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Response of wheat varieties to heat stress under elevated temperature environments

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ABSTRACT

A field experiment was conducted during winter (*rabi*) season of 2014-15 at IARI, New Delhi to evaluate the response of wheat varieties to heat stress. Three wheat varieties (HD 2967, WR 544 and HD 2985) were grown under ambient and elevated temperature (1.9 to 3.4 °C more than ambient during crop season) condition. Results indicated that the variety WR 544 is highly resistant to heat stress as it exhibited stability of leaf area index (LAI), photosynthesis (Pn), grain yield, harvest index (HI) and test weight under elevated temperature. However, HD 2967 recorded more yield but WR 544 performs better in elevated temperature conditions.

Key words: Wheat, heat stress, leaf area index, photosynthesis, yield

Currently agriculture is facing multi-dimensional challenges including climate change. Projected increases in temperatures and frequency of weather extremes (IPCC ARS, 2014) could significantly constrain wheat production in a future climate. In India, wheat is challenged by climatic risks such as early and terminal heat stress, and unseasonal rainfall. Since wheat is sensitive to high temperature (Ortiz *et al.,* 2008), increase in temperature is a severe threat to wheat production, particularly when it occurs during reproductive and grain-filling phases (Sandhu *et al*, 2016). Heat stress reduces plant photosynthetic capacity through metabolic limitations and oxidative damage to chloroplasts, with concomitant reductions in dry matter accumulation and grain yield (Farooq *et al.,* 2011). Both plant growth and development are affected by temperature (Porter and Moot, 1998).

Several low-cost technologies can reduce the negative impacts of climate change (Easterling *et al.,* 2007). These adaptation strategies include improved varieties (Chapman *et al.* 2012) and improved or altered agronomy (Ingram *et al.,* 2008) along with efficient input use. In wheat, conversion of late sown areas into timely sown areas could significantly improve yield even with the existing varieties in the future (Naresh Kumar *et al.*, 2014). Wheat varieties vary for their duration as well as tolerance to temperature stress. A shorter-duration cultivar is likely to yield less, while the longer duration variety may be exposed to more climatic stresses. Hence, farmers always are in dilemma regarding the choice of variety. In northwest China, farmers mostly introduced longer-duration cultivars to counteract the negative impacts of temperature trend on wheat phenology (He *et al.,* 2015).The majority of previous studies showed that increase in temperature shortened crop growing period, leading to reduced crop productivity (Monzon *et al.,* 2007; Wang *et al.,* 2012). This study was aimed to quantify the response of a long duration and medium duration verities to high temperature. This study is expected to provide scientific basis for the choice of variety in changing climates.

MATERIALS AND METHODS

Field and experimental details

A field experiment was conducted during *rabi* season of 2014-15 at the Research Farm of ICAR- Indian Agricultural Research Institute, New Delhi. Geographically, Delhi is situated between latitude of 28°37' and 28°39' N and longitude of 77°9' and 77°11' E at an altitude of 225.7 meter above mean sea level. It has semi-arid, sub-humid and sub-tropical climate with hot dry summer and severe cold winter. The soil of experimental field is slightly alkaline with low electrical conductivity and is well drained. The soil is sandy loam in texture with pH 7.5 and has about 0.43% soil organic carbon.

Experiment was laid out in a homogenous field with three varieties (HD 2967-long duration variety, WR 544 and

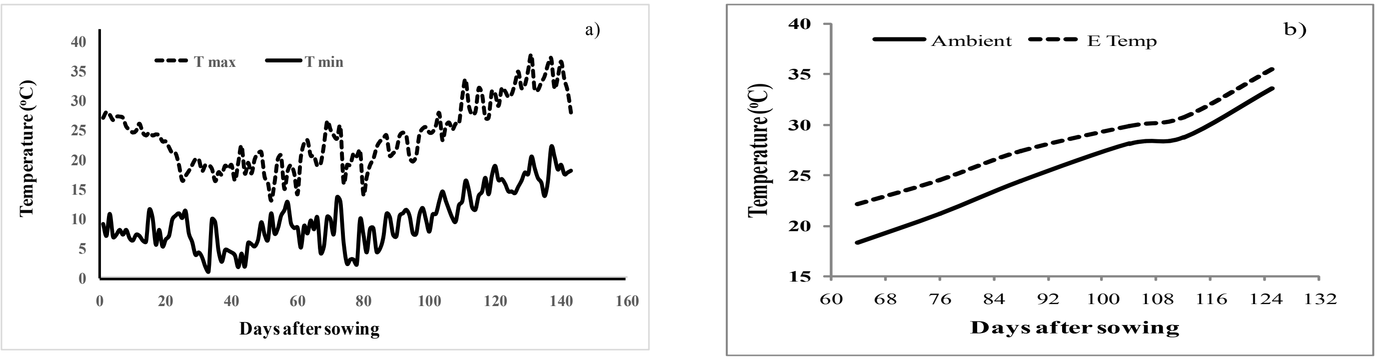

Fig 1: Ambient maximum and minimum temperatures during the crop growing season (2014-15). The temperature inside chamber was 1.9 to 3.7 °C higher than ambient. Figure b shows the ambient and chamber temperature at 11am during the crop growth period (65-124 days).

Table 1: Days to different phenological events in three wheat varieties under ambient and elevated temperature (2014-15)

	Days to 50% emergence		Days to anthesis		Physiological Maturity	
Varieties	Ambient	Elevated temperature	Ambient	Elevated temperature	Ambient	Elevated temperature
HD 2967	8	6	91	82	130	121
WR 544	7	6	86	77	125	116
HD 2985	7	6	83	75	121	110
C.D.(P=0.05)	0.67	NS	0.81	0.91	1.97	1.61
SEM	0.22	0.19	0.27	0.28	0.64	0.55

HD 2985- both of medium duration) in ambient and elevated temperature conditions in four replications. For elevated temperature, the plots were covered with metallic chambers with polythene walls on the top and all four sides to maintain temperature inside the chamber. The dimension of chambers was 5 meter in length and 4 meter in width. Crop was sown on 16 November in 2014. A uniform dose of fertilizers were applied (120N:60P_2O_5:40K_2O) with 50% N applied at the time of sowing, 25% N each at 25 and 45 days after sowing. Total six irrigations were given at all the important physiological growth stages (at pre-sowing, crown root initiation, tillering, flowering, milk and at dough stage) of wheat. The mean maximum temperature during the crop season was 22.9°C while the mean minimum temperature was 9.2°C (Fig 1a). Temperature in chambers was 1.9 to 3.7°C higher than the ambient during crop growth period (Fig 1b). Rainfall during the cop period was 263.6 mm. The mean bright sunshine hours was 4.3 and mean wind speed was 4.5 kmh^{-1}.

Observations on crop:

Observations recorded include dates of phenological events such as 50% seedling emergence, 50% anthesis, and physiological maturity; leaf area index at 15 days interval using plant canopy analyser (LI 2000); gas exchange parameters using infrared gas analyser at various stages of crop; grain and straw yield at harvest; and harvest index and test weight of seed to compare the performance of wheat varieties grown at ambient and elevated temperature. Gas exchange parameters were recorded using a portable photosynthesis system –Infra Red Gas Analyzer (LI-6400XT, LI-COR, USA) at vegetative and reproductive stages. Observations were taken during 9:00 AM to 11:00 AM on flag leaf. The flow rate of input air was set to 300 µmol. s^{-1}. Photosynthatically active radiation was set at 1000 µmol m^{-2} s^{-1} using red and blue light source (6400-40 LCF). Reference air carbon dioxide concentration was kept at ambient level of 400 µmol.mol^{-1}. Readings were logged in when internal CO_2 concentrations attained stability. For each observation, 10 readings were logged in each treatment and then their mean was calculated. Observations on net photosynthesis, transpiration, stomatal conductance, and instantaneous and intrinsic water use efficiency were used for analysis. Grain yield is reported at 14 per cent moisture while the straw yield is on oven dry weight basis. All data were statistically analysed using the SPSS (v16.) and CD was used to compare the means.

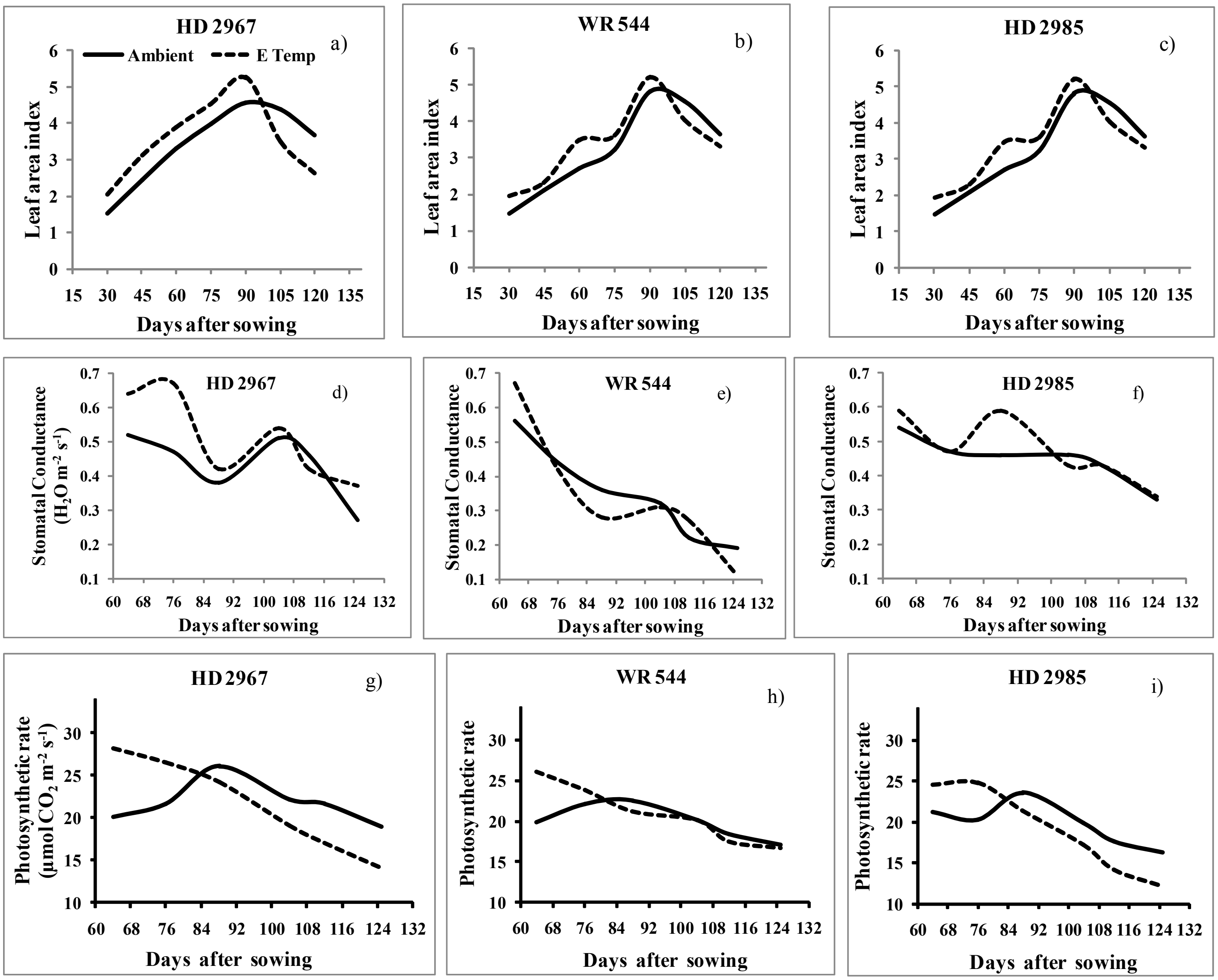

Fig 2: Leaf area index (a-c), stomatal conductance (d-f) and photosynthetic rate (g-i) of three varieties of wheat grown in ambient and elevated temperature conditions (2014-15)

RESULTS AND DISCUSSION

Phenology

Varieties grown in elevated temperature had early anthesis as well as early physiological maturity than those grown under ambient condition (Table 1). The days to emergence and anthesis were more in HD 2967 followed by WR 544 and HD 2985.Days to physiological maturity was more in HD 2967 followed by HD 2985 and WR544. In elevated temperature condition, the percent decrease in days to 50 per cent emergence was more in HD 2967. But percent decrease in days to 50 per cent flowering was almost same for three varieties. Increase in temperature shortened crop growing period leading to reduced crop productivity (Monzon *et al.,* 2007; Wang *et al.,* 2012).

Leaf area index

Under ambient and elevated temperature conditions, leaf area index increased till 90 DAS and thereafter it decreased. Up to anthesis stage, the LAI was more in varieties in elevated temperature than in ambient condition. However, after anthesis, the LAI decreased more rapidly in elevated temperature resulting in lower LAI than in ambient condition. Among the varieties, LAI was more in HD 2967 and WR 544. In elevated temperature, these two varieties had similar LAI up to anthesis, but in post-anthesis period LAI decreased more rapidly in HD 2967 than in WR 544 (Fig. 2 a-c).

Stomatal conductance and photosynthetic rate

Stomatal conductance in general, followed a decreasing trend towards crop maturity and it was higher in elevated temperature conditions (Fig. 2 d-f). In the ambient

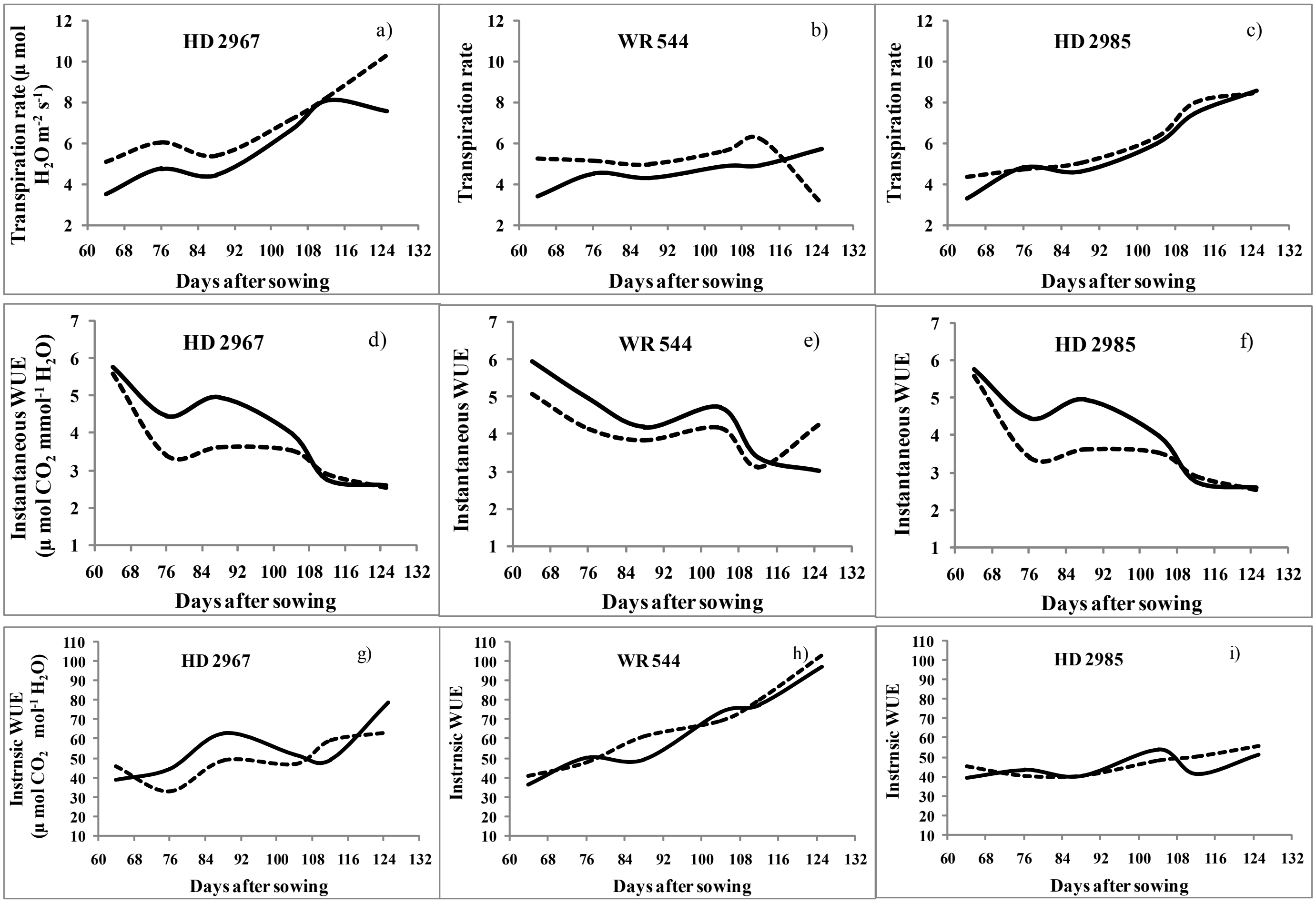

Fig 3: Transpiration rate (a-c), instantaneous water use efficiency (d-f) and intrinsic water use efficiency (g-i) of three varieties of wheat grown in ambient and elevated temperature conditions (2014-15).

condition, photosynthetic rate peaked at 88 days after sowing (DAS) and then declined towards maturity. But in elevated temperature chambers, photosynthetic rate was significantly higher than in ambient grown varieties till 88 DAS in all three varieties. But during grain filling period, the Pn rates declined rapidly and were significantly lower than the ambient in HD 2967 and HD 2985. On the other hand, in WR 544, the Pn rates were almost similar in elevated temperature as well as in ambient condition (Fig 2 g-i). In elevated temperature condition, though HD 2967 had higher Pn rates till 88 DAS, they were significantly higher in WR 544 during grain filling period. After flowering stage the variety WR 544 could maintain the Pn rates in elevated temperature and thus this variety was least affected by heat stress (Fig. 2).High temperature affects photosynthesis (Blum *et al.* 1994) and optimal rates of photosynthesis in wheat are about 25°C (Yamasaki *et al.,* 2002) and they decline as the temperature departs from the optimum. In this experiment, the Pn rates were higher in elevated temperature condition till 88 DAS mainly because the temperature regimes were towards optimum as compared to the ambient. But once the temperatures crossed optimum in elevated temperature condition, Pn rates declined rapidly as compared to the ambient. As mentioned earlier, WR 544 could maintain the Pn rates in elevated temperature condition similar to that of ambient.

Transpiration rate, instantaneous water use efficiency and intrinsic water use efficiency

Transpiration rate was higher in elevated temperature compared to that in ambient condition (Fig. 3 a-c).The instantaneous WUE, calculated after dividing the photosynthetic rate by the transpiration rate (A/E) was higher in ambient condition. The WUE decreased with the progression of crop growth from pre flowering to physiological maturity. Among the varieties, HD 2967 had higher instantaneous WUE till 108 DAS but during the later part of grain filling phase, the WUE was similar in ambient and elevated temperature (Fig 3 d-f). The instantaneous WUE in HD 2985 was almost similar in ambient and elevated

Table 2: Yield, harvest index and test weight of wheat varieties grown in ambient and elevated temperature conditions (2014-15).

Varieties	Grain yield (tha^{-1})		Straw yield (tha^{-1})		Harvest Index (%)		Test weight (g)	
	Ambient	Elevated temperature	Ambient	Elevated temperature	Ambient	Elevated temperature	Ambient	Elevated temperature
HD 2967	5.66	4.16	9.65	8.02	37.00	34.13	40.7	37.5
WR 544	3.80	3.59	7.26	7.01	34.32	33.83	38.6	37.9
HD 2985	3.28	2.58	6.81	5.87	32.51	30.54	35.2	33.0
C.D.(P=0.05)	0.86	0.81	0.98	1.05	0.71	0.59	0.99	0.73
SEM	0.27	0.23	0.32	0.34	0.23	0.19	0.33	0.24

temperature condition. On the other hand, WR 544 maintained higher WUE during later part of grain filling phase. In general, among three varieties in elevated temperature condition, WR 544 had higher WUE.

The intrinsic WUE was calculated after dividing the photosynthetic rate by the stomatal conductance (A/gs). It followed a general increasing trend from vegetative phase to physiological maturity. Though HD 2967 maintained higher intrinsic WUE during in ambient condition during most parts of the growth period, WR 544 and HD 2985 had similar intrinsic WUE in ambient and elevated temperature condition. The intrinsic WUE was higher in WR 544 followed by HD 2967 and HD 2985. Overall results indicate greater efficiency of WR 544 for maintaining LAI, Pn rates and WUE in elevated temperature condition.

Yield and yield components

Elevated temperature caused a reduction in grain and straw yield in all three varieties. Reduction in grain yield was more in HD 2967 (25%), followed by HD 2985 (21%) and WR 544 (6%) as compared to that of ambient grown varieties. Harvest index was reduced more in HD 2967 and reduction was least in WR 544. Test weight was also reduced maximum in HD 2967 (8%), followed by HD 2985 (6%) and WR544 (2%). These results indicated that WR 544 had more stable HI and test weight indicating its stable source-sink balance even in elevated temperature condition (Table 2).

CONCLUSION

The study revealed that wheat varieties differ in their response to elevated temperature. The variety WR 544 is highly resistant to heat stress as it exhibited stability of leaf area index, photosynthetic rate, grain yield, harvest index and test weight in WR 544 grown under elevated temperature. However, HD 2967 outperformed WR 544 under ambient and elevated temperature conditions, despite more yield reduction in HD 2967 in elevated temperature. Hence, it can be concluded that the variety HD 2967 and WR 544 are more suitable in changing climatic conditions of north-west India.

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