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Research Paper

Response of *aestivum* and *durum* wheat varieties to elevated CO_2 and temperature under OTC condition

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ABSTRACT

An experiment was undertaken during *rabi* season of 2020-2021 and 2021-2022 at experimental field of Division of Environmental Science, ICAR-Indian Agriculture Research Institute (IARI), New Delhi inside Open Top Chambers (OTCs) to study the growth and physiological response of *aestivum* (HD 3226) and *durum* wheat (HI 8627) varieties to elevated temperature and CO_2 concentration. Results showed that days to maturity hastened under elevated temperature condition. Photosynthesis rate, leaf area index and tiller number of wheat varieties reduced in elevated temperature treatment while elevated CO_2 concentration of 550 ppm was able to partially compensate the reduction. In *aestivu*m variety of wheat, transpiration rate significantly reduced in elevated CO_2 plus high temperature interaction treatment than ambient while transpiration rate of *durum* variety remained unaffected. The negative effect of elevated temperature on aboveground biomass was more in *aestivum* variety than *durum* variety. Elevated CO_2 concentration compensated reduction in aboveground biomass by 5.9% in HD 3226 (*aestivum*) and by 3.6% in HI 8627 (*durum*) varieties under elevated temperature condition. Hence elevated CO_2 concentration will be able to partially compensate reduced crop growth in both *aestivum* and *durum* wheat varieties under high temperature condition.

Keywords: *Aestivum* wheat, *Durum* wheat, Elevated CO_2, Increased temperature

Meteorological parameter like temperature is an important factor affecting growth and development of crops. Earth's surface temperature is increasing due to the increase in the concentration of atmospheric greenhouse gases (GHG). As per the IPCC 6th assessment report, earth's temperature would rise by 3°C in 2100 due to the rise in atmospheric CO_2 concentration (IPCC 2021). Growth of agricultural crops will get affected by the changes in different climatic parameters. The changing climate will have adverse effect on the food grain production especially in tropical countries (Satapathy *et al.,* 2015). Temperature directly and indirectly affects the growth parameters by affecting water supply, substrate availability and the soil microbial activity (Wahid *et al.,* 2007). Singh *et al.,* (2013) studied the effect of elevated temperature on several crops and concluded that among different crops studied, wheat was found to be more sensitive. Elevated CO_2 enhances crop growth and productivity by stimulating plant photosynthesis which has been reported in many crop species (Dey *et. al*., 2017; Jin *et al.,* 2018; Wang *et al*., 2012). But the quality of the crops gets reduced under elevated CO_2 condition (Chakrabarti *et al*., 2020). Wroblewitz *et al.,* (2014) reported that wheat grains produced under elevated CO_2 level had lower nutritional quality, with lower protein content and more starch and fibres. Increased temperature hastens crop maturity and also reduces photosynthesis rate, leaf area and biomass of the crop (Cai *et al*., 2016; Chakrabarti *et al*., 2013; Maity *et. al*., 2022; Raj *et al*., 2016).

India ranks second in world wheat production with a production of 112.74 million tonnes during the year 2022-2023 (Ministry of Agriculture and Farmers' Welfare, 2023). Bread wheat is the hexaploid wheat species (*Triticum aestivum*) while *durum* wheat is tetraploid wheat (*Triticum turgidum* ssp. *durum*) and they vary in genomic number, grain composition and quality attributes (Shao *et al*., 2006). Bread wheat (*Triticum aestivum*) constitutes up

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to 95% of global wheat production, while *durum* wheat (*Triticum turgidum* ssp. *durum*) contributes 5% of global wheat production (Li *et al.,* 2014). The quality of the kernel of durum wheat makes it suitable for pasta making. In recent times there is increasing demand of durum wheat varieties for making different food items like bread, cake, pasta, biscuit as well as other bakery products (Soomro *et al*., 2014). Wheat crop is sensitive to the changes in climate as temperature affects the growth of the crop (Dubey *et al.,* 2019). Late sowing of wheat and proximity to the equator, exposes wheat crop to high temperature stress in India (Joshi *et al.,* 2007). Phenological behaviour and growth of plants are affected by micrometeorological parameters. Under high temperature, wheat crop completes it life cycle faster while root growth gets reduced and spikelet sterility increases (Chakrabarti *et. al*., 2021; Pramanik *et. al*., 2018). A simulation study showed that yield of bread wheat will reduce by 18.1%, 16.1% and 11.1%, respectively in current, 2020 and 2050 scenarios due to terminal heat stress (Dubey *et. al*., 2020). In general *durum* wheat is better adapted to high temperatures and to semiarid climates than bread wheat. In spite of its relatively high adaptability to the marginal and drought environments, the production of *durum* wheat is threatened by the impacts of climate change (De Vita and Taranto, 2019). Barutcular *et. al*., (2017) reported that, water stress caused significant reduction in grain yield in *durum* wheat varieties.

However, there is limited knowledge regarding the response of *aestivum* and *durum* wheat varieties under changing climatic conditions. In general *durum* wheat is better adapted to high temperatures than bread wheat. So, the present study was undertaken to study the response of *aestivum* and *durum* wheat varieties in terms of crop phenology, and growth under elevated CO_2 and temperature condition.

MATERIALS AND METHODS

The research investigation was conducted at the Genetic-H field of the ICAR-Indian Agricultural Research Institute (IARI), situated in New Delhi situated at 28°35' N and 77°12' E, at an elevation of 228 meters above mean sea level. The region exhibits a semi-arid and subtropical climate, characterized with an average mean temperature of 19°C during the crop growth period.

Experimental design and treatments

The experiment was carried out inside the open top chambers (OTC) for two consecutive years (2020-2021 and 2021-2022) by growing one *aestivum* (HD 3226) and one *durum* (HI 8627) wheat variety. OTCs were constructed using galvanized iron (GI) pipes with transparent vertical sidewalls made up of polyvinylchloride (PVC) sheet built around metal frames (Singh *et al.,* 2012). In order to maintain the ambient humidity and temperature, and facilitate natural air exchange, the upper portion of the OTCs were kept open. In total there were four OTCs. Inside the OTCs, two levels of carbon dioxide (CO_2) concentration were maintained, viz. ambient (419 ppm), and elevated (550 ± 25 ppm). Two levels of temperature were also maintained inside the OTCs. In order to maintain elevated temperatures within the OTCs, the top potion of the chambers was partially covered. The OTC with fully open top had ambient temperature while the OTC with partially covered top had elevated temperature. Mean seasonal temperature rise inside the partially covered OTC was 2.5°C higher than the ambient. As plants utilize CO_2 for the photosynthesis process during the daytime, elevated CO_2 levels were maintained for a period of 8 hrs i.e. 9 a.m. to 5 p.m. Elevated CO_2 concentration was maintained inside the OTC by supplying CO_2 from high pressurized cylinders of commercial grade of 30 kg capacity (Maity *et al*., 2023). CO_2 concentration inside the OTC was measured using infra-red gas analyzer (IRGA), (Fuji, Japan). When the CO_2 concentration dropped below the set value, the solenoid valves automatically opened and released CO_2 enriched air inside the OTC. The daily maximum and minimum temperature values were recorded in each OTC using a digital thermometer and from that the daily as well as seasonal mean temperature values were calculated. Treatment details is given in Table 1.

Table 1: Treatment details

T1	Ambient temperature and ambient CO_2 (419 ppm)
T2	Elevated temperature (+2.5°C) and ambient CO_2 (419 ppm)
T3	Ambient temperature and elevated CO_2 (550 ± 25 ppm)
T4	Elevated temperature (+2.5°C) and elevated CO_2 (550 ± 25 ppm)

Wheat crop was sown during the third week of November inside the OTCs. Recommended dose of N, P, K (120:60:60) was applied through urea, diammonium phosphate (DAP), and murate of potash (MOP). Full dose of P and K were applied during sowing while nitrogen was applied in three splits (50% during sowing and 25% each at tillering, and flowering stages).

Crop observations

Different phenological observations were recorded by taking visual observations in the field. Date on which crop attained 50% flowering and date on which crop attained physiological maturity were noted for all the treatments and from those days to 50% flowering and days to physiological maturity were calculated. The gas exchange parameters (photosynthesis rate and transpiration rate) were measured using a portable photosynthesis system- Infrared Gas Analyzer (LI-6400XT, LiCOR, USA) during the flowering stage of the crop. Observations were recorded on physiologically matured leaves during daytime between 9 AM and 11 AM. Leaf area index (LAI) was recorded using canopy analyzer (LAI-2200C, LiCOR, USA). After harvest plant samples were collected. Growth and yield parameters like number of tillers and above ground biomass was recorded.

Statistical analysis

Statistical analysis of the data was done using SAS software (ver. 9.3) (SAS Institute Inc., CA, USA). The design of the experiment was factorial completely randomized design (CRD). Least square difference (LSD) values were computed at a significance level of 5%.

RESULTS AND DISCUSSION

Crop phenology of wheat as affected by elevated CO_2 and temperature

Days to 50% flowering ranged from 96 to 100 days in different wheat varieties while days to physiological maturity ranged from 121 to 128 days (Table 2). Rise in temperature by 2.5°C

Table 2: Crop phenology of wheat varieties as affected by elevated CO_2 and temperature (mean of 2 years)

Treatments	Days to 50% flowering		Days to physiological maturity	
	HD 3226	HI 8627	HD 3226	HI 8627
Ambient temperature and ambient CO_2 (419 ppm)	100	100	126	127
Elevated temperature (+2.5°C) and ambient CO_2 (419 ppm)	96	98	121	123
Ambient temperature and elevated CO_2 (550 ± 25 ppm)	100	100	126	128
Elevated temperature (+2.5°C) and elevated CO_2 (550 ± 25 ppm)	99	98	123	124
LSD ($p \leq 0.05$)	CO_2: NS; Temp.: 2; Var.: NS; CO_2 X Temp.: NS; CO_2 X Var.: NS; Temp. X Var.: NS; CO_2 X Temp. X Var.: NS		CO_2: NS; Temp.: 3; Var.: NS; CO_2 X Temp.: NS; CO_2 X Var.: NS; Temp. X Var.: NS; CO_2 X Temp. X Var.: NS	

Table 3: Gas exchange parameters in wheat varieties as affected by elevated CO_2 and temperature (mean of 2 years)

Treatments	Photosynthesis rate (µmol CO_2 m^{-2} s^{-1})		Transpiration rate (mmol H_2O m^{-2} s^{-1})	
	HD 3226	HI 8627	HD 3226	HI 8627
Ambient temperature and ambient CO_2 (419 ppm)	24.3	26.5	5.1	4.8
Elevated temperature (+2.5°C) and ambient CO_2 (419 ppm)	21.5	22.4	4.1	4.2
Ambient temperature and elevated CO_2 (550 ± 25 ppm)	28.3	28.7	4.3	4.2
Elevated temperature (+2.5°C) and elevated CO_2 (550 ± 25 ppm)	24.9	24.6	3.6	4.5
LSD ($p \leq 0.05$)	CO_2: 2.1; Temp.: 2.1; Var.: NS; CO_2 X Temp.: NS; CO_2 X Var.: NS; Temp. X Var.: NS; CO_2 X Temp. X Var.: NS		CO_2: NS; Temp.: NS; Var.: NS; CO_2 X Temp.: NS; CO_2 X Var.: NS; Temp. X Var.: NS; CO_2 X Temp. X Var.: NS	

Table 4: Growth and biomass of wheat varieties as affected by elevated CO_2 and temperature (mean of 2 years)

Treatments	Number of tillers m^{-2}		LAImax		Above ground biomass (g m^{-2})	
	HD 3226	HI8627	HD 3226	HI8627	HD 3226	HI8627
Ambient temperature and ambient CO_2 (419 ppm)	405	427	5.6	5.9	1252	1296
Elevated temperature (+2.5°C) and ambient CO_2 (419 ppm)	363	370	5.0	5.3	1102	1199
Ambient temperature and elevated CO_2 (550 ± 25 ppm)	428	443	5.8	6.1	1405	1462
Elevated temperature (+2.5°C) and elevated CO_2 (550 ± 25 ppm)	392	398	5.3	5.5	1175	1246
LSD ($p \leq 0.05$)	CO_2: 21; Temp.: 21; Var.: NS; CO_2 X Temp.: NS; CO_2 X Var.: NS; Temp. X Var.: NS; CO_2 X Temp. X Var.: NS		CO_2: 0.21; Temp.: 0.21; Var.: 0.21; CO_2 X Temp.: NS; CO_2 X Var.: NS; Temp. X Var.: NS; CO_2 X Temp. X Var.: NS		CO_2: 40; Temp.: 40; Var.: 40; CO_2 X Temp.: NS; CO_2 X Var.: NS; Temp. X Var.: NS; CO_2 X Temp. X Var.: NS	

significantly reduced days to 50% flowering by 4 days in *aestivum* variety (HD 3226) of wheat. In the *durum* variety (HI 8627), days to 50% flowering got hastened by 2 days. Same trend was followed in case of days to physiological maturity where elevated temperature shortened the maturity period by 5 days in HD 3226 variety (Table 2). In HI 8627 variety the maturity period reduced by 4 days. However, in elevated CO_2 plus temperature interaction treatment, days to physiological maturity reduced by 3 days in different varieties of wheat crop. An important factor affecting the duration of major crop growth stages is temperature (Bahuguna and Jagadish 2015). Earlier studies also showed that elevated temperature reduces crop growth period in different crops (Chakrabarti *et al.,* 2021; Raj *et al.,* 2016). Chakrabarti *et al*., (2013) reported that a rise in temperature of 1.8 to 2.9°C resulted in a decrease in the length of anthesis period by approximately 4 to 5 days in wheat crop.

Physiology of wheat as affected by elevated CO_2 and temperature

Photosynthesis rate of both *aestivum* and *durum* wheat varieties significantly increased under elevated CO_2 condition while elevated temperature reduced the photosynthesis rate. In elevated CO_2 plus temperature interaction treatment, photosynthesis rate was more than elevated temperature treatment (Table 3). This shows that elevated CO_2 was able to reduce the negative effects of elevated temperature. Photosynthesis rate was more (26.5 µmol CO_2 m^{-2} s^{-1}) in *durum* wheat variety (HI 8627) than *aestivum* variety (HD 3226) (24.3 µmol CO_2 m^{-2} s^{-1}) in ambient treatment. Several experiments conducted under elevated CO_2 condition showed that photosynthesis rate gets stimulated under increased CO_2 concentration (Dey *et. al.*, 2017; Sanyal *et al*., 2022). Transpiration rate was highest under ambient conditions. Transpiration rate of *aestivum* wheat variety (HD 3226) ranged from 3.6-5.1 mmol H_2O m^{-2} s^{-1} while that of *durum* variety (HI 8627) ranged from 4.2-4.8 mmol H_2O m^{-2} s^{-1} (Table 3). In *aestivu*m variety of wheat, transpiration rate was less in elevated CO_2 plus high temperature interaction treatment than ambient while transpiration rate of *durum* variety remained unaffected in both the years. In the case of C3 crops, such as wheat, it is probable that an elevation in carbon dioxide concentration would result in an augmentation in the rate of photosynthesis, while simultaneously decreasing stomatal conductance. There are reports of reduced stomatal conductance as well as transpiration rate under elevated CO_2 and elevated CO_2 plus temperature interaction treatment.

Growth of aestivum and durum wheat as affected by elevated CO_2 and temperature

In HD 3226 variety, tiller number was 405 per m^2 in ambient treatment while in HI 8627 it was 427 per m^2 (Table 4). Elevated temperature reduced the tiller number in wheat varieties than ambient treatment in both the years. In elevated CO_2 treatment number of tillers was more than ambient in wheat varieties. In the elevated CO_2 plus high temperature interaction treatment, tiller number of HD 3226 variety was 392 per m^2 while in HI 8627 variety it was 398 per m^2.

Maximum leaf area index (LAI_{max}) significantly reduced in elevated temperature treatment (Table 4). LAI_{max} of *durum* variety (HI 8627) was more (5.9) than that of *aestivum* variety (HD 3226) (5.6) in ambient treatment. In elevated temperature treatment, LAI_{max} of HI 8627 was 5.3 while in HD 3226 it was 5.0. Elevated CO_2 concentration of 550 ppm was able to partially compensate the reduction in leaf area of wheat crop. In elevated CO_2 plus high temperature interaction treatment, LAI_{max} was 5.5 in HI 8627 and 5.3 in HD 3226 wheat variety. Chakrabarti *et al.,* (2021) also reported that, LAI of wheat crop is negatively affected by elevated temperature during anthesis stage of the crop.

Above ground biomass (grain plus straw weight) of the wheat varieties also reduced by high temperature while elevated CO_2 alone increased aboveground biomass of the crop (Table 4). Above ground biomass of *durum* variety (HI 8627) was found to be more than *aestivum* variety (HD 3226). In elevated CO_2 plus high temperature interaction treatment, aboveground biomass of HD 3226 wheat variety reduced by 6.1% than ambient treatment. In case of HI 8627 wheat variety aboveground biomass reduced by 3.9% than ambient treatment. This shows that negative effect of elevated temperature on crop biomass was more in *aestivum* variety of wheat than *durum* variety. In our study, elevated CO_2 could compensate the reduction in aboveground biomass by 5.9% in HD 3226 and by 3.6% in HI 8627 wheat varieties. Singh *et al*., (2013), also reported that elevated CO_2 level could reduce the harmful effect of temperature rise up to 1.5°C in wheat crop.

CONCLUSION

Rise in temperature by 2.5° C significantly decreased crop growth duration period in both *aestivum* and *durum* varieties of wheat crop. Photosynthesis rate, leaf area and tiller number reduced in elevated temperature treatment while elevated CO_2 concentration of 550 ppm was able to partially compensate the reduction in these crop growth parameters. The negative effect of elevated temperature on crop biomass was more in *aestivum* variety than *durum* variety. Elevated CO_2 concentration compensated reduction in aboveground biomass by 5.9% in HD 3226 (*aestivum*) and by 3.6% in HI 8627 (*durum*) varieties under elevated temperature condition.

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