1. Average climatic condition of experimental site during Rabi season 2013-14

will promote the growth of plants through fertilization effect and enhanced photosynthesis. At the plant level, a higher CO_2 increases photosynthesis, growth, development and yield of a wide range of cultivated crops, including rice (Long *et al.*, 2004, 2006; Ainsworth and Long, 2005). The productivity of most agricultural crops increases under elevated $[\text{CO}_2]$ is in the range of 15 to 41% for C_3 crops and 5 to 10% for C_4 crops (IPCC, 2007; Lotze and Schellnhuber, 2009; Kimball, 2011).

The past 50 years have shown an increasing trend in temperature @ $0.13\text{ }^\circ\text{C}/\text{decade}$, while the rise in temperature during the past one and half decades has been much higher. It is projected that with the rise of GHGs, global average temperature will rise by $3.7\text{--}4.8\text{ }^\circ\text{C}$ by the end of the 21st century (IPCC, 2014). The effect of short periods of exposure to high temperatures ($>31\text{ }^\circ\text{C}$) on wheat grain yields is thought to be equivalent to a $2\text{--}3\text{ }^\circ\text{C}$ warming of the seasonal mean temperature (Wheeler *et al.*, 1996b). Also, up to a 23% reduction in grain yield has been reported from as little as 4 days exposure to very high temperatures (Randall and Moss, 1990; Hawker and Jenner, 1993; Stone and Nicolas, 1994). Elevated temperature will cause heat injury and physiological disorders resulting in reduced yield (Johkan *et al.*, 2011). Elevated temperature as a result of elevated CO_2 will have a major influence on food grain production depending on the locations. With temperature increase by $1.0\text{--}2.0\text{ }^\circ\text{C}$ in tropical and subtropical countries such as India food grain production is projected to decrease up to 30% (IPCC, 2014; Johkan *et al.*, 2011). Higher temperatures thus decreased the number of days during which plants could intercept light for photosynthesis, with consequent reductions in biomass and grain yields. When mean temperature was $>28\text{ }^\circ\text{C}$ and when there were extremely

high temperatures early in the growing season with many days of maximum temperature ($T_{\text{max}} > 34\text{ }^\circ\text{C}$), a critical maximum temperature for wheat (Porter and Gawith, 1999), crops did not reach to anthesis or grain set, so it was not possible to record anthesis or maturity dates. Yield loss of wheat in India due to rising temperature has been projected as 4-5 million tonnes per year with every degree rise in temperature throughout the growing period (Aggarwal, 2007). Therefore, there is a need to develop such cultivars that are either tolerant to warming or to identify cultivars which perform better under predicted climate change scenarios. There are very limited studies on the impact of elevated CO_2 concentration and temperature interaction on this important cereal crop under field conditions (Dwivedi *et al.*, 2015). Objectives of the study were to evaluate the impacts of elevated atmospheric CO_2 and temperature on growth and yield of wheat cultivars in sub-humid climate of eastern IGP under field condition.

2. Materials and method

2.1. Site description

An experiment using OTCs was conducted in the experimental farm of ICAR Research Complex for Eastern Region, Patna. The site is located in the Indo-Gangetic Plains of north-east India at $25^\circ35'37''\text{ N}$ latitude and $85^\circ05'\text{ E}$ longitude and at an altitude of 51.8 m above mean sea level. The climate of the experimental site is semi-arid with dry hot summer and mild winters (November to January). December, January and February are the coldest months with mean daily minimum temperature ranging from $5.8\text{ to }15.2\text{ }^\circ\text{C}$. Mean annual rainfall is 1205 mm, of which 80% occurs during southwest monsoon from June to September. The mean

TABLE 1

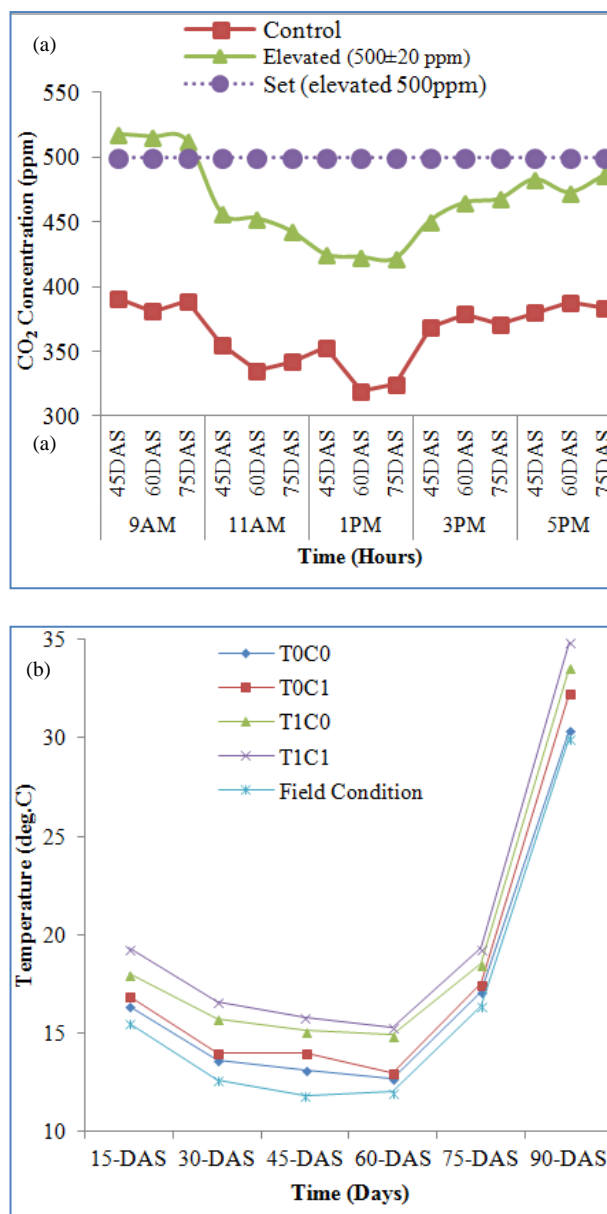
Treatment descriptions

Treatment No.	Name	Description
T ₁	T0C0	Ambient temperature and ambient CO ₂
T ₂	T0C1	Ambient temperature + elevated CO ₂ (500 ± 20 ppm)
T ₃	T1C0	Elevated temperature (1 °C higher than ambient temperature) + ambient CO ₂
T ₄	T1C1	Elevated temperature + elevated CO ₂ (500 ± 20 ppm)

daily pan evaporation reaches a high of 10.1 mm per day in May and a low of 0.9 mm per day in January. The crop season of wheat is from November to March/April (locally called the *Rabi* season). The soil at the experimental site belongs to the major group of Indo-Gangetic alluvium. A soil type was clay loam and good texture with neutral pH 7.4 (Table 2).

2.2. Crop management and plant sampling

Experiment was carried out during *Rabi* season 2013-14. Two wheat genotypes were evaluated inside OTCs at ICAR-RCER, Patna, with an objective to assess the impact of elevated CO₂ and temperature (1 °C > ambient) on morphological traits and yield. Fields (inside the OTCs) were dry ploughed and leveled. Sowing was done in the month of November (25th November) at the rate of 100 kg/ha with the row to row spacing of 23 cm in all plots. In each plot, a uniform plant stand was maintained and standard agronomic practices were followed for raising and maintenance of plants. Experimental plots were fertilized at the rate of 120-60-40 kg NPK ha⁻¹. Nitrogen was applied on three occasions (50% at sowing as a basal, 25% at 21 days and 25% at 45 days), while the P₂O₅ and K₂O were applied as a basal application. Four irrigations were applied at CRI stage, tillering, heading and milking stage, respectively. The experimental plots were kept weed free by regular hand weeding. The observations were recorded on ten randomly selected plants per genotype per replication for all the traits in all the phenological stages, plant height (cm), biomass (dry basis), as well as grain yield. The gaps created by plants removed at all samplings in both OTCs and open plots were immediately filled by wheat plants from outside the experimental plots. These plants were not used for any of the subsequent measurements. Dry weights of leaves, stems, roots and grains were determined by oven drying at 80 °C until a constant weight was attained. Grain yield was measured by harvesting the central 1 m² of each plot at final harvest. Yield components were measured on a sub-sample of 10



Figs. 2(a&b). (a) Weather condition within the OTCs (a) CO₂ concentration at 45, 60 and 75 days after sowing and (b) Mean air temperature at 15, 30, 45, 60, 75 and 90 days after sowing

plants from the final harvest. Grain yields were obtained from a sampling area obtained by discarding the outside rows of each plot.

2.3. Construction of open top chambers and CO₂ supply

Open top chambers (Heagle *et al.*, 1973) were extensively used as plant exposure units both in air pollution and in CO₂ response studies in the field. The

TABLE 2

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)	Available Phosphorus (kg/ha)	Available Potassium (kg/ha)
2013 -14	29.7	41.8	28.5	0.66	7.4	1.46	0.26	235	27.4	203.6

TABLE 3

Radiation use efficiency (RUE in g MJ⁻¹), for wheat cultivars under T0C0, T0C1 and open field treatment conditions in *rabi* season (2013-14)

Cultivars	Treatment	RUE±SE (Heading stage)	R ² (%)	RUE±SE (Physiological maturity)	R ² (%)
DBW14	T0C0 (Ambient CO ₂)	1.85 ± 0.23	84	1.83 ± 0.13	82
	T0C1 (Elevated CO ₂)	1.97 ± 0.33	88	1.95 ± 0.29	86
	Field condition	1.87 ± 0.20	81	1.81 ± 0.16	84
HD2967	T0C0 (Ambient CO ₂)	1.81 ± 0.19	84	1.79 ± 0.36	87
	T0C1 (Elevated CO ₂)	2.09 ± 0.18	89	1.98 ± 0.31	90
	Field condition	1.86 ± 0.21	79	1.86 ± 0.34	83

Climate in OTCs tracks the dynamic change in temperature, light, rainfall as experienced in open area without costly and complex environmental controls characteristics of closed chambers. The principle advantage of OTCs is the ability to provide control over the atmospheric variations to which plants are exposed while maintaining more or less the same soil conditions of the field setting. The circular structure of OTCs was made with an aluminium frame covered with UV-treated poly carbonate sheet, which transmits around 85% of natural sunlight. The frame was 4 m high and the upper part of the OTCs was kept open to maintain the near-natural conditions of temperature and relative humidity. The base of each OTC was provided with a hollow ring of 0.4 m diameter covered with PVC sheet and having perforation inside for the supply of CO₂-air mixture inside the OTCs.

Each open top chamber was divided into four equal quadrants with waterproof brick partitioning. Pure CO₂ was (99.7%, v/v CO₂ and less than 10 ppm CO) was released from a commercial grade cylinder fitted with a regulator. The CO₂ concentration of air within the elevated CO₂ chambers was maintained at the target concentration by a PC-based real-time data acquisition and control (DAC) system designed based on the principles described in Collins *et al.* (1995). The air sample from the middle of the chamber was drawn periodically into a CO₂ sensor (NDIR, make Topak, USA) to monitor CO₂ concentration. The set level of CO₂ was maintained with the help of solenoid valves which were controlled by Program Logic

Control (PLC) and Supervisory Control and Data Acquisition (SCADA) system running Winlog software (Make SELCO, Italy). A data logger recorded the mean CO₂ within all chambers at 15-min intervals. The CO₂ supply was switched on only during the daylight hours. The chambers were washed regularly with a gentle stream of water to remove the dust and to maintain transparency.

2.4. Weather during crop season

Daily maximum and minimum temperatures, maximum and minimum relative humidity (RH), total radiation, daily rainfall and Sunshine hrs (SSH) were recorded from the meteorological observatory of the ICAR Research Complex, Patna (Fig. 1). Mean daily maximum and minimum temperatures and CO₂ changing trend inside the OTCs were recorded using data logger.

2.5. Photosynthetically active radiation and radiation use efficiency

The 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 sensor LI-191SA (LICOR Inc., Lincoln, NE, USA. Radiation use efficiency (RUE) was estimated as the slope of the linear regression between total biomass accumulation and cumulative radiation interception (Monteith, 1977).

TABLE 4
Effect of elevated CO₂ and temperature on yield attributing traits of wheat crop in OTCs

Treatment	Ear length (cm)	No. of grain/ear	Test wt. (g)	Plant height (cm)	Physiological maturity (days)										
Environmental condition (Ec)															
T0C0	9.46	32.16	41.00	82.08	117.00										
T0C1	10.01	40.50	44.83	96.50	121.83										
T1C0	9.20	29.83	39.00	93.50	113.83										
T1C1	9.63	37.83	40.83	98.67	119.00										
Cultivars (C)															
DBW 14	8.82	29.91	38.08	90.92	114.92										
HD 2967	10.30	41.25	42.41	100.56	122.42										
Environmental condition * Cultivars															
Ec	C														
T0C0	DBW 14	8.76	26.66	38.33	84.67	115.33									
	HD 2967	10.16	37.66	41.66	95.50	122.67									
T0C1	DBW 14	9.20	36.00	40.00	94.00	118.00									
	HD 2967	10.76	45.00	45.66	103.00	125.67									
T1C0	DBW 14	8.50	23.00	36.00	93.67	110.00									
	HD 2967	9.85	37.67	40.00	99.33	117.67									
T1C1	DBW 14	8.80	34.00	38.00	99.33	116.33									
	HD 2967	10.43	43.67	42.33	104.00	123.67									
Factors	Ec	C	Ec x V	Ec	C	Ec x V	Ec	C	Ec x V	Ec	C	Ec x V	Ec	C	Ec x V
SEm+	0.44	0.31	0.63	1.48	1.04	2.09	0.88	0.62	1.25	2.08	1.47	2.95	0.87	0.61	1.23
LSD (p=0.05)	1.15	0.78	1.74	3.49	2.17	5.35	1.68	0.89	2.79	4.33	2.47	6.75	2.45	1.73	3.43
CV (%)	11.44			10.19			5.38			5.28			1.80		

Ec - Environmental conditions; C- Cultivars; Ec x V- Interaction

2.6. Analysis of soil samples

Soil samples were collected from 0 to 15 cm depth from three places in the OTCs using a 5-cm diameter sample auger. Each sample was a composite from three locations. The composite samples were analyzed for pH and electrical conductivity (Jackson, 1973), organic C (Walkey and Black, 1934) and alkaline KMnO₄ extractable N (Subbiah and Asija, 1956), Olsen P (Olsen, 1954), and NH₄OAc-extractable K (Hanway and Heidel, 1952) contents.

2.7. Experimental design and Statistical analysis

The experiment was conducted in a two factors completely randomized design with three

replications, CD at 5% (p = 0.05) and ANOVA were calculated. The data were analyzed using Statistics 8.1 software programme.

3. Results and discussion

3.1. Weather outside and within open top chambers

Variations in meteorological parameters within different OTCs treatments (Table 1) during the daytime on a sunny day are shown in Figs. 2(a&b). The hourly average CO₂ in the T0C1 ranged between 436 and 518 ppm with a mean of 477 ppm. The corresponding means and ranges for T0C0 and T1C0 were 337ppm (319-391) and 330 ppm (322-387), respectively. Findings of the study suggest that the CO₂ concentration was higher

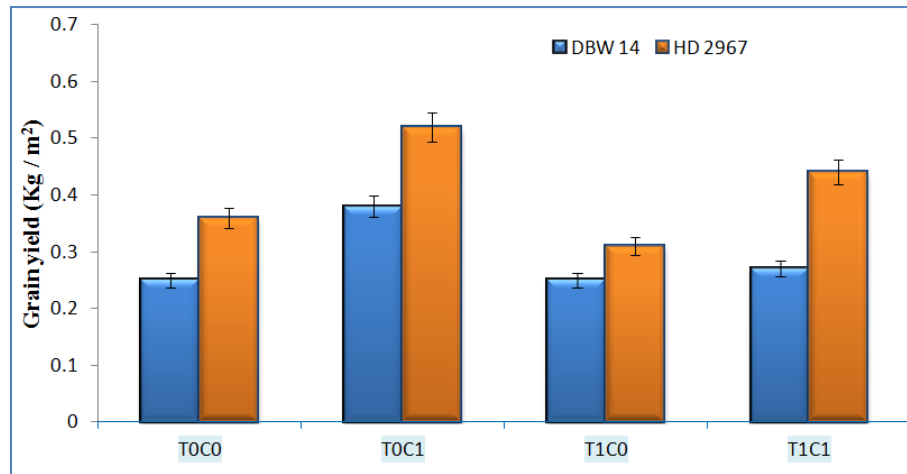


Fig. 3. Effect of temperature in segregation and in combination with CO₂ on grain yield of wheat genotypes

during morning hours and decrease the day progress due to photosynthetic activity of wheat during day time and during evening hours the concentration of CO₂ again increased [Fig. 2(a)]. In all OTCs, the concentration of CO₂ showed a reduction during a 2-hr period around midday and an increase towards the end of the day. The mean air temperature was more inside the all OTCs compared to open field conditions [Fig. 2(b)]. The mean air temperature of the T1C1 treatment was consistently greater than that of the TOC0 treatment. This temperature difference ranged from 0.09 to 3.9 °C.

3.2. Radiation use efficiency

The greater biomass under TOC1 treatment was brought about by an increase in radiation use efficiency (RUE), during the anthesis periods 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 RUE of the TOC1 (1.95 & 1.98 for DBW 17 and HD 2967, respectively) was significantly ($p < 0.05$) greater than the TOC0 (1.83 & 1.79 for DBW 17 and HD 2967, respectively) treatment (Table 3). 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.

3.3. Yield and yield attributes

The yield attributes and yield of all the wheat genotypes showed the positive response to elevated CO₂ and negative with elevated temperature. Yield and yield attributes of wheat cultivars growing in different environmental conditions were recorded in terms of number of ear length (cm), no. of grain ear⁻¹, test weight

(g), plant height (cm) and physiological maturity (days). The maximum length of ear (10.7) recorded in HD2967 when crop sown under TOC1 treatment and the lowest (8.5) T1C0 treatment in DBW14. In case of wheat cultivars the maximum ear length (10.3) was found in HD2967 followed by DBW14 (8.8), respectively. The highest number of grain ear⁻¹ (45) and test weight (45.66) was observed under TOC1 treatment in HD2967 and the lowest (23, 36 respectively) was recorded in DBW14 under T1C0 treatment condition. Days to physiological maturity reduced by 4 to 7 days in both wheat cultivars under elevated temperature condition and increased by 3 to 4 days under elevated CO₂ condition (Table 4). The grain yield was significantly higher (0.40 and 0.48 kgm⁻¹) in TOC1 treatment compared to TOC0 treatment (0.25 and 0.34 kgm⁻¹) in HD2967 and DBW14, respectively (Fig. 3). The higher grain yields under TOC1 treatment were primarily due to their greater biomass production capacity and not due to a greater fraction of total biomass being partitioned to grains. Wang *et al.* (2016) also reported that grain yield and total biomass were significantly increased for rice and wheat with elevated CO₂ while decrease with elevated temperature. Tao and Zhang (2013) and Abebe *et al.* (2016) also reported that increasing CO₂ concentration in the atmosphere could lead to higher crop yields. Singh *et al.*, 2013 found that elevated CO₂ generally stimulates plant photosynthetic processes, thereby increasing crop growth and yield. Ghannoum *et al.* (2000) observed that this positive effect of CO₂ on plant growth is more pronounced in C₃ crops such as wheat but less notable in C₄ crops such as maize.

4. Conclusions

It can be concluded that the elevated CO₂ and temperature has a direct impact on wheat yield as there was increase in wheat yield with the increase in CO₂

concentration. Yield attributes (number of ear length, no. of grain ear⁻¹, test weight, plant height and physiological maturity) and yield of wheat was improved under elevated CO₂ condition and had negative response with elevated temperature. On the contrary, rise in temperature, decrease yield attributes and yield of wheat. The elevated ambient temperature by 1 °C along with elevated CO₂ up to 500 ± 20 ppm, however, increased grain yield. The positive role of CO₂ in enhancing photosynthesis and productivity of wheat is expected to counteract the negative effect of increase in temperature. HD2967 performed better than DBW14 under elevated CO₂ (500 ppm) as well as elevated temperature condition. Since wheat is a staple food crop, long-term studies may provide the better understanding on the efficiency of such genotypes which are increasingly associated with food security.

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