



Changes in thermal requirements, growth and yield of wheat under the elevated temperature

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ABSTRACT

A field experiment was conducted inside a temperature gradient tunnel (TGT) at the ICAR-Indian Agricultural Research Institute, New Delhi during *rabi* 2014–15 to quantify the impacts of elevated temperature on thermal requirement, growth and yield of wheat crop. Wheat crop was subjected to five temperature treatments, i.e. +0°C (representing ambient condition), +0.9°C, +2.5°C, +2.8°C and +3.5°C. Temperature elevation of 3.5°C increased accumulated growing degree days (GDD) and photo-thermal unit (PTU), thereby hastening maturity of the crop. Leaf area index (LAI) of the crop was affected most by the high temperature at the anthesis stage. Temperature elevation by 2.5°C and above significantly reduced the LAI of wheat. Grain weight decreased by 17.1%, while the straw weight reduced by 10.5% with temperature elevation of 3.5°C. Temperature elevation by 2.5°C and above significantly reduced the straw weight, but grain weight of wheat got significantly reduced even with 0.9°C elevated temperature. Reduced number of spikes per/m² and number of grains/spike decreased grain yield. In fact, the increase in the spikelet sterility contributed towards the grain yield reduction. The information generated from this study will help in developing the appropriate management practices for production of wheat crop.

Keywords: Elevated temperature, LAI, Thermal requirement, Wheat yield.

According to the recent fifth assessment report (2014) of the Inter-Governmental Panel on Climate Change (IPCC) based on the different representative concentration pathways (RCPs), it has been reiterated that the warming of the atmospheric system is unequivocal. Global climate has experienced a warming of about 0.85°C over the period of 1880 to 2012 (IPCC 2014). Agriculture sector being very sensitive to changes in the climate is expected to get immediately affected by any change in the climatic parameters as well.

Wheat (*Triticum aestivum* L.) is the second major food grain crop grown in India and occupied 31.19 million hectares area with a production of 95.85 million tonnes during 2013–14 (Bishnoi and Hooda 2018). It is highly climate-sensitive and its growth and developmental stages are affected by temperature (Dubey *et al.* 2019). Temperature directly and indirectly affects the different growth parameters by influencing the water supply, substrate availability and the soil microbial activity. Several studies have reported that a crop plant completes its life cycle faster, under elevated temperature condition (Nahar *et al.* 2010, Challinor and Wheeler 2008). There are reports that

elevated temperature reduced the photosynthesis rate, leaf area as well as grain weight in wheat (Shah and Paulsen 2003). Increase in maximum and minimum temperature throughout the cropping season might change the thermal requirement of the crops. Hence it is important to quantify the effect of elevated temperature on the changes in thermal requirement, growth and yield of major crops like, wheat as it would have crucial implications on the global food security. In our earlier investigation, the photosynthesis rate, stomatal conductance and root growth of wheat was observed to be reduced at higher temperatures (Pramanik *et al.* 2018). However, studies on the effect of increasing temperatures on changes in thermal requirement of wheat and their relationship with the crop phenology, growth and yield are still very limited. Hence, the present study aimed to quantify the changes in thermal requirement of wheat and their relationship with growth and yield under the elevated temperature conditions.

MATERIALS AND METHODS

Experimental details: The study was carried out at the Genetics H farm site of the ICAR-Indian Agricultural Research Institute (IARI), New Delhi, India during *rabi* (November to April) 2014–15. The site is situated at 28°35'N and 77°12'E having subtropical and semi-arid climate. The experiment was carried out inside the temperature gradient tunnel (TGT) in an area of 15 m × 2.5 m soil surface. The

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TGT was covered with UV stabilized polythene sheet with transparency level of 90%. Inside the TGT, there was a greenhouse like atmosphere resulting in higher air temperature than the outside environment (Chakrabarti *et al.* 2013). Ambient air was sucked inside the tunnel using exhaust fans from one end (inlet) and releasing to the other (outlet), thereby creating a temperature gradient inside. The area inside the TGT was divided into five equal plots, each of 3 m length and 2.5 m width with a temperature sensor (S1, S2, S3, S4, and S5) installed at 1.7 m height in each plot. The design of the experiment was completely randomized design (CRD) with 5 levels of temperature treatments, replicated four times. Temperatures were recorded using the temperature sensors and logged at every 1 min interval by the data logger. Temperature data recorded by all the five sensors during the crop growing season was later downloaded and the temperature gradient created inside the tunnel was calculated. At the inlet point, air temperature was lowest. Mean temperature elevation in the four plots over the plot nearest to the inlet point was calculated. The cultivated variety of wheat, HD 2967 was grown in the *rabi* season (November to April) of the year 2014-15. Five irrigations were applied to the crop. Nitrogen, phosphorus and potassium were applied at the rate of 120, 60, 60 kg/ha.

Growth and yield attributes: Observations related to crop phenology, i.e. days to anthesis (50% flowering) and days to maturity were recorded. Leaf area index (LAI) was recorded at 10:00–11:00 AM, using a canopy analyzer (LAI 2000, LiCOR Lincoln, NE). Observations on LAI were recorded at 70 days after sowing (DAS), 91 DAS and 111 DAS corresponding to flag leaf initiation, anthesis and physiological maturity stages of the crop, respectively. After maturity, wheat crop was harvested and plant samples (grain and straw) were collected from 1 m² quadrat in the four replicates. Grain weight and straw weight were recorded from the air dried harvested plants. Observations on other yield parameters such as number of spikes/m², number of grains/spike, thousand grain weight and spikelet sterility were also recorded from the harvested plants.

Computation of agro meteorological indices: Different agrometeorological indices, like growing degree days (GDD), photothermal units (PTU), heat use efficiency (HUE) are used to describe changes in the phenological behaviour and growth of crops under varying temperature conditions

(Kumar *et al.* 2010). These indices for different crop growth stages were calculated using the formulae as suggested by Nuttonson 1955. Base temperature for wheat was taken as 3.6°C for sowing to germination, 5°C for germination to 50% flowering and 7.5°C for flowering to physiological maturity (Aggarwal *et al.* 2006).

Statistical analysis: The design of the experiment was completely randomized design (CRD). Statistical analysis of the data was done using analysis of variance (ANOVA) technique recommended for the design (Gomez and Gomez 1984). Critical difference (CD) values were calculated at the 5% level of significance.

RESULTS AND DISCUSSION

Temperature elevation in TGT: Observed data recorded by the 5 temperature sensors inside the temperature gradient tunnel (TGT) showed that temperature gradient was created during the crop growth period inside the TGT. In the whole crop growing season the mean temperature elevation inside the TGT was found to be +3.5°C>+2.8°C>+2.5°C>+0.9°C>+0°C for the sensors S1 to S5, respectively. Temperature recorded by S5 sensor represented ambient atmospheric temperature and was represented by +0°C temperature elevation.

Wheat phenology at elevated temperatures: Days to anthesis and days to maturity were 90 and 119 days in wheat with no temperature elevation. Temperature elevation by 2.8°C and 3.5°C reduced total duration in wheat by 4 days. On the other hand, anthesis period of wheat got shortened by 4 days when temperature increased by 2.5°C and above. Temperature influences the time of development in plants both alone and along with the photoperiod (Partanen *et al.* 1998). Some other studies have also showed that warmer temperatures shortened the growth period in different crops (Raj *et al.* 2016, Challinor and Wheeler 2008). According to Chakrabarti *et al.* (2013), increase in temperature by 1.8–2.9°C caused reduction in anthesis duration by 4-5 days and subsequent decline in yield.

Thermal requirement of wheat at elevated temperatures: Results from the study indicated that growing degree days (GDD) from sowing to anthesis and from sowing to physiological maturity were higher at high temperature treatments (Table 1). GDD from sowing to anthesis varied from 933 to 1158 degree days, whereas GDD values ranged

Table 1 Crop phenology, cumulative growing degree days (GDD) and photo thermal unit (PTU) of wheat under different temperature elevation

Temperature elevation	Phenology		GDD (degree-days)		PTU (degree-days hour)	
	Days to anthesis	Days to maturity	Anthesis	Maturity	Anthesis	Maturity
+0°C	90	119	933	1285	9903	14067
+0.9°C	89	119	991	1383	10499	15129
+2.5°C	86	117	1070	1522	11282	16585
+2.8°C	86	115	1096	1521	11551	16538
+3.5°C	86	115	1158	1603	12199	17421

LSD (P≤0.05): Days to anthesis: 3; Days to maturity: 3

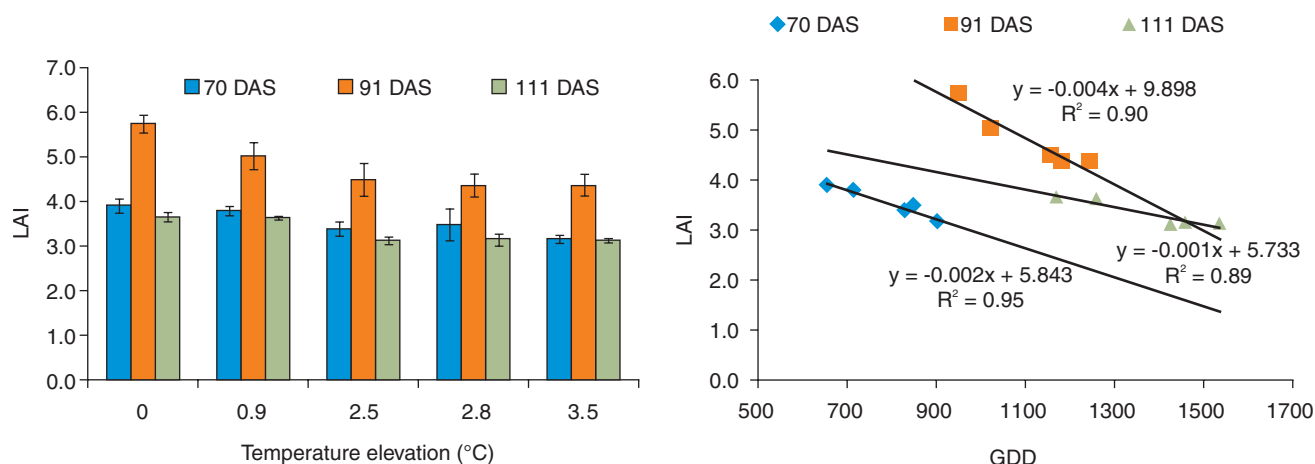


Fig 1 (A) Leaf area index (LAI) of wheat and (B) Correlation analyses between growing degree days (GDD) and leaf area index (LAI) at different crop growth stages. (DAS: Days after sowing).

from 1285 to 1603 degree days from sowing to physiological maturity at different temperature treatments inside the TGT. Temperature elevation of 2.5°C and above increased the GDD for the total crop growth period to more than 1500 degree-days. With temperature elevation of 3.5°C, GDD of wheat increased to 1603 degree-days. Similarly photo-thermal unit (PTU) also increased at high temperature treatment. PTUs recorded from sowing to anthesis were 9903 degree-days hour in the treatment without temperature elevation. It increased to 12199 degree-days hour in the treatment with 3.5°C temperature elevation. PTU values calculated from the sowing to maturity increased from 14067 degree-days hour in +0°C temperature gradient to 17421 degree-days hour in +3.5°C temperature gradient (Table 1). Gill *et al.* (2014) had reported the similar kind of variation in thermal requirement of wheat in their experiment conducted in open field condition with different dates of sowing to obtain variation in growing temperature of the crop.

Growth and yield at elevated temperatures: Elevated temperature throughout the crop growing period resulted in a reduced crop growth of wheat. This was observed in terms of reduced leaf area index (LAI) of the crop. LAI decreased from 3.9–3.2 at 70 DAS, from 5.7–4.4 at 91 DAS, and from

3.7–3.1 at 111 DAS with temperature elevation of 3.5°C (Fig 2A). At anthesis stage of the crop (91 DAS), increase in temperature up to 0.9°C had no significant effect on LAI. But temperature elevation of 2.5°C and above significantly reduced the LAI of wheat at this stage. LAI recorded at different growth stages was found to be negatively correlated with accumulated GDD for those stages.

The correlation coefficient between GDD and LAI were -0.97 at 70 DAS, -0.95 at 91 DAS and -0.94 at 111 DAS. The best fit linear regression equations between GDD and LAI showed that among three different stages, increase in GDD had more negative impact on LAI at 91 DAS which corresponded to the anthesis stage of the crop (Fig 1B). The results demonstrate that elevation of temperature caused more accumulated GDD in wheat and negatively affected the growth of the crop. This result of reduced LAI with increase in temperature is consistent with different greenhouse experiments that documented reduction in photosynthesis rate and viable leaf area in plants exposed to high temperature during the anthesis (Al-Khatib and Paulsen 1999). Temperature is a major factor affecting the duration of key developmental phases like flowering (Bahuguna and Jagadish 2015). Different physiological processes which

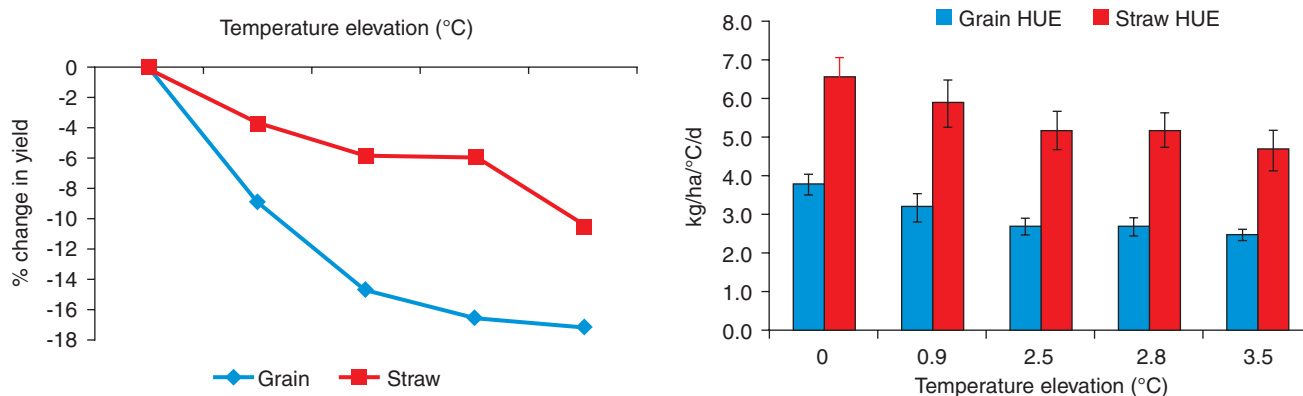


Fig 2 (A) Grain and straw yield of wheat and (B) Heat use efficiency (kg/ha/°C/d) of grain and straw yield in wheat grown under different temperature.

Table 2 Effect of elevated temperature on yield parameters in wheat

	Temperature rise					LSD (P≤0.05)
	+0°C	+0.9°C	+2.5°C	+2.8°C	+3.5°C	
Spike/m ²	456	455	446	436	414	13
Grains/spike	39	37	35	33	32	2
Spikelet sterility (%)	11.2	11.5	15.0	20.4	24.7	4.2
1000 grain wt.	35	34	36	35	35	NS

occur at this stage like pollination, pollen germination, receptivity of stigma and fertilization are very sensitive to changes in the temperature (Maity *et al.* 2019). Hence, increase in temperature will have significant impact at the flowering stage. Reduced leaf area also led to the reduction of total wheat biomass under the high temperature.

Straw weight was reduced by 10.5% and grain weight by 17.1% with mean temperature elevation of 3.5°C (Fig 3A). Temperature elevation by 0.9°C had no effect on straw weight but increase in temperature by 2.5°C and above reduced the straw weight of wheat by 5.8%. On the other hand, grain weight of wheat got significantly reduced (8.8%) even with temperature elevation of 0.9°C. Number of spikes/m² and number of grains/spike decreased with an increase in the temperature. Number of spikes/m² and grains/spike in wheat were 456 and 39 under no temperature elevation which reduced to 414 and 32, respectively at 3.5°C temperature elevation (Table 2). Temperature elevation of 2.8°C and above significantly reduced the number of spikes/m² of wheat. However, number of grains/spike was significantly affected at temperature elevation of 2.5°C and above showing that this yield attribute was more sensitive to the increased temperature. Nuttall *et al.* (2018) observed that grain number in wheat was reduced by 27% in high temperature treatment over the ambient temperature treatment.

Temperature elevation of 2.8°C and above significantly increased the spikelet sterility of wheat. Spikelet sterility was 11.2% without temperature elevation and it increased to 24.7% with temperature elevation of 3.5°C (Table 2). There are reports that high temperature during flowering reduced the pollen germination in rice which resulted in poor grain setting and higher spikelet sterility (Chakrabarti *et al.* 2010). According to Prasad and Djanaguiraman (2014) the combination of low floret fertility and reduced grain weight significantly decreases the grain yield in wheat. Singh *et al.* (2013) stated that among the different crops studied, wheat and groundnut were more thermal sensitive than rice, chickpea and mustard which were found to have greater thermal tolerance. In the current study, heat use efficiency (HUE) (kg/ha/°C/d) of grain and straw yield of wheat reduced with an increase in temperature. Grain HUE reduced from 3.8–2.5 kg/ha/°C/d, while straw HUE decreased from 6.6–4.7 kg/ha/°C/d (Fig 2B). This showed that higher temperature increased the accumulated GDD, but simultaneously lowered the crop yield under the elevated temperature and reduced the HUE of wheat crop.

We conclude that increase in temperature directly affected the wheat growth by reducing the leaf area and spikelet fertility, thereby reducing the grain yield of wheat. Besides this, the increased accumulated GDD for all growth stages shortened the wheat growth period. Increase in GDD with temperature rise of 2.5°C and above had more significant impact on LAI at the anthesis stage of wheat. Temperature elevation by 2.5°C and above significantly reduced the straw weight, but grain weight started falling significantly even at 0.9°C temperature elevation suggesting clearly that grain yield was more sensitive to high temperature than the straw yield of the wheat crop. Reduction in number of spikes/m², number of grains/spike and increased spikelet sterility reduced the grain yield at higher temperatures. Increase in accumulated GDD and lower yield under the elevated temperature reduced the heat use efficiency of the crop. These climate change studies are conducted in controlled environmental facilities, having certain limitations like changes in micrometeorology within the crop canopy and needs field validation. Despite these limitations the results are a valuable source of information for development of high temperature stress response algorithms for use in crop models. Better understanding of the effect of elevated temperature on yield of wheat will also help in developing the suitable management options under the changing climate.

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