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Impact of projected climate change on wheat varieties in Uttarakhand, India

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ABSTRACT

Crop production is naturally sensitive to variability in climate. Temperature and CO_2 are two important parameters related to climate change, which affect yield of crop. To test the hypothesis an attempt has been made to assess the impact of these two parameters on the growth, yield and physiology of wheat cultivars (HD2285, HUW 234, PBW 343, PBW 226, Raj 3765 and Raj 3077) grown in North – West plain of Uttarakhand. For this purpose CERES-Wheat model v.4.5 was used. Total five CO_2 concentrations as projected by IPCC i.e. Ambient (380 ppm), +100, +200, +300, and +400 ppm have been used in the model. However, on the basis of study carried out in the region, the model was run and rerun for temperatures rise by 0.5⁰C, 1.0⁰C, 1.5⁰C and 2.0⁰C from current temperature levels. Percent deviation of phenology, leaf area index, yield, evapotranspiration and WUE from baseline was estimated and analyzed to assess the effect of elevated temperature and CO_2.The model results showed that the yields and WUE of all the varieties increased significantly under elevated CO_2 concentrations and decreased significantly with increasing temperatures. Among the cultivars PBW 343 performed well under various temperature as well as CO_2 scenarios and found to be high yielding with an average grain yield potential of 5628 and 5669 kg ha^{-1}. Variety HD 2285 was found to be more sensitive in response to varying level of CO_2 with the average change of 40.6% from baseline. Varieties such as PBW 343, HUW 234 and Raj 3765 are best performer varieties in term of growth (LAI), yield (grain and biomass) physiology (total evapotranspiration and WUE) and have ability to sustain in changing climate. Thus these cultivars can be recommended for cultivation in SW plains of Uttarakhand state.

Keywords: DSSAT4.5, Wheat varieties, Water use efficiency, CO_2, Temperature

Wheat (*Triticum aestivum* L.) is one of the most important and widely cultivated crops in the world, and provides 20% of food calorie and 22% the daily protein for 4.5 billion people. India is one of the utmost witnesses of Green revolution, now has the credit of second largest producer as well as consumer of wheat in the world. Since last two to three decades abrupt changes in climate i.e. increase in CO_2 and temperature has been noticed by researchers and reported that by the middle of 21st century expected climate change will cause a threat to Indo-Gangetic Plains of India. Gangetic Plains contributes ~15% of the world's wheat production and serves the food to more than 200 million people (Ortiz et al., 2008). IPCC has stated that the climate change is mainly attributed to human-induced activities and sole driver of this change is CO_2. Current atmospheric CO_2 concentrations are higher than at any time in the last 15 million years (Tripati *et al.,* 2009). If the effect of greenhouse gas removed, real global temperature will be -15 to -25 ⁰C. Current global mean warming is ~0.85 (0.65 to 1.06) °C above preindustrial time over the period i.e.1880 to 2012. Average annual surface temperature over the northern part of India will be increased up to 3- 5°C in high emission scenario (A_2) and 2.5- 4⁰C for low emission scenario (B_2) by the end of 21stcentury (Rupa Kumar *et al.*, 2006). Impact of climate change on wheat crop is well known (Asseng *et al*., 2013; Attri and Rathore, 2003; Lobell *et al*., 2011). As a C_3 plant wheat has positive sign of increasing biomass potential under elevated CO_2 condition while increase in temperature have negative impact on dry matter and quality components (Högy *et al*., 2013). A Meta analysis study (Amthor, 2001) revealed that elevated CO_2 on wheat have positive response as increase in accumulation of photosynthates, water use efficiency and decrease in stomatal conductance and transpiration effects. Planning and decision making in agriculture is being a challenging job specially under changing climate. In that context crop simulation models would be an easier tool. Performance of crop model under diverse climatic situation is tested by numerous researchers in various part of world (Lal *et al*., 1998; Özdoðan, 2011). The aim of this study is to evaluate the (a) future impact of climate change on the major cultivar of wheat grown in northern part of India; (b) impact of temperature and CO_2 alone and together on

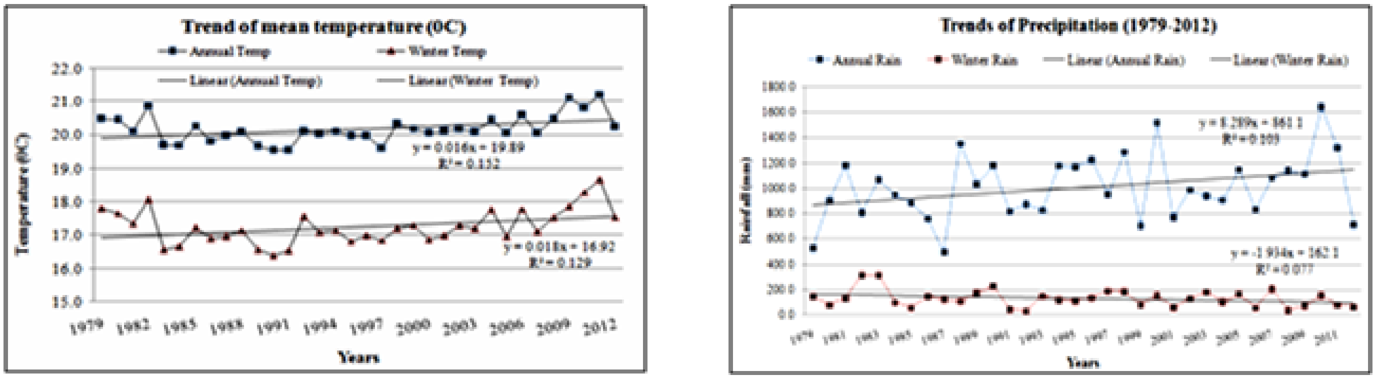

Fig. 1: Trends of mean temperature and precipitation for annual and winter season (wheat period) in the study area from the period 1979-2012

the growth, yield, evapotranspiration and water use efficiency of wheat crop; (c) to suggest the suitable variety for Uttarakhand region under changing climate.

MATERIAL AND METHODS

Description of study area

Study area comes in the Haridwar district of Uttarakhand situated in the south western plain of the state and lies between 290 30' - 310 02' N and 770 20'- 790 20' E. Area is agriculturally very sensitive and contributes about 35% food grain and 80% sugar to the total production of the state (Tripathi *et al.*, 2013). District is situated in the foot hills of the Shivalik forms a transition between the per-humid northern and dries to sub-humid southern plain zones of great Himalaya also famous for its recreational beauty and abundance of natural resources. This area contributes about 14 % of total wheat production of the state with the average productivity of 2590 kgha^{-1}. Climate is hot sub humid with extreme cold in winter especially in the month of January and extreme hot in summer in the month of May due to blowing of hot wind called "Loo". The average maximum temperature was 30.1 ^{0}C varies from 18.7-38 ^{0}C while minimum temperature was 17.6 ^{0}C with the annual variation of 1.4-26 ^{0}C. Annual rainfall of the region was 1011 mm.

Rainfall and temperature of study area (1979-2012) show an increasing trend in annual mean temperature with 0.016^{o}Cy^{-1} while winter mean temperature (during the period of wheat crop in north India from 46th week to 18th week of next year) show an increasing trend with 0.018^{o}Cy^{-1} (Fig.1). Also increasing trends in annual rainfall at the rate of 8.2 mmy^{-1} was observed but the trend is tends to decrease during the winter season (wheat crop season) with the rate of -1.93 mmy^{-1}. This increase in trend of temperature and decrease in the rate of precipitation during winter season confirmed the impact of climate change that might be appearing in future on winter crop especially on wheat.

Model description

DSSAT v4.5 is a process oriented Cropping System Model (CSM) that has the capability to simulate the growth, development, biomass production of crop over the time as well as the soil water, carbon and nitrogen processes and management practices under dynamic environmental situation (Hoogenboom *et al.*, 2004). The model has ability to simulate all these parameters based on different modules like carbon balance module, water balance and the nitrogen balance modules.

Weather scenarios

About 5 scenarios have been developed to evaluate the response of different varieties of wheat as described by (Attri and Rathore, 2003). Temperature scenarios consist of T_0, T_1, T_2, T_3 and T_4 i.e. ambient temperature, ambient+0.5, ambient+1.0, ambient+1.5, ambient+2.0 ^{0}C increase in daily maximum and minimum temperatures respectively. IPCC has proposed the rate of increment in greenhouse gases by an average of 1.6 % per year while particularly for CO_2 this rate is almost 1.9 % per year (Parry, 2007). Thus the elevated CO_2 scenario considered for model simulation is equivalent 750 ppm which is projected to increase by the end of this century for B_2 scenario. CO_2 scenarios used in the study denoted as S_0, S_1, S_2, S_3, and S_4 i.e. ambient CO_2 (350 ppm), ambient+100, ambient+200, ambient+300, ambient+400 ppm CO_2 concentration respectively. (Lal *et al.,* 1996) carried out a study using global circulation model output on the basis of this data projected rainfall for north western part of

Table 1: Physico-chemical property of soil for study site

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (1:2)	SCEC (meq+/ 100g)	SOC (%)	BD (g cm^{-3})	SAT (cm^3 cm^{-3})	SRGF	LL (cm^3 cm^{-3})	DUL (cm^3 cm^{-3})
Soil texture: Sandy loam											
0-15	60.6	21.2	18.2	6.4	18.8	0.46	1.51	0.41	1.0	0.12	0.25
15-30	62.6	20.8	16.6	6.8	17.9	0.38	1.47	0.42	0.4	0.11	0.26
30-60	63.6	20.2	16.2	7.4	17.4	0.33	1.47	0.42	0.2	0.10	0.23
60-90	66.3	18.4	15.3	7.1	17.4	0.30	1.46	0.42	0.1	0.10	0.22
90-120	67.4	18	14.6	7.5	17.1	0.28	1.44	0.44	0.8	0.10	0.22

SCEC- soil cation exchange capacity; SOC- soil organic carbon; BD- bulk density; SAT- saturation SRGF: soil root growth factor; LL: lower limit; DUL: soil drained upper limit.

Table 2: Genetic coefficient of different wheat varieties

Cultivars	P_1V	P_1D	P_5	G_1	G_2	G_3	PHINT
HD 2285	20	60	780	25	50	1.7	90
PBW-226	20	68	550	19	44	1.2	95
HUW- 234	20	60	820	26	49	1.7	90
PBW 343	20	70	800	20	45	1.5	95
RAJ 3765	20	55	830	20	47	1.7	95
RAJ-3077	20	82	680	18	42	1.5	95

country for the period of 2040-49, no signiûcant changes in rainfall was reported. Hence, the rainfall data has not been modiûed in our analysis.

Input data

Weather information : Weather data of the study area used in study were collected from the Agro Met Field Unit (AMFU) of India Meteorological Department (IMD) situated at Indian Institute of Technology Roorkee for a period of 33 years (1979-2012).

Soil information : The following is the dataset required for soil.SOL file to run the model.

Crop information : Crop varieties selected in study are early, medium and late in duration varies from 115-140 days and suitable for Uttarakhand state. The minimum data sets for X build are planting date; planting density, row spacing, planting depth, irrigation, and fertilizer applications etc. Beside this agronomic practice like tillage, irrigation, fertilizer, and intercultural operation applied as per widely accepted and recommended for the area. November 15 taken as a planting date up to that period about 75 percent crop being sown. Plant spacing kept 15 cm while line to line spacing 20 cm and sowing depth 5 cm which recommended for Mexican wheat (*T. aestivum*) varieties.

Genetic coefficients: Already calibrated and validated genetic coefficients of wheat varieties grown in North India viz., HD2285, HUW – 234, PBW- 343, PBW -226, Raj 3765 and Raj 3077were collected from literatures (Attri and Rathore, 2003; Singh *et al.,* 2010).

Where, P_1V: Days at optimum vernalizing temperature required to complete vernalization; P_1D:Percentage reduction in development rate in a photoperiod 10 hour shorter than the threshold relative to that at the threshold; P_5:Grain filling (excluding lag) phase duration in degree days(^{0}C.d); G1:Kernel number per unit canopy weight at anthesis (g); G_2:Standard kernel size under optimum conditions (mg); G_3:Standard, on-stressed dry weight (total, including grain) of a single tiller at maturity (g) and PHINT: Interval between

Table 3: Analysis of variance of selected parameters

Sources of Variation	DF	F cal	CD	CV	SEm	SEd
Straw yield (kg ha^{-1})			P<0.05	%		
Variety	5	5998.93				
Temperature (^{o}C)	4	19.56*	102.778	3.07	37	52
CO2 (ppm)	4	451.81*	102.778		37	52
Temp X CO_2	16	0.81	NS		83	117
Grain Yield(kg ha^{-1})						
Variety	5	4368.24				
Temperature (^{o}C)	4	18.83*	57.249	3.471	21	29
CO_2 (ppm)	4	536.11*	57.249		21	29
Temp X CO_2	16	0.32	NONSIG		46	65
LAI (%)						
Variety	5	3099.47				
Temperature (^{o}C)	4	03.16*	0.033	2.957	0.012	0.017
CO_2 (ppm)	4	31.04*	0.033		0.012	0.017
Temp X CO_2	16	0.76	NONSIG		0.026	0.037
ETCM-Total evapotranspiration (mm)						
Variety	5	4754.18				
Temperature (^{o}C)	4	09.35*	2.066	2.089	0.7	1.1
CO_2 (ppm)	4	38.78*	2.066		0.7	1.1
Temp X CO_2	16	0.8	NONSIG		1.7	2.4
Total water use efficiency (kg ha^{-1}mm^{-1})						
Variety	5	4995.15				
Temperature (^{o}C)	4	15.52*	0.324	3.242	0.12	0.17
CO_2 (ppm)	4	487.77*	0.324		0.12	0.17
Temp X CO_2	16	0.94	NONSIG		0.26	0.37

successive leaf tip appearances (^{0}C.d).

DSSAT v 4.5 Run

Detailed methodologies for simulating impacts of changing climate on crop production have been described by (White *et al.*, 2011). Main driver program interlinks all the databases and different crop simulation models within the DSSAT program. Different varieties, temperature and CO_2 scenarios were used as treatments to runs the simulation. Total 150 time simulations have been made to cover the study objective by running DSSAT v4.5 software.

Statistical analysis

Two-factor Analysis of Variance (ANOVA) was used to determine the interactive response of elevated CO_2 and temperature on Wheat crop (Table 3). The magnitude of responses CO_2 and temperature as a percent change from baseline was assessed to see the impact of climate change. All statistical tests were carried out using SPSS 16.0. Figure used in the study were prepared in Origin plot 8.0.

Climate change impact analysis

Percentage difference between the simulated crop duration (days taken to anthesis and days taken to maturity), leaf area index (LAI), water use efficiency (WUE), seed yield and biological yield were calculated for each year (1979-2011) using actual weather data with the rising temperature data. Calculated result of each averaged

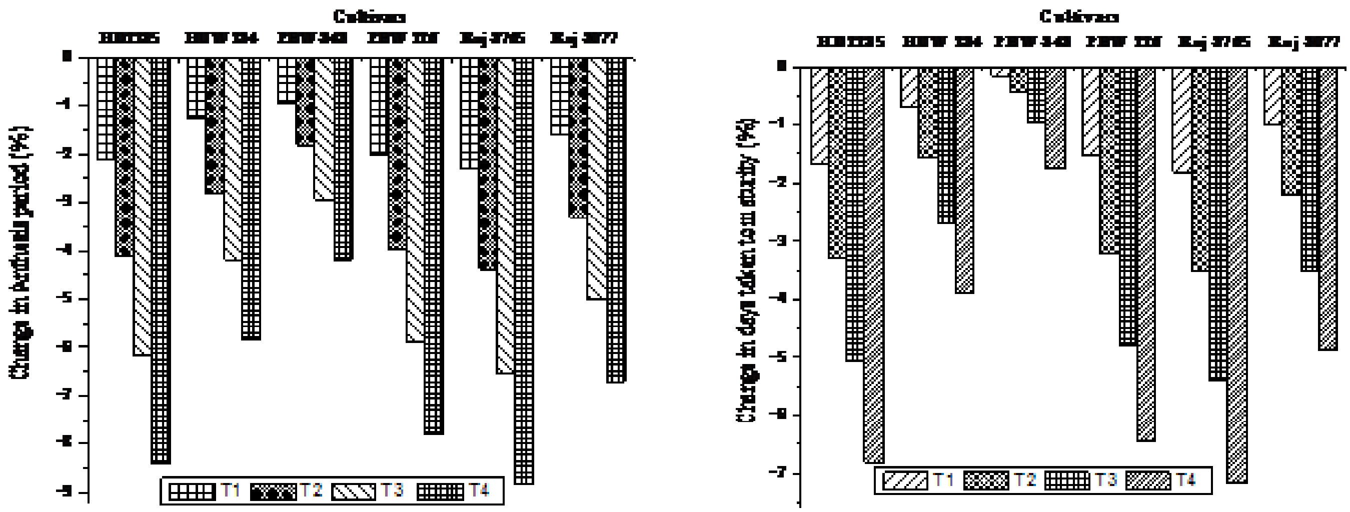

Fig.2: Phenological phases of wheat under various temperature scenarios

out, which indicates the impact of rise in temperature on the above parameters. For studying the percentage difference between net effects of elevated CO_2 on various parameters varying CO_2 levels was taken as described in scenarios. The average differences for each generated scenario were analyzed for indicating the sensitivity of CO_2 to different varieties, as well as various physiological parameters. Interactive impact of temperature and CO_2 was also analyzed to see whether the positive effect of rising CO_2 can mitigate the adverse effect of temperature on crop yield and if yes to what extent.

RESULTS AND DISCUSSION

Effect of elevated temperature

Phenology : Days taken to anthesis and maturity by different varieties as affected by various level of temperature were depicted in Fig 2. Linear decrease in phenological phases was observed as increase in temperature levels. Maximum reduction in days taken to anthesis was observed at T_4 (2^0C) in each varieties. The reduction were 6.8% in HD2285, 3.9% in HUW-234, 1.8 % in PBW-343, 6.4% in PBW-226, 7.2% in Raj- 3765 and 4.9% in Raj 3077. Similar trends were noticed for days taken to anthesis in all the varieties. The reductions were 8.4% in HD2285, 5.8% in HUW-234, 4.2 % in PBW-343, 7.8% in PBW-226, 8.8% in Raj- 3765 and 6.7% in Raj 3077. Decrease in phenological duration of crop is due to rapid accumulation of growing degree days (GDD) which enhance the rate of growth and development resulting shorten the life span. Approximate 5 days reduction in ûowering and of 4 days in days taken to maturity was reported in northwest Indian conditions by 1 °C temperature enhancement (Attri and Rathore, 2003). Lobell et al. (2012) carried out a study on three sites (9 year) over north India and reported a decrease in wheat yields due to shortening of growing period.

Leaf area index : Model generated LAI indicates the maximum value over entire growing period. Maximum interception of light in term of LAI was observed for variety PBW-343 (2.18) while minimum for Raj 3765 (Fig.3a). The LAI decreased signiûcantly ($P<0.05$) with increase in temperature levels. Maximum variation was observed in Raj 3765 under different scenarios while minimum in Raj 3077 (Fig. 3a). Maximum reduction were observed at T_4 (2^0C) i.e. 13.3% in HD2285, 4.4% in HUW-234, 3.2 % in PBW-343, 5.5% in PBW-226, 15.5%in Raj- 3765 and 2.8% in Raj 3077. Average decrease in LAI of various cultivars under different temperature scenarios was observed to be 3.5 %.

Biological yield : The simulation results showed that any increase in temperature would cause decline in biological yield of all varieties except Raj 3077 that have some positive response up to 1 ^{0}C increase in temperature (Fig.3b). The biological yield of various cultivars declined significantly ($P<0.05$) with increase in temperature levels. Among the cultivars PBW 343 performed well under temperature scenarios and found to be high yielding with an average yield of 10668 kg ha^{-1} and Raj 3765 is found to be less yielding with average potential of 3254 kg ha^{-1}. Variety Raj 3765 was found more sensitive to temperature increment with reduction in straw yield between 2.5 to 21 percent whereas, minimal sensitivity with in the treatment

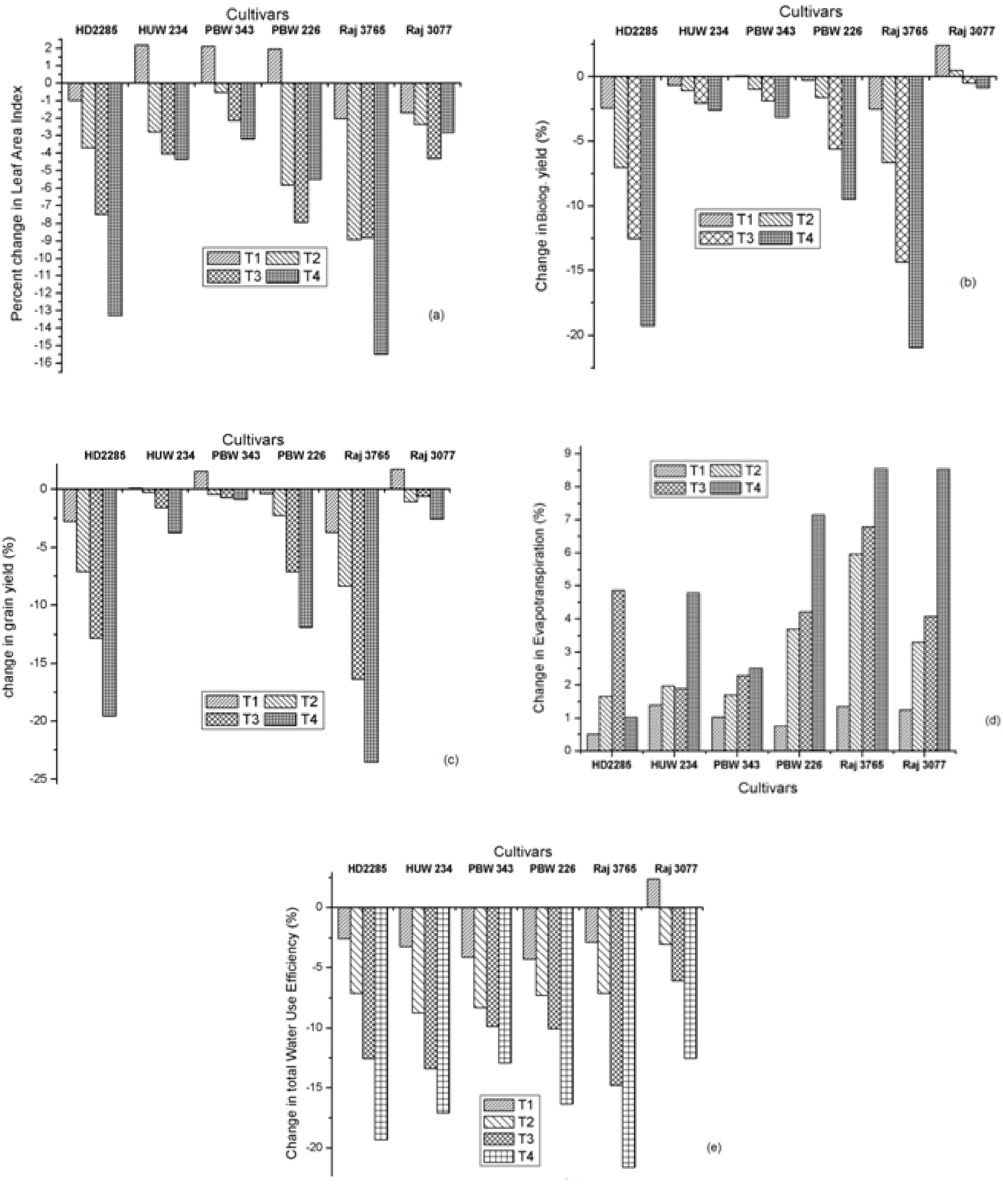

Fig. 3: Effect of elevated temperature on leaf area index, biological yield, grain yield, evapotranspiration and water use efficiency of wheat crop

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was observed for variety Raj 3765.

Grain yield : Simulated grain yields also showed that any increase in temperature would have negative response for all varieties except PBW 343 and Raj 3077, which have positive response up to 1 ^{0}C increase in temperature. Grain yields (kg ha^{-1}) of all varieties were found to be significantly ($P<0.05$) influenced by increasing levels of temperature. Maximum average yield under various temperature scenarios was observed for variety PBW-343 (5628) while minimum for Raj 3765 (1675). Reduction in yield in Raj 3765 was observed due to decrease in life cycle of variety. Highest change in yield under various temperature scenarios was observed for variety Raj 3765 varies from 3 (T_1) – 24 (T_4) while minimum (< 1%) was observed for variety PBW-343 (Fig.3c).

Evapotranspiration : Total season evapotranspiration (ETCM-mm) has significant ($P<0.05$) positive influence as increasing levels of temperature. Highest rate of average ETCM (mm) was observed for variety PBW-343 (275) while minimum for Raj 3765 (154) (Table 3). Maximum variation within the various temperature scenarios was observed for variety Raj 3765 varies from 3 (T_1) – 18 % (T_4) while minimum (1-8%) was observed for variety HD2285 (Fig.3d). Maximum positive change in ETCM were recorded at T_4 (2^{0}C) which is 2% in HD2285, 12% in HUW-234, 7 % in PBW-343,11% in PBW-226, 13% in Raj- 3765 and 18% in Raj 3077. Similar trend of increased evapotranspiration by increasing temperature in wheat crop has already been documented in literature by the researchers (Kaur *et al.*, 2012).

Total water use efficiency (WUE) : The negative impact of elevated temperatures on water use efficiency and dry matter production of wheat crops is well documented (Singh *et al.,* 2010). Data pertaining to simulated WUE presented in table 3 revealed that the highest average value was observed for variety PBW-343 (30.4 kgha^{-1}mm^{-1}) and minimum for variety Raj 3765 (9.9 kgha^{-1}mm^{-1}). Significant ($P<0.05$) decrease in WUE with increasing levels of temperature was observed for various cultivars (Fig.3e). Total reduction varied between 2-21% for various cultivars. Highest reduction was observed at T_4 (2^{0}C) which is 19.3% in HD2285, 17.1% in HUW-234, 12.9 % in PBW-343,16.3% in PBW-226, 21.6% in Raj- 3765 and 12.6% in Raj 3077.

Effect of elevated CO_2

LAI : The highest average LAI was observed for variety PBW-343 (2.37) while minimum for Raj 3765(0.44) and significant ($P<0.05$) increase was observed by increasing CO_2 levels. Maximum variation within the treatment was observed in Raj 3077 while minimum was observed in PBW343 (Fig. 4a). Maximum increment was observed at S_4 (ambient+400 ppm) which is 48.2% in HD2285, 26.3% in HUW-234, 2.7 % in PBW-343, 61.3% in PBW-226, 55.3% in Raj- 3765 and 58% in Raj 3077. Average increase in LAI of various cultivars under different CO_2 scenarios was 23.6 %. Under elevated CO_2 concentrations the green leaf area index of the main shoot increased largely due to an increase in green leaf area duration. According to Kaur et al (2012) leaf area index is projected to increase by 10-41 % under elevated CO_2 concentrations (750 ppm).

Biological yield : Response of CO_2 fertilization on biological yield and grain yield was taken with reference to ambient CO_2 level. The simulation results showed that increasing CO_2 levels have gradual yield increment of wheat varieties. Data presented in table 2 revealed that biological yield of various cultivars increased significantly ($P<0.05$) with increase in CO_2 levels. Cultivars PBW 343 performed very well under different elevated scenario and found to be high yielding with an average biomass yield of 10668 kg ha^{-1}while Raj 3765 is found to be less sensitive with average potential of 3254 kg ha^{-1}. Average increase in biomass yield by 27.6% was observed in different cultivars (Fig. 4b). Variety HD 2285 was found to be more sensitive to elevated CO_2 and have greater (39.5%) response between the treatments. Minimum sensitivity (8.8%) with in the treatment was observed in case of PBW 343.The result has close proximity with the finding of Singh *et al.*, (2010).

Grain yield : The seed yield of various cultivars shows linearly rising trend with increasing CO_2 levels. Average percent change in seed yield under various scenarios ranges between 11-41% (Fig 6b). Highest and lowest average yield potential was recorded for PBW-343 and Raj 3765 respectively.

Variety HD 2285 was found to be more (40.6%) sensitive (between the treatments) to elevated CO_2 while minimum (11.8%) was served in case of PBW 343 (Fig.4c). The result is consensus with the study of Pandey *et al.* (2007); Attri and Rathore, (2003) according to this study wheat yield rising from 1.54–18.4 % due to increasing CO_2 levels up to 425 ppm in different regions of India.

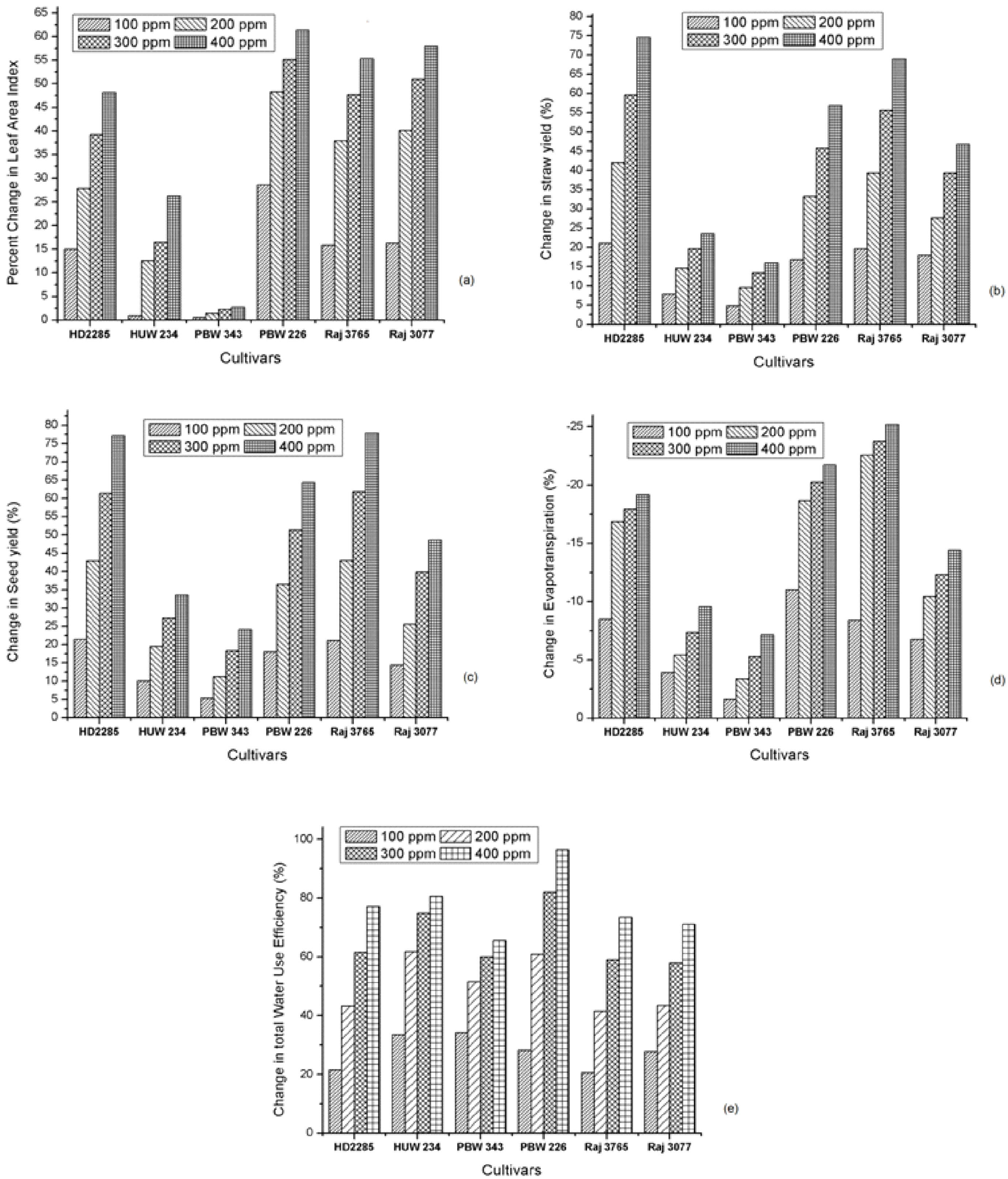

Fig. 4: Effect of elevated CO_2 on leaf area index, biological yield, grain yield, evapotranspiration and water use efficiency of wheat crop

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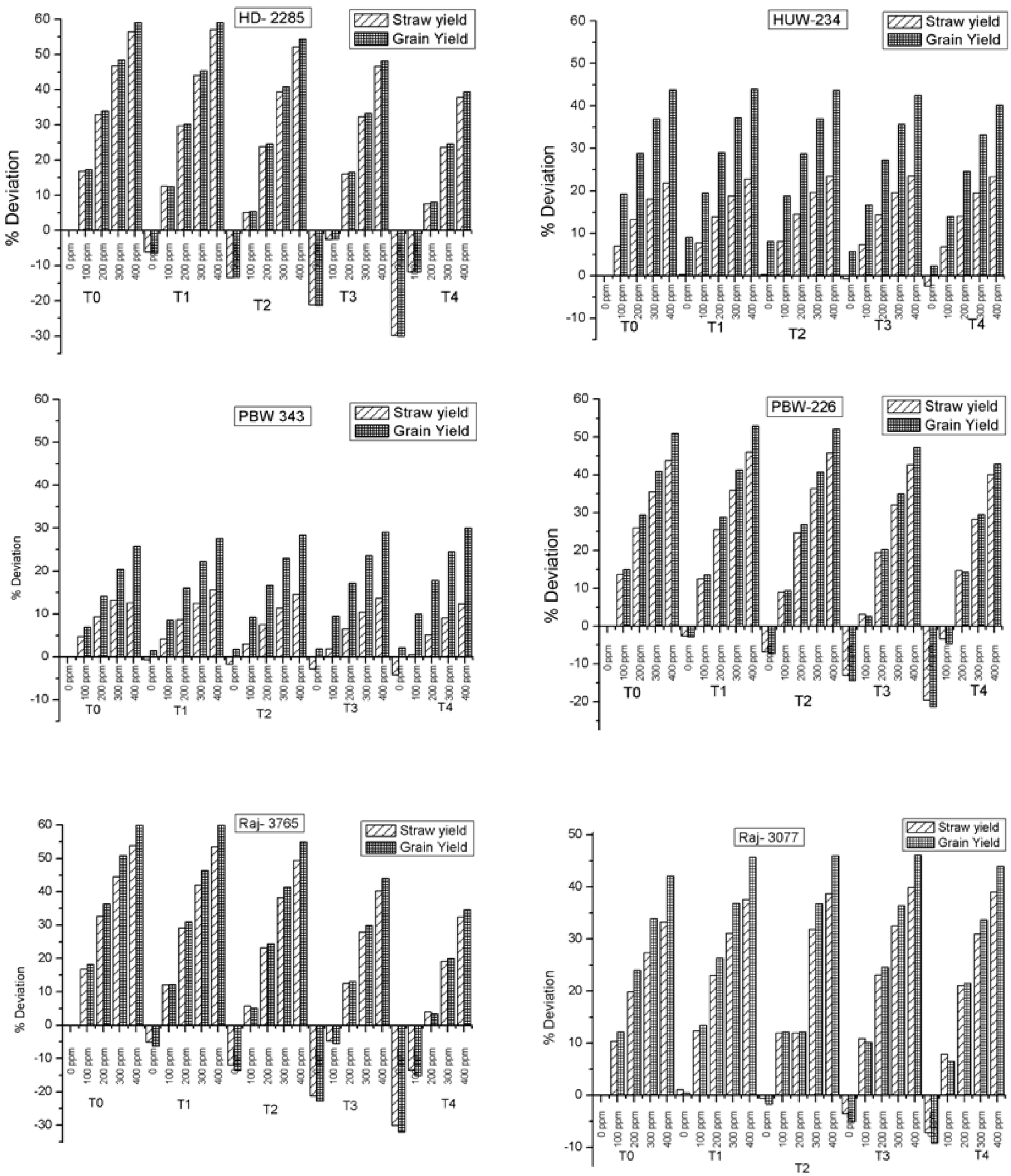

Fig.5: Percent deviation in grain and straw yield as affected by various levels of temperature ^{O}C (T) and CO_2.

Evapotranspiration : Total evapotranspiration as affected by various CO_2 levels showed significant ($p<0.05$) decrease for all the selected cultivars (Table 4). Average percent change (Fig. 4d) in evapotranspiration is -12.5, -5.2, -3.5,-14.3, -16.0 and -8.8 percent from the ambient for HD2285, HUW 234, PBW 343, PBW 226, Raj 3765 and Raj 3077 respectively. Maximum sensitivity between the treatments was observed in Raj 3765 (-8.8 to -25.2) while minimum in PBW 343 (-1.5 to 3.6). Findings correlated with the study of (Lal *et al.*, 1998).

WUE : Data pertaining to simulated WUE (Table 4) also have significant ($P<0.05$) increasing impact as affected by various levels of elevated CO_2. Highest average value was observed for variety PBW-343 (30.4 kg ha^{-1} mm^{-1}) and minimum for variety Raj 3765 (9.9 kg ha^{-1} mm^{-1}). Highest sensitivity in term of percent change from ambient CO_2 between the treatments (Fig. 4e) was observed in PBW 226 (53.5%) while lowest was observed for Raj 3765 (38.9). Lawlor and Mitchell (1991) have reviewed a number of field studies based on the response of elevated CO_2 on crop and reported similar results in many studies.

Interactive effect of elevated CO_2 and temperature on yields of different varieties

The major focus of this study was to detect and quantify the interaction effects of elevated CO_2 and temperature on final production i.e. grain yield (GY) and biological yield (BY). The positive impact of elevated CO_2 and negative impact of temperature resulted in interactive effects on different varieties (Fig 5). Variety PBW 343 has excellent performance with the average BY of 10668 kg ha^{-1} and GY of 5628 ha^{-1} under various climate change scenarios. Poor response under similar climate change scenarios was observed for variety Raj 3765 both in term of average BY (3254 kg ha^{-1}) as well as GY (1675 kg ha^{-1}). Other selected varieties like HD2285, HUW 234 PBW 226, and Raj 3077 performed quite well with average potential BY and (GY) of 3723 (2288), 9236 (4143), 4671 (2354) and 7927 (3367) kgha^{-1} respectively under changing climate scenarios based on climatic situation of Uttarakhand.

Percent deviation from the control (T_0 and ambient CO_2) to different changing scenario was quantified to see the degree of change (positive or negative) in yield of various cultivars and result depicted in Fig 5. It is cleared that the negative impact of temperature is compensated by the positive impact of CO_2. Variety HD 2285 have increasing performance both in term of GY and BY under different elevated CO_2 scenarios under ambient temperature (T_0). As the temperature increased under ambient CO_2 the variety shows decreasing trend, negative trend was compensated (up to T_1) with the elevated levels of CO_2. The highest negative impact was observed under T_4+0 ppm scenario which is -30.1 % (GY) and -29.8% (BY). Variety HUW 234 not much affected with various climate scenarios and has positive response until (T_2) after that tends to respond negatively in absence of CO_2. Highest negative response was observed under T_4 temperature level in absence of elevated CO_2 which is -6.2% (GY) and -18.0% (BY). Variety PBW 343 has quite good performance under different changing scenario and not much affected with increasing temperature. In case of grain yield it decreased with the increasing level of temperature up to T_4 but not affected negatively. Under high temperature (T_4) negative impact was observed for BY (-4.2). Variety PBW 226 is found sensitive in term of increasing CO_2 and temperature both because under elevated CO_2 it has got total increment of about 53 % (GY) and 46 % (BY). In case of temperature increment the negative trend was observed up to -21.4 % (GY) and -19.5% (BY). Highest sensitivity for increasing CO_2 and temperature both was observed for variety Raj 3765. It has highest degree of negative (T_4+ ambient CO_2) as well as highest degree of positive effect (T_0+400ppm CO_2). Total negative change due to temperature was -32.1 % for GY and -30.1% for BY. Raj 3077 is quite popular variety of wheat crop grown in Uttar Pradesh and Uttrakhand region showed more or less similar impact of changing climate as HUW 234. Highest negative impact was observed for GY and BY is -9.2% and -18.4% respectively. Haris *et al.* (2013) reported that an increase in temperature would decrease wheat yield in different part of Bihar but increased CO_2 can compensate this negative effect by enhancing photosynthesis and stomatal conductance. Yang *et al.* (2013) has reported to decrease in wheat yield by rise in temperature while increase under elevated CO_2 under north China plain.

CONCLUSION

The simulated impact of elevated CO_2 and temperature on wheat varieties generated by DSSAT CERES-Wheat model for different scenarios showed that under existing conditions variety PBW 343 is an endowed variety in terms of growth, yield as well as physiological response. Even with climate change effect PBW 343 would still be the high yielding if both CO_2 and temperature increase simultaneously and at the same pace, as CO_2 fertilization effect nullifies the ill effects of higher temperatures. But under higher temperature scenario T_3 cultivar HUW 234 is found to be suitable for grown under water limiting conditions whose yields and WUE are less affected. The above studied crop parameters would be rather unaffected or the impact would be positive up to T_1 but for T_2 and T_3 when temperatures would be greater than 1 ^{0}C the effect would be negative. When the CO_2 concentrations more than the normal yields and other parameters would be positively impacted if CO_2 fertilization effect prevails. Today's promising varieties like PBW 226, HD2285, and Raj 3077 may be extinct in future due to lower performance especially in term of yield. If only CO_2 rise continues yields and WUE would continue to increase. It is proved that if CO_2 increases even temperature is bound to increase in such situations the yields of all the cultivars increase under T_2S_3 and T_3S_4 it would be 6-7and 3-5 % respectively. Under elevated CO_2 scenario varieties like Raj 3765 and HD 2285 have high affinity to utilize higher CO_2 in producing more carbohydrates and thereby resulting in higher yields. WUE increases for all the cultivars but PBW 343 even in this perspective possess inherent property to give better yields in future when water would become scarce resource. Based on this evidence, varieties such as PBW 343, HUW 234 and Raj 3765 are quite excellent in term of yield and can be recommended for cultivation in SW plains of Uttarakhand state.

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