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SHORT COMMUNICATION

Impact of Sowing Dates on Terminal Heat Tolerance of Different Wheat (*Triticum aestivum* L.) Cultivars

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Abstract Terminal heat stress leads to significant yield reduction in wheat. Adaptation strategies to combat this could be either growing heat-tolerant cultivars or adjustments in sowing date. A study was conducted for 2 years to understand the impact of terminal heat stress on wheat using three different wheat cultivars (HD 2932, WR 544 and HD 2967) and three sowing date, viz. D_1 (second week of November), D_2 (first week of December) and D_3 (last week of December) at Indian Agricultural Research Institute (IARI), New Delhi, India. Results revealed that timely sown crop (D_1) showed significantly higher number of tillers m^{-2} (450), plant height (93.5 cm), 1000-grain weight (38 g), grain yield (6.3 t ha^{-1}) and harvest index (0.44) compared with D_2 and D_3. Yield loss occurred by 70, 29 and 77 kg ha^{-1} per day due to delay in sowing beyond D_1 in varieties, viz. 'HD 2932,' 'WR 544' and 'HD 2967,' respectively. The late-sown crop resulted lower yield, which encountered higher temperature in its terminal growth stages. Among three varieties used, 'WR 544' had lesser decline in growth and yield than other two varieties due to late sowing. It implied that 'WR 544' had thermo-tolerant characteristics. Higher yield in wheat requires both heat-tolerant cultivars and better agronomic strategy under terminal heat stress condition. This study concluded that varietal selection and adjustment in sowing date could be the appropriate adaptation strategies under changing climate especially the terminal heat stress.

Keywords Grain yield · Indo-Gangetic plains · Sowing date · Terminal heat stress · Wheat

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Global mean ambient temperature is predicted to increase by 3.7 to 4.8 °C by the end of this century [1]. Wheat (*Triticum aestivum* L.) is a sensitive crop to high temperature. Trends in increasing growing seasonal temperatures have already been reported for major wheat-producing areas [2, 3]. Wheat experiences heat stress to varying degrees at different phenological stages, but reproductive phase is most detrimental as it affects grain number and grain weight [4]. At the global level, around 7 Mha of wheat is affected by heat stress throughout its life cycle and 40% crop face terminal heat stress leading to significant yield reduction [5]. Also, several researchers report that terminal heat stress is likely to increase for wheat in near future [6, 7]. High temperature ($>$ 30 °C) after anthesis affects grain setting, duration and rate, and ultimately grain yield [8]. Proximity to the equator and late sowing of wheat expose the crop to high temperature (exceeding 35 °C) during grain-filling stage in Indo-Gangetic plains (IGP) in India. This is one of the major environmental factors that plays crucial role in determining production and productivity of wheat crop [8]. Therefore, different adaptation strategies are urgently required to reduce the impact of climate change on agriculture [9]. Some of the adaptation options for success of wheat crop could be, to use thermo-tolerant genotypes and timely sowing to avoid terminal heat stress. However, there are limited studies available which comprehensively evaluated the impact of heat stress on growth and yield of wheat, and assessed the heat tolerance of popular wheat cultivars of IGP and developing options to reduce adverse effects. Therefore, objective of this study was to evaluate the effect of adaptation options considering tolerant variety and changing sowing date on alleviating terminal heat stress in wheat.

A field experiment was conducted at the experimental farm of Indian Agricultural Research Institute (IARI), New Delhi, India (28°40′N, 77°12′E) by growing wheat in *rabi* season (November–April) during 2011–2012 and 2012–2013. The climate of the area is subtropical, semiarid with dry hot summer and cold winter. The mean annual maximum and minimum temperature was 35 °C and 18 °C, respectively. The soil of the experimental site was *Typic Ustochrept* with pH 8.6 and sandy loam in texture; bulk density of 1.38 Mg m^{-3}, electrical conductivity of 0.48 dS m^{-1}; and organic carbon (4.5 g kg^{-1}), total N (0.3 g kg^{-1}), Olsen P (0.007 g kg^{-1}) and ammonium acetate extractable K (0.13 g kg^{-1}).

Staggered sowing strategy [10] was used to impose heat stress treatment with three date of sowing (DOS), i.e., normal date of sowing during second week of November (D_1), late sowing during first week of December (D_2) and very late sowing during last week of December (D_3) with three popular wheat varieties in the IGP. The varieties used were: 'HD 2932,' 'WR 544' and 'HD 2967.' The experimental design was split-plot design with nine treatments and three replications. Size of each subplot was 7 × 7 m. Seeds were sown at a recommended spacing of 22.5 cm (row–row). Nitrogen, phosphorous and potassium were applied @ 120 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}, in the form of urea, single super phosphate and muriate of potash, respectively. Cultural practices were carried out as per standard procedures [11]. Plant samples were collected at the time of harvest. Growth and yield-related parameters were measured by standard methods [12]. Analysis of variance was carried out using SPSS version 21, and the significance of mean values was compared using least significant difference values [13]. All parameters were analyzed considering year as a source of variation in addition to variety and date of sowing. It was observed that the interaction effects (year × variety, year × dates of sowing and year × variety × dates of sowing) were not found significant at $p < 0.05$ for most of the parameters studied. It indicated that the effect of year was negligible, and hence, the data reported in this paper are average of 2 years. Weather data reveal that crop faced terminal heat stress at one or more stages between anthesis to physiological maturity stage in both the years of experimental period,

Plant height decreased under late sowing condition (D_2 and D_3) than normal sowing (D_1) in all varieties. Mean values of the plant height in D_1, D_2 and D_3 were 93.5, 86.4 and 83.9 cm, respectively (Table 1). Percent reduction in plant height in 'HD 2932,' 'WR 544' and 'HD 2967' was 11.0, 2.8 and 13.0% in D_2 than D_1, respectively, and reduction was 15.6, 4.1 and 16.9% in D_3 compared with D_1. It reveals that delay in sowing of wheat adversely affected plant height. This might have occurred due to higher temperature during growing period that resulted in shortening of crop growth period. Also, significant differences in plant height were observed as a result of interaction between variety and sowing date. Other researchers [14] also reported similar findings of reduction in plant height by 7.3–9.5% in different wheat genotypes due to late sowing.

Number of tillers per m^2 reduced in all three varieties under late sowing treatments. Percent reduction was the highest in 'HD 2967' (10.5 and 16.0% in D_2 and D_3, respectively, over D_1) followed by 'HD 2932' (11.0 and 15.0% in D_2 and D_3, respectively, over D_1), and the least reduction was found in 'WR 544' (8.9 and 11.3% in D_2 and D_3, respectively, over D_1). This suggests that tiller production in 'WR 544' was the least affected by high-temperature stress. As expected, crop sown at normal date (D_1) had highest number of tillers, and the least was in very late (D_3) sown treatment. This was due to survival of less number of tillers under high-temperature condition. The ability to producing tillers of wheat and their survival depends on genotype as well as environmental factors, especially air temperature that decides tiller initiation process in the axils of the basal leaves of wheat plant and under unfavorable environment growth of tillers either slowed downs or stopped [15]. Therefore, high-temperature stress inhibits the initiation and survival of tiller in wheat, as also observed in our experiment.

A similar trend was also found in biomass yield. It was significantly higher in all three varieties sown on normal date (D_1) and declined in late sowing condition (D_2 and D_3). Decline in biomass yield under late sowing was observed the least for 'WR 544' (9.7%) and the highest in 'HD 2967' (26.3%) (Table 1).

Test weight, i.e., 1000-grain weight, reduced due to terminal heat stress because of impaired grain filling. Grain yield and 1000-grain weight reduced significantly under D_2 and D_3 as compared with D_1 (Table 2). Though test weight reduced in all varieties due to delay in sowing, 'WR 544' performed better under heat-stressed environment than 'HD 2932' and 'HD 2967.' The decrease in test weight was the highest in 'HD 2967.' This might be ascribed to grain shrinkage, increased production of reactive oxygen species, reduced pollen tube development and increased pollen mortality, which were linked to elevated temperature,

Table 1 Effect of crop sowing dates and cultivars on plant height, tillers number and biomass yield in wheat

Date of sowing	Plant height (cm)			Mean	No of tillers m^{-2}			Mean	Biomass yield (t ha^{-1})			Mean
	HD 2932	WR 544	HD 2967		HD 2932	WR 544	HD 2967		HD 2932	WR 544	HD 2967	
D_1	91.1	88.6	100.9	93.5	444	451	456	450.3	14.5	14.1	14.5	14.4
D_2	82.1	87.8	89.3	86.4	395	411	408	404.7	13.3	13.0	12.7	13.0
D_3	78.8	86.5	86.3	83.9	376	400	383	386.3	11.3	12.6	10.3	11.4
Mean	84.0	87.6	92.2		405	421	415		13.0	13.3	12.5	
$LSD_{0.05}$												
Sowing date (*S*)				1.8				7.9				0.7
Variety (*V*)				1.5				5.2				0.2
S × *V*				1.2				9.3				0.3

Table 2 Effect of crop sowing dates and cultivars on grain yield, harvest index and 1000-grain weight

Date of sowing	Grain yield (t ha^{-1})			*Mean*	Harvest index			*Mean*	1000-grain weight (g)			*Mean*
	HD 2932	WR 544	HD 2967		HD 2932	WR 544	HD 2967		HD 2932	WR 544	HD 2967	
D_1	6.3	6.1	6.4	6.3	0.43	0.43	0.44	0.44	38.1	37.7	38.4	38.0
D_2	5.2	5.5	5.3	5.3	0.39	0.42	0.40	0.40	36.5	36.8	35.9	36.4
D_3	4.1	5.1	4.0	4.4	0.37	0.40	0.36	0.39	32.8	34.5	31.8	33.0
Mean	5.2	5.6	5.2		0.40	0.42	0.41		35.8	36.3	35.4	
$LSD_{0.05}$												
Sowing date (*S*)				0.8				0.4				2.1
Variety (*V*)				0.3				NS				0.3
S × *V*				0.4				0.1				0.9

thereby enhanced grain abortion and reduced grain weight [16]. Hence, stability in grain weight under heat stress environment is an important trait that determines the grain yield [17]. The duration of grain growth in post-anthesis period is considered as the most significant determinant of yield in wheat [6]. Heat stress shortens grain-filling duration and thereby influencing grain-filling rate and resulting in lower yield [18, 19]. Similar results were observed in the present study. With delayed sowing, grain yield reduction was 1.1 and 1.9 t ha^{-1} in D_2 and D_3, respectively, compared with D_1. This was due to terminal heat stress during reproductive phases [15]. Although yield loss occurred in all varieties under delayed sowing, the decline was the least in 'WR 544.' Interaction of date of sowing and varieties, viz. 'HD 2967' and 'HD 2932,' was not found significant, but it was significant with variety 'WR 544.' It indicates that 'WR 544' showed its thermo-tolerant characteristics. Yield loss per day due to delay in sowing from normal sowing date was estimated as 29, 70 and 77 kg ha^{-1} d^{-1} in 'WR 544,' 'HD 2932' and 'HD 2967,' respectively (Fig. 1). Higher relative grain yield was also observed by researchers [20], who reported that stable and/or long duration of photosynthetic activity had been affected; hence, under heat stress this trait should be used as a selection criterion for heat tolerance of wheat genotypes. Delayed sowing also affected harvest index (HI), and percent reduction in HI was the greatest in 'HD 2967' (9.1 and 18.2% in D_2 and D_3, respectively, over D_1) followed by 'HD 2932' (9.3 and 14.0% in D_2 and D_3, respectively, over D_1) and the least in 'WR 544' (2.3 and 7.0% in D_2 and D_3, respectively, over D_1) (Table 2). Among varieties, 'WR 544' showed the lowest reduction in HI, which was attributed to its stay green character and better grain filling in heat stress conditions [21]. Earlier, it was found that harvest index is highly correlated with grain yield [17] and in agreement to this a similar trend was also found in the present study (Table 2).

The present study clearly demonstrates that delayed sowing increases the probability to occurring terminal heat stress during grain-filling stage which significantly reduces grain yield. Hence, the escape mechanism can be formulated by avoiding delay in wheat sowing which improves

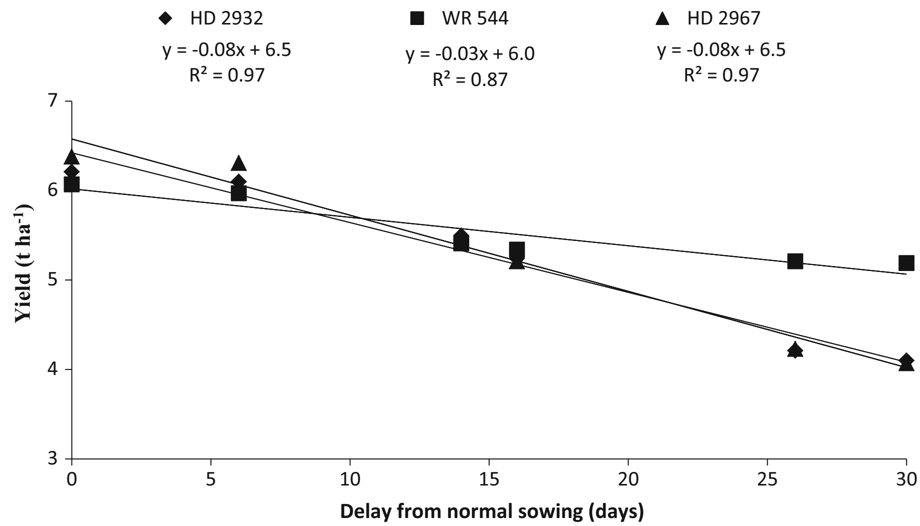

Fig. 1 Relationships between the delay sowing and yield decline in three different wheat varieties ($n = 6$)

grain filling. The timely sowing in the period between 15 and 25 November may be advocated to avoid terminal heat stress in wheat in the IGP region, India. Firstly, the strategy should be such that grain filling is completed before the onset of high-temperature stress. Secondly, cultivars like 'WR 544' having thermo-tolerance characteristics should be used. Our study confirmed that 'WR 544' variety had these characteristics and performed better in terms of grain yield as well as other related parameters than other two cultivars, viz. 'HD 2932' and 'HD 2967.' Therefore, an adaptation strategy to terminal heat stress should be timely sowing, i.e., avoiding delay and/or use of thermo-tolerant varieties.

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