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PERFORMANCE OF WHEAT VARIETIES UNDER LATE PLANTING-INDUCED HEAT STRESS CONDITION

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Abstract

The effect of late planting heat stress on physiological traits, yield attributes and yield of four wheat varieties (BARI Gom 25, BARI Gom 26, BARI Gom 28 and Sourav) were tested in the study. November 30 sowing was considered as control and December 30 sowing as the late planting heat stress condition. Wheat Var. BARI Gom 25, BARI Gom 26 and BARI Gom 28 showed greater stability of flag leaf chl, higher level of proline in flag leaf and kernel and greater ability to keep the canopy cooler compared to Sourav under late planting heat stress condition. More spike dry matter accumulation at peak, longer grain growth duration, better yield components such as number of grains spike^{-1}, grain weight spike^{-1} and 1000-grain weight under heat stress contributed to better tolerance of BARI Gom 25, BARI Gom 26 and BARI Gom 28. The order of tolerance based on grain yield was BARI Gom 25 > BARI Gom 28 > BARI Gom 26 > Sourav and the order of tolerance based on above ground biological yield was BARI Gom 28 > BARI Gom 26 > BARI Gom 25 > Sourav.

Introduction

Wheat (*Triticum aestivum* L.) is the world's most widely cultivated food crop. It is the second important cereal crop after rice, and grown worldwide as the major sources of energy for human being**.** Bangladesh covers an area of 0.43 million hectare for wheat cultivation with an annual production of about 1.30 million metric tons and average grain yield of 3.03 t ha^{-1} (Anonymous, 2014). In Bangladesh, about 60% of the wheat is cultivated at late sowing condition after harvesting the transplanted aman rice (Badaruddin *et al*., 1994).

Late planting wheat exposed to high temperature (mean air temperature of >26ºC) at reproductive stage causing reduction in yield and it is one of the major reasons of yield gap (Hasan and Ahmed, 2005). However, this problem will be further increased due to global warming. In this context, the temperature in Bangladesh would be increased to 1.3ºC and 2.6ºC by the year 2030 and 2075, respectively with respect to the base year 1990. In spite of low yield of wheat due to post anthesis heat stress, cultivation of wheat cannot be avoided totally. Because the irrigation dependent Boro rice cultivation may need to be replaced in future by partially irrigated or non irrigated wheat cultivation. Therefore, effort ought to be made to minimize the late sown yield reduction by screening or developing high temperature tolerant wheat genotypes/varieties or by ameliorating the effect of heat stress through agronomic strategies.

Different yield related characters were identified as contributing to heat tolerance in wheat. The most responsive yield component are number of grain spike^{-1}, grains spikelet^{-1}, grain weight, rate of grain filling, biomass at harvest (Zong-hu and Rajaram, 1994). In addition to these, other physiological characters like chlorophyll (chl) content, stem reserves mobilization (Sikder and Paul, 2010), canopy temperature depression (Sikder and Paul, 2010) and stomata conductance (Renolds *et al*., 1994) have been associated with performance of wheat under high temperature level. Considering the above importance the present investigation was carried out to study the sensitivity of physiological traits resulting reduced grain yield of wheat in heat stressed environment and to observe the effect of late planting heat stress on yield contributing characters and yield of wheat.

Materials and Methods

The experiment was set up at the research farm of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh. The experiment was conducted in a split- plot design with three replications. The unit plot size was 2.5 m. x 2.4 m. November 30 sowing was considered as control and December 30 sowing as late planting heat stress condition. Sowing times were placed in the main plots whereas four wheat varieties viz., BARI Gom 25, BARI Gom 26, BARI Gom 28 and Sourav in the sub-plots. A fertilizer dose of 140-35-75-18-2-0.5 kg ha^{-1} N, P, K, S, Zn and B was applied in the form of urea, triple super phosphate (TSP), muriate of potash (MOP), gypsum and boric acid, respectively. After land preparation, full dose of P, K, S, Zn, B and two-third of N were incorporated thoroughly into the soil as basal dose. The remaining amount of N was applied at 25 after seedlings emergence. Seeds of four wheat varieties were sown on November 30, 2014 and December 30, 2014 in rows of 20 cm apart, at the rate of 120 kg ha^{-1}. After sowing, light irrigation was given for uniform germination and other intercultural operations were done as per requirement. Maximum, minimum and mean air temperature was recorded and days required to anthesis also calculated.

Spike dry matter accumulation

At anthesis 80 main shoots were tagged from each plot. Four tagged main shoot spikes were harvested at every 4^{th} day beginning from anthesis to quantify spike dry matter accumulation pattern. Collection of main shoot spike in all genotypes was continued up to 40 days after anthesis (DAA) for both well watered and water deficit stress condition. The harvested spikes were kept in oven at 70°C for 72 hours. After oven drying, spikes were weighted with an analytical balance (AND Electronic Balance Model EK 300 i).

Determination of free proline content

Proline (Pro) content of flag leaf and kernel at 16 DAA of wheat genotypes grown in two growing conditions were estimated according to Bates (1973) from a standard curve and calculated on a fresh weight basis as follows:

$$\mu\text{moles Pro g}^{-1}\text{ of fresh plant material} = \{(\mu\text{g Pro / ml x ml toluene}) / 115.5\ \mu\text{g}/\mu\text{moles}\} / (\text{g sample}/5)$$

Determination of chlorophyll content

Total chl content of the flag leaf at 8 and 24 days after anthesis was estimated according to Witham *et al.* (1986) using following formula-

$$\text{Total chl (mg g}^{-1}\text{ FW)} = [20.2\ (D_{645}) + 8.02\ (D_{663})] \times [V/ (1000 \times W)]$$

(Where, V = Volume of 80% aqueous acetone (ml), W = Weight of fresh leaf (g), D_{645} = Absorbance at 645nm wave length and D_{663} = Absorbance at 663nm wavelength)

Determination of leaf relative water content (RWC)

Relative water content in flag leaf was determined at 16 DAA from the equation of Schonfeld *et al*. (1988).

RWC (%) = {(Fresh weight – Dry weight)/(Turgid weight - Dry weight)} x 100

Canopy temperature Depression (CTD)

The hand held infra-red thermometer (Model: Crop *TRACK* item no. 2955L-Spectrum *Tecnologies*, Inc.) was used to measure the CTD at 8 and 24 DAA during noon period under bright sunlight and less wind conditions.

Agronomical traits

Plant height, spike length (excluding awn), number of spikes m^{-2}, number of grains spike^{-1}, grain dry weight spike^{-1}, thousand grain weights, grain yield and above ground biological yield of wheat genotypes were taken properly. Grain and above ground biological yield were adjusted to 12% moisture content.

Stress susceptibility index (SSI)

Stress susceptibility index (SSI) was calculated for grain yield using following formula

$SSI = (1- Y/Y_p) / (1- X/X_p)$

(Where, Y = Grain yield of genotype in a stress environment, Y_p= Grain yield of genotype in a stress-free environment, X = Mean Y of all genotypes and X_p= Mean Y_p of all genotypes

All the collected data were analyzed by partitioning the total variance with the help of computer by using MSTAT program. The treatment means were compared using Duncun's Multiple Range Test (DMRT) at $P \leq 5\%$ level. Correlation analysis was done using MSTAT program.

Result and Discussion

Maximum, minimum and mean air temperature during the growing period

Maximum, minimum and mean air temperature recorded from the experimental site during 16 January to 16 April 2015 is presented in Fig. 1. From this figure it is revealed that the wheat varieties sown on November 30 experienced less than 26^{o}C throughout their whole reproductive growth phase was considered as control and wheat varieties sown on December 30 experienced more than 26^{o}C considered as late planting heat stress.

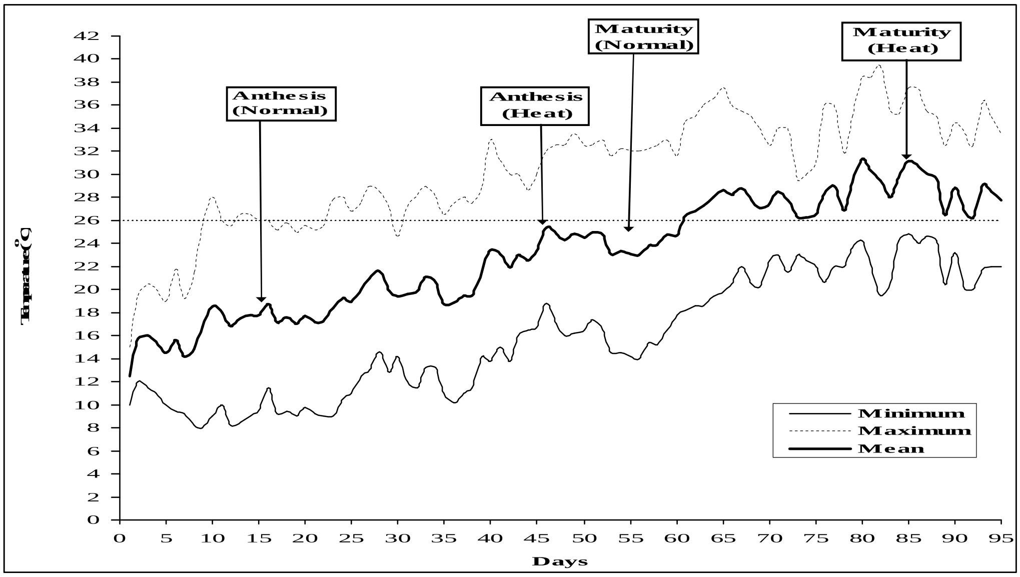

Fig. 1. Maximum, minimum and mean air temperature from 16 January to 16 April 2015 showing the period of anthesis and maturity of normal and late planting wheat.

Phenological parameters

Due to late planting heat stress number of days required to anthesis was reduced but it was not influenced significantly by the interaction effect of wheat varieties and temperature regimes (Table 1). Under late planting heat stress condition, all the wheat varieties required shorter time (63-64 days) to attain anthesis compared to control (73-74 days).

Table 1. Effect of late planting heat stress on days required to attain anthesis and physiological maturity of different wheat varieties

Wheat varieties	Temperature regimes	Days to anthesis		Days to physiological maturity	
		Number of days	Early in days over control	Number of days	Early in days over control
BARI Gom 25	Control	73	-	113 a	-
	Heat stress	64	9	104 a	7
BARI Gom 26	Control	73	-	113 a	-
	Heat stress	63	9	95 b	18
BARI Gom 28	Control	73	-	109 a	-
	Heat stress	63	10	95 b	14
Sourav	Control	74	-	114 a	-
	Heat stress	63	11	91 c	23
Level of significance		NS		*	
CV (%)		1.42		3.50	

In a column, values followed by similar letter (s) did not differ significantly by DMRT at P≤5%. Asterisk represents level of significance.

Wheat varieties and temperature regimes interacted significantly to influence the number of days required to attain physiological maturity (Table 1). Under late planting heat stress condition, all the wheat varieties required shorter time (91-104 days) to attain physiological maturity compared to control (109-114 days). Sourav required maximum days (114 days) to attain physiological maturity under control and it attained at physiological maturity 23 days earlier under heat stress condition, BARI Gom 25 required 113 days to and 7 days earlier under heat stress condition, BARI Gom 26 required 113 days under control and 18 days earlier under heat stress condition whereas BARI Gom 28 required minimum days (109 days) under control and 14 days earlier under heat stress condition. The Phonological stages of wheat were influenced by the environment during growing period. Sikder (2009) observed that the number of days for attaining anthesis, grain filling and maturity stages were higher for normal sowing condition compared to late sowing and also reported that the heat tolerant cultivars required higher number of days for attaining different phenological stages than the heat sensitive cultivars.

Physiological traits

Flag leaf chlorophyll content

Flag leaf chl content at 8 days after anthesis (DAA) was not significantly influenced by the interaction effect of wheat varieties and temperature regimes but flag leaf chl content at 24 days after anthesis was significantly influenced (Table 2). Due to heat stress, all the wheat varieties showed lower flag leaf chl content (0.97-1.28 mg chl g^{-1} FW) compared to control (1.29-1.49 mg chl g^{-1}FW)**.** Due to heat stress, flag leaf chl was reduced by 22, 6, 16 and 24% in BARI Gom 25, BARI Gom 26, BARI Gom 28 and in Sourav.

In the present study flag leaf chl content was reduced in all wheat varieties at 24 days after anthesis. Dhyani *et al.* (2013) and Almeselmani and Deshmukh (2012) also found that chl content was reduced in wheat due to heat stress. Possible reasons of reduction in chl content due to high temperature stress may be increased activity of peroxidase (Jiang *et al*., 2007), increase in chlorophyll breakdown (Thomas *et al.,* 1980) and reduction in chl biosynthesis. The present showed that heat tolerant cultivars retain higher amount of chl.

Table 2. Effect of late planting heat stress on different physiological traits of four wheat varieties

Wheat varieties	Temperature regimes	Flag leaf chl content				Proline content				CTD			
		At 8 DAA		At 24 DAA		Flag leaf		Kernel		At 8 DAA		At 24 DAA	
		mg g^{-1} FW	% change over control	mg g^{-1} FW	% change over control	μμmol g^{-1} FW	% change over control	μμmol g^{-1} FW	% change over control	°C	% change over control	°C	% change over control
	Control	1.62	-	1.49 a	-	8.10 b	-	7.33 b	-	4.17	-	3.72 a	-
BARI Gom 25	Heat stress	1.65	2	1.15 c	-22	10.46 a	29	11.05 a	50	2.75	-34	1.58 b	- 57
	Control	1.78	-	1.37 ab	-	6.75 bc	-	6.75 b	-	4.20	-	3.93 a	-
BARI Gom 26	Heat stress	1.54	-13	1.28 bc	-6	8.07 b	19	10.51 a	55	2.74	-34	1.78 b	- 54
	Control	1.78	-	1.41 ab	-	7.81 b	-	6.25 b	-	4.47	-	3.93 a	-
BARI Gom 28	Heat stress	1.75	-2	1.18 c	-16	11.34 a	45	10.76 a	72	2.72	-39	1.58 b	-59
	Control	1.67	-	1.29 bc	-	5.62 c	-	6.82 b	-	4.37	-	3.90 a	-
Sourav	Heat stress	1.78	6	0.97 d	-24	5.37 c	-4	6.65 b	-2	2.75	-37	1.05 c	-73
Level of significance		NS		**		**		**		NS		*	
CV (%)		11.34		4.45		8.60		12.41		5.65		8.16	

CTD = Canopy Temperature Depression, DAA= Days after Anthesis

In a column, values followed by similar letter(s) did not differ significantly by DMRT at P≤0.05
Asterisk represents level of significance

Flag leaf and kernel proline content

Wheat varieties and temperature regimes interacted significantly to influence flag leaf and kernel Pro content at 16 days after anthesis (Table 2). On November 30 sowing, BARI Gom 25 contained the highest amount of Pro in flag leaf (8.10 μmole g^{-1} FW) followed by BARI Gom 28 (7.81 μmole g^{-1} FW) and BARI Gom 26 (6.75 μmole g^{-1} FW) while Sourav contained the lowest amount of Pro in flag leaf (5.62 μmole g^{-1} FW). Under late planting heat stress condition, flag leaf Pro was increased by 29,19, 45 in BARI Gom 25, BARI Gom 26 and BARI Gom 28 whereas the flag leaf Pro was reduced by 4.45% in Sourav compared to control (November 30 sowing). Under control, BARI Gom 25 contained the highest amount of Pro in kernel (7.33 μmole g^{-1} FW) which was followed by Sourav (6.82 μmole g^{-1} FW) and BARI Gom 26 (6.75 μmole g^{-1} FW) while BARI Gom 28 contained the lowest amount of Pro in kernel (6.25 μmole g^{-1} FW). Under late planting heat stress condition, kernel Pro was increased by 50% in BARI Gom 25, 55% in BARI Gom 26 and 72% in BARI Gom 28 whereas the kernel Pro was reduced by 2% in Sourav compared to control (November 30 sowing). Increased Pro synthesis in heat stressed environment may be due to loss of feedback regulation in Pro biosynthetic pathway (Boggess and Stewart 1980).

Canopy temperature depression (CTD)

Canopy temperature depression at 8 days after anthesis was not influenced significantly by the interaction effect of wheat varieties and temperature regimes but at 24 days after anthesis was influenced significantly (Table 2). At 8 days after anthesis, all the wheat varieties maintained higher canopy temperature depression (4.17 to 4.47ºC) on November 30 sowing (Control) compared to heat stress condition (2.72 to 2.75ºC) i.e. all the wheat varieties maintained cooler canopy on November 30 compared to heat stress condition. At 24 days after anthesis, all the wheat genotypes maintained higher CTD (3.72 to 3.93ºC) under control compared to that (1.05 to 1.78ºC) under heat stress condition. CTD was reduced by 57% in BARI Gom 25, 54% in BARI Gom 26, 59% in BARI Gom 28 and 73% in Sourav. In the present study, it was observed that wheat variety BARI Gom 25, BARI Gom 26 and BARI Gom 28 recorded higher CTD under late planting heat stress condition than Sourav. That indicated that three varieties had greater ability to maintain canopy cooler than Sourav. This performance in CTD of different cultivars was reflected to their yield performance.

Spike dry matter accumulation

A typical sigmoid pattern of dry matter accumulation in spike were found in all wheat varieties both under optimum sowing and late plating heat stress condition (Fig. 2). Under control condition, the spike dry weight was observed to be increased up to 2.38 g at 40 DAA in BARI Gom 25, 2.77 g at 40 DAA in BARI Gom 26, 2.55 g at 36 DAA in BARI Gom 28 and 2.65 g at 40 DAA in Sourav and decline thereafter slowly. Under heat stress condition, maximum dry matter accumulation in spike was reduced in all wheat varieties and days required to attain maximum dry weight were reduced in all genotypes except BARI Gom 25. The reduction in maximum spike dry weight was 5.46% in BARI Gom 25, 5.56% in BARI Gom 26, 5.10% in BARI Gom 28 and 13.96% in Sourav. Number of days required to attain maximum spike dry weight which indicates grain growth duration were reduced 8 days in BARI Gom 26, 4 days in BARI Gom 28 and 12 days in Sourav whereas no reduction was found in BARI Gom 25 (Fig. 2 and 3). The declining tendency in spike dry weight after attaining the peak could be due to respiratory loss of kernel after physiological maturity. Hasan and Ahmed (2005) and Roy *et al.* (2013) also found post anthesis heat stress resulted in reduced dry matter accumulation at peak and reduced grain filling period but reductions were lower in heat tolerant genotypes than those in sensitive wheat genotypes.

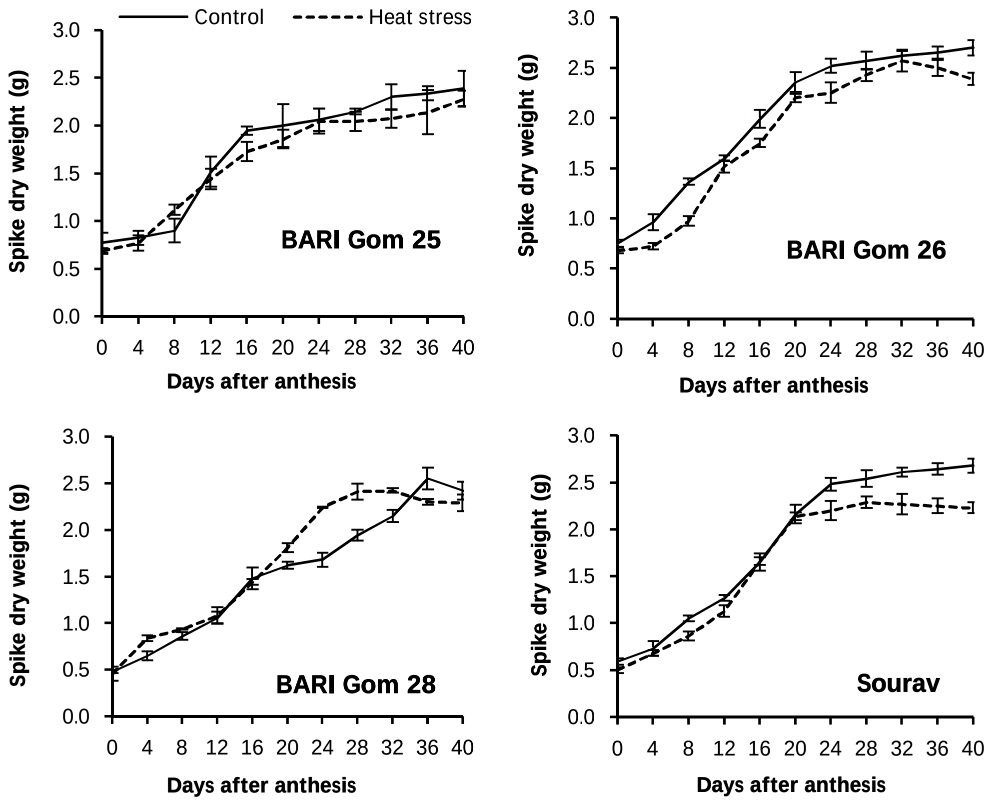

Fig. 2. Spike dry matter accumulation in different wheat varieties at different days after anthesis as influenced by late planting heat stress.

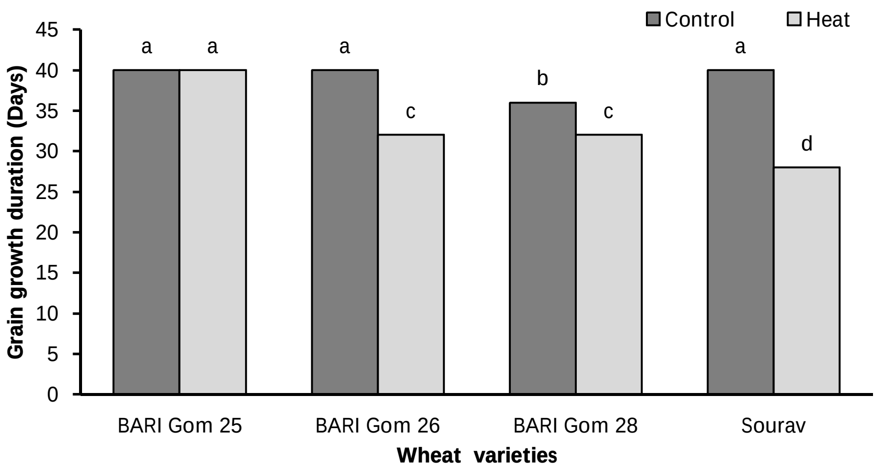

Fig. 3. Effect of late planting heat stress on grain growth duration (days) of different wheat varieties.

Grain dry weight spike^{-1}

Grain dry weight spike^{-1} was influenced significantly by the interaction effect of wheat varieties and temperature regimes (Fig. 4). On November 30 sowing, BARI Gom 28 and Sourav provided the highest grain dry weight spike^{-1} which was followed by BARI Gom 26 whereas BARI Gom 25 provided the lowest grain dry weight spike^{-1}. Due to late planting heat stress, grain dry weight spike^{-1} was reduced in al wheat varieties but the degree of reduction in grain dry weight spike^{-1} was different in different varieties. Grain dry weight spike^{-1} was reduced by 1.74% in BARI Gom 25, 7.50% in BARI Gom 26, 9.09% in BARI Gom 28 and 15.31% in Sourav due to heat stress compared to control (November 30 sowing).

Hasan and Ahmed (2005) and Roy *et al*. (2013) also found post anthesis heat stress resulted in reduced grain dry weight spike^{-1} but reductions were lower in heat tolerant genotypes than those in sensitive wheat genotypes. Reduction in grain dry weight spike^{-1} in different magnitude in different wheat genotypes under heat stress might be due to variation in grain growth rate (Hasan and Ahmed, 2005 and Hasan 2009), grain growth duration (Hasan and Ahmed, 2005 and Hasan, 2009) and stem reserve utilization (Roy *et al*., 2013).

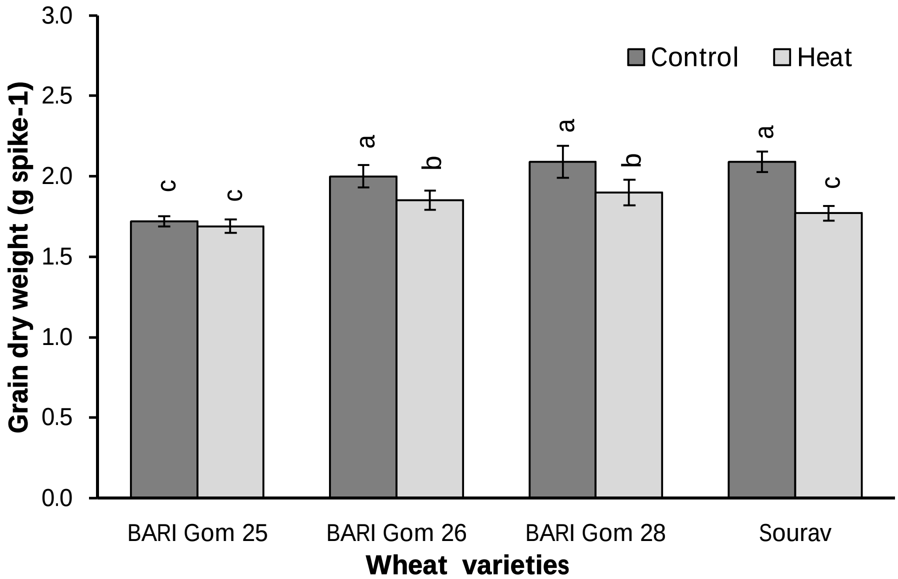

Fig. 4. Effect of late planting heat stress on grain dry weight spike^{-1} of different wheat varieties.

Agronomic traits

Plant height and spike length at harvest

Plant height and spike length at harvest were not influenced significantly by the combined effect of wheat varieties and temperature regimes but all the wheat varieties provided shorter plant and spike under optimum sowing compared to late planting heat stress condition except spike length in BARI Gom 26 (Table 3).Due to late planting heat stress, the development of plant organs, photosynthesis rate and transfer of assimilate from source (Sial *et al*., 2005, Hasan, 2009) were remarkably affected, which was reflected by overall shortening of plant height.

Number of spikes m^{-2}

The combined effect of wheat varieties and temperature regimes on number of spikes m^{-2} was significant (Table 3). On November sowing (control), the highest number of spikes per m^{-2} was observed in BARI Gom 28 (351) which was followed by Sourav (308) and BARI Gom 26 (297) whereas, the lowest number of spikes m-^{2} was observed in BARI Gom 25 (295). Due to the effect of heat stress number of spikes m-^{2} was reduced in all wheat varieties. But the degree of reduction was different in different varieties. Spikes m^{-2} was reduced by 2% in BARI Gom 25, 3% in BARI Gom 26, 1% in BARI Gom 28 and 20% in Sourav due to heat stress compared to control (November 30 sowing). Sial *et al.* (2005), Roy *et al*. (2013) and Hasan *et al.* (2007) also found reduced number of ears m^{-2} in heat stressed environment.

Number of grains spike^{-1}

Number of grains spike^{-1} was significantly influenced by the combined effect of wheat varieties and temperature regimes (Table 3). On November sowing (control), the highest number of grains spike^{-1} was observed in BARI Gom 26 (53) which was followed by BARI Gom 28 (50) and Sourav (49) and whereas the lowest number grains spike^{-1} was observed in BARI Gom 25 (38). Due to the effect of heat stress number of grains spike^{-1} was reduced in different magnitude in different varieties. The reduction was 13% in BARI Gom 25, 1% in BARI Gom 26, 6% in BARI Gom 28 and 18% in Sourav. Significant variation among different wheat genotypes in the reduction in number of grain ear^{-1} under heat stress was found by Hasan *et al.* (2007), Sial *et al.* (2005) and Radhika and Thind (2014).

1000-grain weight

The combined effect of wheat varieties and temperature regimes on thousand grain weight was found significant (Table 3). On November sowing (control), the maximum thousand grain weight was recorded in BARI Gom 25 (50.93 g) which was followed by BARI Gom 28 (43.80 g) and BARI Gom 26 (42.97) whereas the lowest in Sourav (40.70 g). Due to late planting heat stress thousand grain weights was reduced in all wheat varieties except in BARI Gom 26 but the degree of reduction was different in different varieties. Thousand grain weights were reduced by 4% in BARI Gom 25, 2% in BARI Gom 28 and 9% in Sourav. On the other hand thousand grain weigh was increased somewhat (0.09%) due to heat stress in BARI Gom 26. Significant variation in reduction in grain size under heat stress among different wheat genotypes was also observed by Sial *et al.* (2005), Dhyani *et al*. (2013) and Hasan and Ahmed (2005). Greater grain size in heat tolerant genotypes due to longer duration of rapid grain growth rate (Hasan and Ahmed 2005).

Table 3. Effect of late planting heat stress on agronomical traits of wheat varieties

Wheat varieties	Tempera-ture regimes	Plant height		Spike length		Spike m^{-2}		Grains $spike^{-1}$		1000-grain weight		Grain yield		Above ground biological yield	
		cm	% change over control	cm	% change over control	number	% change over control	number	% change over control	g	% change over control	tha^{-1}	% change over control	tha^{-1}	% change over control
BARI Gom 25	Control	107.9	-	11.4	-	295 b	-	38 d	-	50.93 a	-	3.12 a	-	9.32 a	-
	Heat stress	97.0	-10	10.6	-7	288 b	-2	33 e	-13	48.83 b	- 4	2.65 b	-15	6.74 bc	-27
BARI Gom 26	Control	102.8	-	10.1	-	297 b	-	53 a	-	42.97 c	-	3.49 a	-	9.23 a	-
	Heat stress	96.0	-6	10.4	3	288 b	-3	52 ab	-2	42.93 c	0.09	2.71 b	-22	6.75 bc	-26
BARI Gom 28	Control	103.0	-	10.7	-	351 a	-	50 ac	-	43.80 c	-	3.26 a	-	8.94 a	-
	Heat stress	97.1	-5	9.2	-14	346 a	-1	47 c	-6	42.53 cd	-2.	2.67 b	-18	7.51 b	-15
Sourav	Control	103.6	-	10.9	-	308 b	-	49 bc	-	40.70 c	-	3.47 a	-	9.53 a	-
	Heat stress	99.9	-3	10.5	-3	246 c	-20	40 d	-18	36.77 e	- 9	2.16 c	-37	5.94 c	-37
	Level of significance	NS		NS		**		**		**		**		**	
	CV (%)	4.94		2.84		3.22		3.17		1.90		4.84		5.09	

In a column, values followed by similar letter(s) did not differ significantly by DMRT at P≤5%
Asterisk represents level of significance

Grain yield

The combined effect of wheat varieties and temperature regimes on grain yield was found significant. (Table 3). On November sowing (control), the maximum grain yield was recorded in BARI Gom 26 (3.49 t ha^{-1}) which was followed by Sourav (3.47 t ha^{-1}) and BARI Gom 28 (3.26 t ha^{-1}) whereas the lowest grain yield was found in BARI Gom 25 (3.12 t ha^{-1}). Due to late planting, heat stress grain yield was reduced in all wheat varieties but the degree of reduction was different in different varieties. Grain yield was reduced by 15% in BARI Gom 25, 22% in BARI Gom 26, 18% in BARI Gom 26 and 37% in Sourav. Significant variation in reduction in grain yield in different wheat genotypes due to heat stress was also found by Baloch *et al.* (2012), Khan and Kabir (2014), Laghari *et al*. (2012), Dhyani *et al*. (2013), Radhika and Thind (2014), Hasan *et al*. (2007) and Roy *et al*. (2013). They found that better performance of all the yield parameters such as number of spike m^{-2}, number of grains $spike^{-1}$, grain weight $spike^{-1}$ and grain size had contribution to better grain yield of heat tolerant wheat genotypes.

Above ground biological yield

Above ground biological yield was influenced significantly by the combined effect of wheat varieties and temperature regimes (Table 3). On November sowing (control), the highest above ground biological yield was recorded in Sourav (9.53 t ha^{-1}) which was followed by BARI Gom 25 (9.32 t ha^{-1}) and BARI Gom 26 (9.23 t ha^{-1}) whereas the lowest above ground biological yield was found in BARI Gom 28 (8.94 t ha^{-1}). Due to late planting heat stress, above ground biological yield was reduced in all wheat varieties but the degree of reduction was different in different varieties. The reduction was 27% in BARI Gom 25, 26% in BARI Gom 26, 15% in BARI Gom 28 and 37% in Sourav. The reduced above ground biological yield in wheat under heat stress was due to the reduced grain and straw yield. Khan and Kabir (2014), Hasan and Ahmed (2005) and Roy *et al.* (2013) also reported reduced biological yield under high temperature.

Correlation analysis between relative performances of various parameters

Correlation analysis between relative performances of various parameters studied in this investigation is presented in Table 4. Relative grain yield maintained a significant positive correlation with relative flag leaf chl content at 24 DAA (0.43*), relative flag leaf Pro content at 16 DAA (0.89**), relative kernel Pro content at 16 DAA (0.91**), relative canopy temperature depression at 24 DAA (0.88**), relative spikes m^{-2} (0.97**), relative grains $spike^{-1}$ (0.57**), relative thousand grain weight (0.77**), relative grain dry weight $spike^{-1}$ (0.90**) and above ground biological yield (0.77**). Nagrajan and Rane (2002) reported a significant correlation between grain weight $spike^{-1}$ and CTD in general. Hasan and Ahmed (2005) was found significant positive correlation between Pro level and grain yield of wheat under heat stress environment.

Table 4. Relationship among the relative performances of physiological traits, grain yield and straw yield of different wheat varieties

	Relative flag leaf chl content at 24 DAA	Relative flag leaf Pro content at 16 DAA	Relative kernel Pro content at 16 DAA	Relative canopy temperature depression at24 DAA	Relative spikes m^{-2}	Relative grains $spike^{-1}$	Relative thousand grain weight	Relative grain dry weight $spike^{-1}$	Relative grain yield	Relative above ground biological yield
Relative flag leaf chl content at 24 DAA										
Relative flag leaf Pro content at 16 DAA	0.57**									
Relative kernel Pro content at 16 DAA	0.75**	0.95**								
Relative canopy temperature depression at 24 DAA	0.67**	0.71**	0.88**							
Relative spikes m^{-2}	0.63**	0.60**	0.97**	0.94**						
Relative grains $spike^{-1}$	0.97**	0.60**	0.81**	0.82**	0.75**					
Relative thousand grain weight	0.74**	0.67**	0.87**	0.97**	0.88**	0.94**				
Relative grain dry weight $spike^{-1}$	0.15^{NS}	0.60**	0.67**	0.83**	0.81**	0.37*	0.66**			
Relative grain yield	0.43*	0.89**	0.91**	0.88**	0.97**	0.57**	0.77**	0.90**		
Relative above ground biological yield	0.73**	0.96**	0.93**	0.65**	0.84**	0.70**	0.68**	0.41*	0.77**	

Stress susceptible index (SSI)

Fig. 5 shows stress susceptibility index of different wheat varieties based on grain yield. Wheat var. BARI Gom 25 showed the lowest heat stress susceptibility index that was followed by BARI Gom 28 and BARI Gom 26. Sourav showed the highest heat stress susceptibility index. These stress susceptibility index values indicated that BARI Gom 25, BARI Gom 26 and BARI Gom 28 were heat tolerant varieties and Sourav was heat susceptible variety.

Fig. 6 shows stress susceptibility index of different wheat varieties based on above ground biological yield. BARI Gom 28 showed the lowest heat stress susceptibility index that was followed by BARI Gom 26 and BARI Gom 25. Sourav showed the highest heat stress susceptibility index. These stress susceptibility index values indicated that BARI Gom 25, BARI Gom 26 and BARI Gom 28 were more tolerant varieties than Sourav. Hossain *et al.* (2013), Agrawal *et al.* (2014), Hasan and Ahmed (2005) and Rasal *et al.* (2006) found that the heat tolerant genotypes showed lower susceptibility index than the heat sensitive genotype.

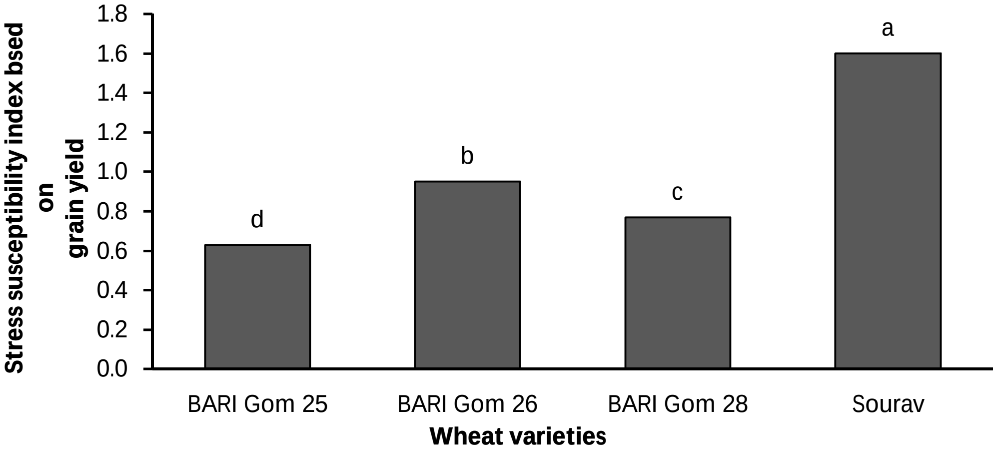

Fig. 5. Stress susceptibility index of different wheat varieties based on grain yield.

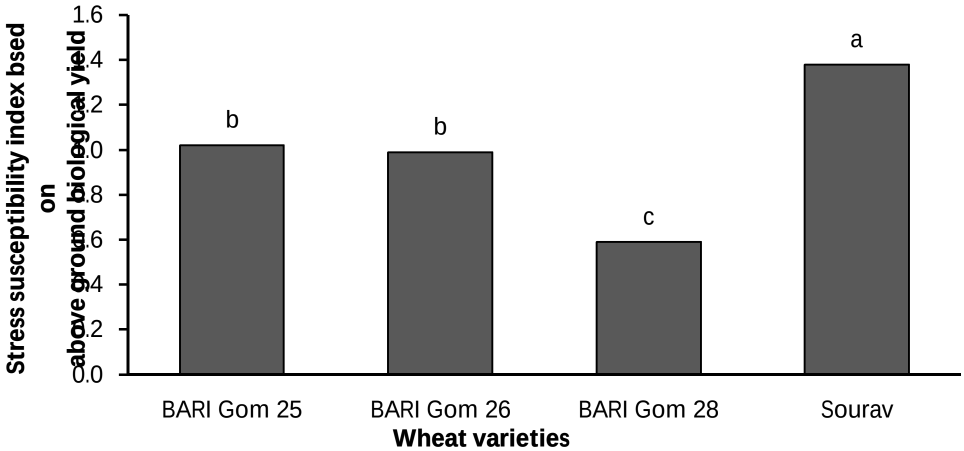

Fig. 6. Stress susceptibility index of different wheat varieties based on above ground biological yield.

Conclusion

From the overall results it may be concluded that wheat var. BARI Gom 25, BARI Gom 26 and BARI Gom 28 showed greater stability in chl and higher level of Pro in flag leaf and kernel as well as greater ability to keep the canopy cooler compared to Sourav under late planting heat stress condition. Greater spike dry matter accumulation at peak, longer grain growth duration, better yield components such as spikes m^{-2}, grains $spike^{-1}$, grain weight $spike^{-1}$ and 1000-grain weight under heat stress contributed to better tolerance of BARI Gom 25, BARI Gom 26 and BARI Gom 28. The order of tolerance based on grain yield was BARI Gom 25 > BARI Gom 28 > BARI Gom 26 >Sourav and the order of tolerance based on above ground biological yield was BARI Gom 28 > BARI Gom 26 > BARI Gom 25 >Sourav.

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