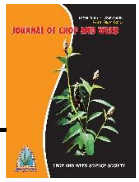
ISSN-O : 2349 9400; P : 0974 6315

Journal of Crop and Weed, 20(1):125-131 (2024)



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Canopy development, relative water content and productivity of wheat (*Triticum aestivum* L.) varieties under late sowing induced terminal high temperature environment in Eastern India

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Received: 01.02.2024, Revised: 12.04.2024; Accepted: 15.04.2024

DOI: https://doi.org/10.22271/09746315.2024.v20.i1.1769

ABSTRACT

A field experiment was laid out in split-plot design during the rabi season of 2022-2023 at Sabour, Bhagalpur, Bihar to assess seven wheat varieties (HD 3388, HD 3249, HD 3086, HD 2967, DBW 222, DBW 187 and PBW 826) for their canopy growth dynamics, relative water content and productivity under timely (3^{rd} week of November) and late sown (3^{rd} week of December) conditions. Late sowing exposed the post-anthesis stage of wheat to 4-5℃ higher temperatures over timely sowing, affecting all growth and yield attributes, ultimately reducing yield by 34.17.%. The variety HD 3249 emerged as the top yielder (3730 kg ha^{-1}) irrespective of sowing windows showing superior aerial biomass at 10 days after anthesis (694.16g m $^{-2}$), and strong positive correlation ($r \geq 0.99$, $p<0.001$), mainly contributed by higher spike density (253.70 m^{-2}; $r=0.97$, $p \leq 0.01$) ; maintaining favourable canopy water relations, even under higher degree of stress (relative water content 68.45% at post-anthesis stage) refuting the ill effect of stress. Thus, HD 3249 may be selected to sustain wheat yield against terminal high temperature environments in eastern India.

Keywords: Canopy development, late sown, productivity, relative water content, terminal high temperature, wheat.

Wheat is the staple cereal during *rabi* season, covering around 23.3% of the area and 34% of the production under the total foodgrains in India (Anonymous 2022). Elevated temperature beyond the optimum range of 12-22 ºC, causing terminal heat stress, led to yield loss of wheat (18-34%) in eastern India (Dwivedi *et al*., 2017). In general, all wheat varieties, when sown late, face severe temperature stress especially during their post anthesis stage, significantly affecting morphology, anatomy, phenology, growth and finally yield as reported from eastern India (Tripathy *et al*., 2020). Therefore, sustaining wheat yield under terminal heat stress must be addressed with due priority. Screening wheat cultivars with stable and optimum yield levels, along with stress tolerant traits, may be a viable strategy to combat terminal heat stress.

Plant water balance *vis-à-vis* canopy temperature and relative water content (RWC), serve as a direct metric for assessing the drought response or heat stress tolerance of crops, providing a gauge of water deficiency within the leaf (Roy Chowdhury and Mitra, 2021). RWC of leaf indicates the actual water content to its maximum turgidity, ranging from 98% in turgid, actively transpiring leaves to about 40% in highly desiccated leaves. Leaf water potential and grain yield in wheat are highly correlated, particularly under abiotic stress (Shaukat *et al*., 2021). Despite substantial progress in screening of wheat genotypes based on higher leaf RWC to evaluate the magnitude of stress, there are scanty reports in this ecological region regarding the relationship between the grain yield of popular wheat varieties and leaf RWC around anthesis and thorough insights to evaluate the genotypes to combat terminal heat stress.

Short communication

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How to cite: Raj, J., Pathak, S.K., Roy Chowdhury, A., Bhavya, Ghosh, M., Acharya, S. S. and Choudhary, S.B. 2024. Canopy development, relative water content and productivity of wheat (*Triticum aestivum* L.) varieties under late sowing induced terminal high temperature environment in Eastern India. *J. Crop and Weed*, 20(1): 125-131.

Therefore, this study aimed to assess the canopy growth dynamics of prevalent wheat varieties in the region, accounting the impact of late sowing-induced terminal high temperature episodes. It also seeks to employ leaf RWC as a reliable indicator of terminal heat stress in wheat varieties, elucidating its role in explaining variations in yield under such conditions. We hypothesize that diverse varieties, will respond differently to the terminal high temperature environments, so as to detect and recommend suitable one for such ecology.

The field experiment was carried out during the *rabi* season of 2022-23 at the Bihar Agricultural University, Sabour, Bhagalpur, (25˚ 15’40” N latitude; 78˚ 2’45” E longitude, 45.75 meters altitude). The experimental location experiences an increasing trend in temperature from February 2nd week and reach at its peak level during March – April (≥30/15°C) coinciding with the post anthesis period of wheat with occasional torrential rain. The top soil (0-15 cm) of the experimental plot was light in texture, having pH of 7.62, 0.38% organic carbon, and 150.53, 37.42 and 129.60 kg ha^{-1} of mineralizable N, Olsen’s P and ammonium-acetate extractable K, respectively. The experiment was laid out in a split plot design (SPD) and replicated thrice. Two distinct sowing windows, *viz.* timely sown (3rd week of November) and late sown (3rd week of December) were taken as main plots. Each main plot consisted of seven sub-plots of the dimension (1.6 m×8 m=12.80 m^2) accommodating seven wheat varieties (HD 3388, HD 3249, HD 3086, HD 2967, DBW 222, DBW 187 and PBW 826). The standard agronomic package of practices was followed to raise the crop. The crop was harvested manually from the net plot (1.20m×7m=8.4 m^2), discarding the border rows. For recording aerial biomass at harvest, grain and straw yield were taken separately and summed. RWC was determined from flag leaf at the pre-anthesis, anthesis and 10 days after anthesis stages using the formula provided by Petrov *et al.* (2018) as follows:

$$RWC = \frac{FW - DW}{TW - DW} \times 100$$

Where, FW is the fresh weight of leaf tissue; DW is the dry weight of the same leaf tissue obtained after drying the fresh leaf tissue in a hot air oven at 80°C for four hours until constant weight is achieved; TW is the turgid weight of that fresh leaf tissue measured after immersing the tissue for 24 hours in water in the presence of light. The relationship between canopy development, RWC and grain productivity was assessed through bivariate correlation analysis (utilizing Pearson correlation coefficients and graphs).

Statistical analysis of the data for canopy developmental attributes depicts that tiller density (TD), leaf area index (LAI) and aerial biomass (AB) have direct relationship with abiotic stress and yield performance of wheat varieties (Table 1). TD varied significantly with sowing dates (timely and late sowing), recording highest at maximum tillering stage (MTS) (270 no. m^{-2}) and gradually decreasing thereafter to 259 no. m^{-2} at 10 days after anthesis (DAA) under timely sown condition, being statistically superior to late sown condition (240 and 227 no. m^{-2} at MTS and 10 DAA, respectively) due to normal ageing of the crop, which leads to tiller mortality in all the wheat varieties (Dubey *et al.*, 2019). The number of tillers per unit area significantly reduced irrespective of varieties starting from 11.1% at MTS to 12.3% at 10 DAA due to late sowing by one month (Table 1), and a parallel increase in mean maximum and minimum temperature during the post-anthesis period (30-32 and 12-16°C, respectively) (Detail data not shown). The variety, HD 3249 displayed the highest TD at the maximum tillering, anthesis and 10 DAA stages, with counts of 278, 269 and 265 respectively; whereas the variety PBW 826 exhibited the lowest tiller density i.e., 244, 236 and 232 tillers at the same observation stances. Date of sowing and wheat varieties exhibited significant interaction on TD at 75 and 100 DAS. The decrease is attributed to the suppression of tiller initiation from the basal leaf axils, less tiller survival and subsequent mal growth under elevated air temperatures with delayed planting (Dubey *et al.*, 2019).

On the contrary, LAI tend to increase till pre-anthesis stage for all the varieties, despite tiller mortality, due to increase in leaf width and emergence of flag leaf (Gupta *et al.*, 2017) and reduced thereafter at 10 DAA due to normal ageing of crop and senescence of leaf. Late sowing marked higher reduction of LAI (14.3% at MTS to 25.8% at 10 DAA) over timely sowing due to late sowing mediated elevation in mean maximum and minimum temperature during the post-anthesis period (30 to 32 and 12 to 16°C, respectively). The variety HD 3249 exhibited maximum LAI (2.02, 3.51 and 3.01) at MTS, PA and 10 DAA, respectively and was statistically at par with HD 3086 at the respective growth stages. The variety PBW 826 recorded least LAI across all stages of growth (Table 1). It is noteworthy that HD 3249 substantially reduced its LAI, particularly during anthesis to 10 DAA to the tune of 25-28%, which is closely followed by HD 3086 (27-28%), in response to elevated temperature, arising from late sowing, which constrained its transpiration demand for sustenance of current photosynthesis. A comparable stress response in crops was also documented by Saxena *et al*. (2016).

AB production increased continuously until harvest. The reduction in AB tends to increase with the advancement in crop growth, ranging from 13.65% at MTS to 35.81% at 10 DAA due to late sowing over timely sowing (Table 1). Under late sowing, HD 3249 exhibited maximum AB (281, 501 and 548 g m^{-2}) growth stages, while PBW 826 recorded least AB at all growth stages.

Irrespective of varieties, spike density (SD), number of grains per spike (GPS) and 1000 grain weight (GW) were significantly reduced (12.24, 27.0 and 9.75%, respectively) under late sowing over timely sown condition (Table 2) due to increment in mean maximum and minimum temperature during the post-anthesis period (30-32 and 12-16°C, respectively). Under late sowing, HD 3249 recorded maximum SD, GPS and 1000 GW (229 m^{-2}, 40. 7 and 36.7 g, respectively).

Owing to elevated values in all yield attributes, HD 3249 achieved the highest grain yield (3.7 t ha^{-1}) but this was significantly reduced by 35.13% under late sown conditions (Table 2). This reduction in grain yield can be fairly explained by the reduction of all the growth attributes, ultimately manifested in terms of AB. Correlation study also revealed a significant positive correlation between AB and grain yield under both the sowing conditions, especially during the post anthesis period ($r=1.0$, $p<0.001$) (Fig 2a and 2b). HD 3249 could maintain significant higher LAI, during the post anthesis stage, which favoured unhindered supply of photosynthates to the developing grains, even under late sown condition. Correlation study also depicts the strong association between LAI at 10 DAA and grain yield, especially when stress is mild ($r=0.84$, $p\leq0.05$) (Fig 2a).

Higher flag leaf RWC was found at pre anthesis stage and then after, its content decreased gradually under both the sowing windows, but the rate of decrement varied significantly. Rate of decrement was noted to lie around 4.3, 7.2 and 5.5 % at different growth stages respectively under late sowing over timely sowing. HD 3249 recorded least percent decrement in RWC during pre-anthesis to 10 DAA under timely and late sown windows (12.2-12.4%, respectively). This is due to maintenance of favourable water balance by the higher reduction of LAI vis-à-vis lower canopy transpiration. The retention of a relatively higher relative water content under the late sown conditions, particularly at 10 DAA (68.5%) might be the potential explanation for minimizing the adverse effects of terminal heat and sustenance of higher grain yield, which is further supported by a significant positive correlation observed between the RWC at 10 DAA during both timely sown ($r=0.97$,$p<0.001$) and late sown ($r=0.83$,$p\leq0.05$) conditions (refer to Fig 2a and 2b). Shaukat *et al.*, (2021) also opined that persistency of higher RWC in a wheat cultivar under terminal heat conditions reflects the tolerance of that specific variety to the stress.

Table 1: Canopy development traits of wheat varieties under timely and late sown conditions

		TD (No. m^{-2})			LAI			AB (g m^{-2})		
		Max. Tillering stage	**Pre anthesis**	**10 DAA**	**Max tillering stage**	**Pre anthesis**	**10 DAA**	**Max. tillering stage**	**Pre anthesis**	**10 DAA**
DOS-TS	HD 3388	255	248	247	2.1	2.9	2.5	312	537	642
	HD 3249	301	293	290	2.2	4.0	3.5	325	550	840
	HD 3086	283	275	271	2.1	4.0	3.5	323	548	801
	HD 2967	264	257	252	2.0	3.9	3.4	304	529	673
	DBW 222	263	255	251	2.1	2.9	2.5	316	541	652
	DBW 187	268	261	256	2.1	3.9	3.4	321	546	722
	PBW 826	254	247	242	2.0	2.9	2.5	307	532	556
MEAN		270	263	259	2.1	3.5	3.1	315	540	698
DOS-LS	HD 3388	238	229	226	1.8	2.8	2.3	274	494	434
	HD 3249	255	245	241	1.9	3.0	2.5	281	501	548
	HD 3086	243	233	229	1.9	2.9	2.5	279	499	455
	HD 2967	241	232	227	1.8	2.8	2.4	277	497	440
	DBW 222	234	225	221	1.8	2.5	2.1	263	483	421
	DBW 187	235	226	224	1.8	2.6	2.2	269	489	423
	PBW 826	234	225	221	1.7	2.3	2.0	259	479	417
MEAN		240	231	227	1.8	2.7	2.3	272	492	448
Variety mean	HD 3388	247	238	237	2.0	2.8	2.4	293	516	538
	HD 3249	278	269	265	2.0	3.5	3.0	303	525	694
	HD 3086	263	254	250	2.0	3.5	3.0	301	523	628
	HD 2967	253	244	240	1.9	3.4	2.9	290	513	556
	DBW 222	249	240	236	1.9	2.7	2.3	289	512	536
	DBW 187	252	244	240	2.0	3.3	2.8	295	517	573
	PBW 826	244	236	232	1.9	2.6	2.2	283	506	487
LSD (P=0.05)	DOS	27.8	30	28	0.24	0.12	0.26	35.91	34.25	49.1
	V	10.92	8	9	0.06	0.07	0.04	9.39	8.34	35.37
p Value	DOS*V	NS	0.013	0.017	NS	0	0	NS	NS	0.0008

DOS= Date of sowing; TS= Timely sown; LS= Late sown; TD=Tiller density; LAI= Leaf area index; AB= Aerial biomass; DAA= Days after anthesis; NS= Non-significant

Table 2: Yield and yield attributes of wheat varieties under timely and late sown conditions

		YIELD PARAMETERS				
		S D (No m^{-2})	GPS	1000 GW (g)	GY (t ha^{-1})	SY (t ha^{-1})
DOS-TS	HD 3388	236	46.1	37.7	3.4	5.26
	HD 3249	278	52.7	41.0	4.5	6.38
	HD 3086	259	50.8	40.3	4.2	6.16
	HD 2967	238	47.1	37.6	3.6	5.39
	DBW 222	236	46.7	37.3	3.5	5.27
	DBW 187	243	50.3	38.9	3.9	5.66
	PBW 826	226	44.8	36.8	3.0	4.69
MEAN		245	48.3	38.5	3.7	5.54
DOS-LS	HD 3388	213	34.5	35.1	2.4	4.00
	HD 3249	229	40.7	36.7	2.9	4.71
	HD 3086	217	37.4	36.6	2.5	4.11
	HD 2967	215	35.1	35.8	2.4	4.03
	DBW 222	211	32.8	34.8	2.3	3.93
	DBW 187	211	34.2	34.9	2.3	3.93
	PBW 826	209	32.6	34.5	2.3	3.92
MEAN		215	35.3	35.5	2.4	4.09
Variety mean	HD 3388	224	40.3	36.4	2.9	4.63
	HD 3249	254	46.7	38.8	3.7	5.55
	HD 3086	238	44.1	38.5	3.4	5.14
	HD 2967	227	41.1	36.7	3.0	4.71
	DBW 222	224	41.1	36.0	2.9	4.60
	DBW 187	227	42.2	36.9	3.0	4.80
	PBW 826	218	38.7	35.7	2.6	4.31
	DOS	30	4	2	4.7	6.7
ANOVA (P=0.05)	V	9	1	1	2.8	2.7
p Value	DOS*V	0.01	0.04	0.0005	0.01	0.0033

DOS= Date of sowing; TS= Timely sown; LS= Late sown; SD= Spike density (No. m^{-2}); GPS= Number of Grains per spike; GW= Grain weight; GY= Grain yield; SY=Straw yield

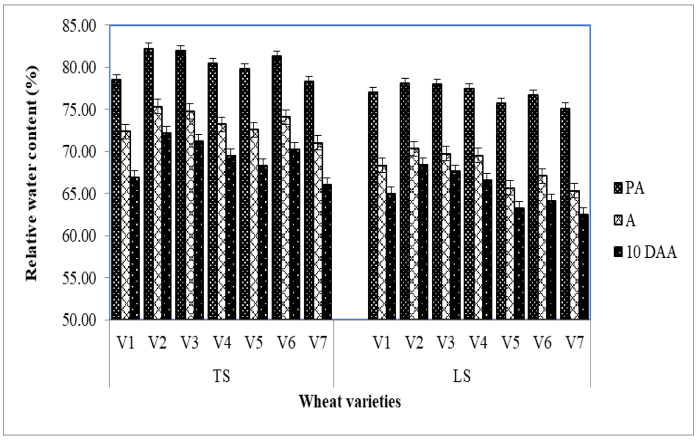
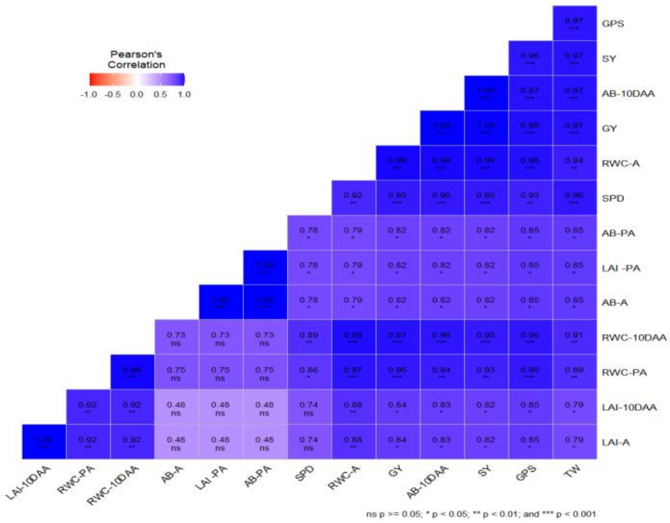
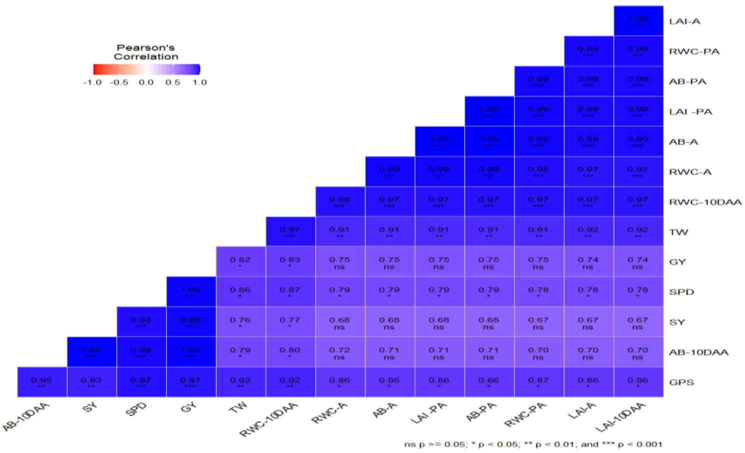


Fig 1: Relative water content of different wheat varieties under timely (TS) and late sown (LS) conditions
V1 = HD 3388, V2 = HD 3249, V3 = HD 3086, V4 = HD 2967, V5 = DBW 222, V6 = DBW 187 and V7 = PBW 187; PA= Pre-anthesis; A= Anthesis; 10 DAA= 10 Days after anthesis. Error bars on the top of each bars signifies standard error of mean (SE_m) for each treatment



(a)



(b)

Fig 2: Correlation matrix between different canopy attributes, RWC and grain yield of wheat varieties under Timely sown (a) and Late sown conditions (b)

LAI-PA/A/10DAA= Leaf area index at pre-anthesis/anthesis/10 days after anthesis; RWC-PA/A/10DAA= Relative water content at pre-anthesis/anthesis/10 days after anthesis; AB- PA/A/10DAA= Aerial biomass at pre-anthesis/anthesis/10 days after anthesis; TW= Test weight; GW= Grain yield; SPD= Spike density; SY= Straw yield; GPS= Grains per spike

CONCLUSION

Thus, based on one-year experiment, it's evident that the terminal high temperatures significantly restricted crop canopy growth and yield attributes irrespective of varieties leading upto 35% yield drop. RWC may serve as a fairly good indicator of terminal heat stress, and maintenance of higher flag leaf RWC during the post anthesis stage of wheat can be correlated with its grain yield. The variety HD 3249 emerged out with the higher degree of resistivity against terminal heat stress by maintaining optimum LAI and there by regulating favorable water balance, higher RWC and ensuring efficient source activity and ultimately leads to higher grain yield.

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