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Grain growth and yield potential of wheat genotypes under late sown heat stressed condition

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ABSTRACT

This open field experiment was conducted to evaluate the adaptation of wheat genotypes in late sown heat stress condition. Grain growth, yield components and yield of four wheat genotypes (BARI gom 25, BARI gom 26, BAW 1135 and Pavon 76) was determined at different sowing dates. Sowing on 29 November was considered the normal growing period (control) with a mean air temperature 24.08 °C during the post anthesis stages. Mean temperature was as high as 28.4 °C on 30 December sowing which is heat stress condition for wheat. Under stress condition (30 December sowing), BARI gom 25 and BARI gom 26 continued to increase grain dry matter up to 32 days after anthesis (DAA) which stopped 8 days earlier in Pavon 76. Under post anthesis heat stress condition the higher number relative spike m^{-2} (92%), higher relative grain number spike^{-1} (92%) and higher relative 1000-grain weight (96%) were found in BARI gom 26 compared to Pavon 76. Higher yield reduction was recorded in Pavon 76 (78.06 kg ha^{-1} d^{-1}) compared to BARI gom 26 (19.36 kg ha^{-1} d^{-1}) on 30 December sowing. In terms of grain growth and seed yield, BARI gom 26 was found to be the superior variety for growing under warmer environment.

Keywords: Anthesis, grain size, heat stress, sowing date, wheat, yield

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1 Introduction

Wheat is the second most important staple food in Bangladesh after rice which accounts for about 12% of total cereal consumption (GAIN, 2017). It is the second main source of world's food energy and nutrition, grown on about 4.28 lac hectares with annual production of about 14.24 lac metric tons (AIS, 2018). Though it is widely grown cereal in temperate environments, its area and production have been extended from temperate to tropical and later subtropical regions. In Bangladesh, about 60% of the wheat is cultivated at late sown condition after harvesting of transplanted aman rice (Badruddin et al., 1994) and thus the crop frequently encounters high temperature stress during the reproductive stage of growth (mean air temperature of >26 °C) causing significant yield reduction (2 t ha^{-1}) (Hasan and Ahmed, 2005).

Due to increased temperature the gradual changes are occurring in the performance of crop variety, yielding ability and ultimately the cropping pattern. The annual mean temperature of Bangladesh which is 25.75 °C is expected to rise about 0.21 °C by 2050 (Karmakar and Shrestha, 2000). The seasonal variation of temperature will be more in winter than in summer. Such variation will be 1.3 °C in winter and 0.7 °C in summer for 2030 and 2.1 °C for winter and 1.7 °C for summer for 2075 (Ahmed and Alam, 1999).

Such global warming will push the wheat farming further into heat stressed environment in future and may cause further reduction of present yield level.

Post anthesis heat stress environment in wheat induces early onset of senescence or retards conversion of sucrose to starch in developing grains of wheat. Thus, altered source activity or sink activity or combine effect of both due to heat stress may be the casual factors for a yield penalty through reduction in grain filling period as well as the rate of grain filling (Hasan and Ahmed, 2005). Although high temperatures accelerate growth it also reduce the phenology, which is not compensated by the increased growth rate (Zahedi and Jenner, 2003). However, temperatures >30 °C, during floret formation, may cause complete sterility (Saini and Aspinall, 1982). Therefore, when temperatures are elevated between anthesis to grain maturity, grain yield is reduced because of the reduced time to capture resources (Farooq et al., 2011).

Grain development at elevated temperature can affect membrane integrity and can cause increase in membrane leakage of both electrolytes and macro molecules during germination which subsequently impair germination and seedling vigor (Givelberg et al., 1984). Thus poor utilization of wheat seed endosperm under heat stress condition may reflect its heat susceptibility to the adult crop that might cause yield loss. Therefore efforts ought to be made to minimize the late sown yield reduction by screening or developing high temperature tolerant wheat genotypes. Considering above circumstances the present study was carried out to find out the genotypic differences in grain growth and yield of wheat genotypes due to exposure to late sown elevated temperature.

2 Materials and Methods

2.1 Experimental site

The experiment was conducted at the research farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur located at 24°2′18.9″N, 90°23′58.4″E during November, 2010 to April, 2011. Seeds of four wheat genotypes (BARI gom 25, BARI gom 26 and Pavon 76 were cultivar and BAW 1135 was a line) were collected from Bangladesh Agriculture Research Institute (BARI), Gazipur.

2.2 Experimental design and treatment

The experiment was conducted in a split plot design with three replications. The unit plot size was 3 m × 2.5 m having a plot to plot and block to block distance of 0.5 m. The distance between the main plots was 1.0 m. Five sowing dates (sown on 29 November, 5 December, 16 December, 23 December and 30 December) were placed in the main plots as main plot treatments (Factor A) whereas four wheat genotypes (BARI gom 25, BARI gom 26, BAW 1135 and Pavon 76) were placed randomly in the sub-plots as sub-plot treatments (Factor B). Seeds were sown in rows of 20 cm apart, at the rate of 120 kg ha^{-1} seeds.

2.3 Grain growth rate

At anthesis 40 main shoots were tagged at each plot sowing on 29 November and 30 December only. Spike from three tagged main shoots were harvested at every 4th day beginning from anthesis to quantify grain growth in all genotypes. The harvesting of spike from tagged main shoot in all genotypes was continued up to maturity in case of two selected sowing dates. Here anthesis indicates onset of first flowering, maturity indicates above 90% spike turns into yellowish color and physiological maturity indicates dry matter accumulation stop in grain. The harvested spike was then kept in oven at 70 °C for 72 h. After oven drying 17 grains were separated from the middle two spikelets of each three spike in all genotypes. During separation only first and second grain of a spikelet were collected. Then weight of 17 grains of each spike was taken with analytical balance (AND Electronic Balance Model ER 180A A & D Company Limited, Tokyo, Japan).

The absolute grain growth rate (AGR) was calculated according to Hasan and Ahmed (2005) using the following formula:

$$AGR = \frac{W_2 - W_1}{T_2 - T_1} \tag{1}$$

where W_1 = grain weight at initial time (T_1), and W_2 = grain weight at final time (T_1).

2.4 Yield contributing characters and yield indices

The samples were collected from an area of 2 m × 2 m from the center of each plot by cutting the plant at ground level. Then spikes were counted and collected in a cloth bag. The samples were dried in sun, threshed and cleaned manually and fresh weight of grain was taken. The husk, straw and representative samples of grain were dried again in sun properly to obtain grain and straw weight/2 m^2. Numbers of grain and spike were counted manually. From each plot thousand grain were taken randomly and weighted. From there, individual grain size was recorded.

Harvest index was calculated by the following formula:

$$HI = \frac{Y_e}{Y_b} \times 100 \tag{2}$$

HI =harvest index (%), Y_e = economic yield, and Y_b = biological yield.

Yield reduction of a genotype per day is calculated using the following formula:

$$Y_R = \frac{Y_2 - Y_1}{T_2 - T_1} \tag{3}$$

where Y_R = grain yield reduction due to a sowing time treatment in comparison to the control sowing time (kg ha^{-1} d^{-1}), Y_1 = grain yield at control sowing time (hg ha^{-1}), W_2 = grain yield with a particular sowing time (kg $^{-1}$), $(T_2 - T_1)$ = number of days between sowing date of the control treatment (T_1), and = sowing date of a particular treatment T_2.

The relative performance of a wheat genotype for a particular trait was calculated as the ratio of the variable measured under stressed and normal (unstressed) conditions as stipulated by Asana and Williams (1965).

Heat susceptibility index (S) was calculated for grain yield as described by Fisher and Maurer (1978).

$$S = \frac{1 - Y/Y_p}{1 - X/X_p} \tag{4}$$

Where, Y = grain yield of a 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. $S<0.5$ = highly stress tolerant; $0.5<S<1.0$ = moderately stress tolerant, and $S>1.0$, stress susceptible.

2.5 Statistical analysis

The findings were analyzed by partitioning the total variance by using MSTAT–C program. The treatment means were compared using Duncun's Multiple Range Test (DMRT) at 5% level of significance.

3 Results and Discussion

3.1 Ambient temperature during post anthesis period

Wheat genotypes sown on 29 November spent their early grain filling period not exceeding 26 °C. This temperature was not considered as heat stress as the optimum temperature for reproductive stage of wheat range between 22 to 26 °C (Campbell and Read, 1968; Campbell et al., 1969). On the contrary, genotypes sown on 30 December spent their whole grain filling period in heat stressed environment as temperature was above 26 °C (Fig. 1). Thus sowing at 29 November was considered as normal growing period while sowing at 30 December was considered as post anthesis heat stressed growing period in present study. Temperature above 26 °C at reproductive growth phase causes harmful premature ripening of wheat (Abrol et al., 1991). Post anthesis maturity period was reduced gradually with increasing temperature. Sowing at 29 November and 5 December required about 40 days of post anthesis period for maturity. Sowing at 16 December require about 36 days of post anthesis period for maturity and sowing at 23th December and 30 December both require about 32 days of post anthesis period for maturity (Fig. 1). Tashiro and Wardlaw (1989) also found a reduction in grain growth duration and dry matter accumulation in grain in wheat with increasing temperature above a mean of 26.7 °C.

3.2 Absolute grain growth rate

All genotypes in early seeding dates showed a relatively slower grain growth rate and took a longer time to attain the maximum rate of grain growth (Fig. 2). Absolute growth rate indicates accumulation of dry matter on grain per day basis. Under normal growing condition, rapid growth rate (more than 1 mg grain^{-1} d^{-1}) was observed in all wheat genotypes, apparently 24–28 days after anthesis. Under stressed condition, this rate was continued upto 20–24 day after anthesis in case of BARI gom 25, BARI gom 26 and BAW 1135 whereas in Pavon 76, rapid growth rate was continued only upto 12 days after anthesis. In late seeded crop, the physiological maturity was shifted to 8 day earlier in Pavon 76 which continued upto 32 day after anthesis in early seeded crops. On the contrary, 4-day earliness was observed to reach the physiological maturity in BARI gom 25, BARI gom 26 and BAW 1135 under stressed condition. Hasan and Ahmed (2005) and Hasan (2009) also agreed with this result that grain growth rate and duration is reduced in all genotypes due to post anthesis heat stress but reduction is less in heat tolerant genotypes than that of heat sensitive genotypes. They also found that duration of rapid growth rate was reduced due to heat stress but reduction was lower in tolerant genotypes than heat sensitive genotypes.

The grain growth rate pattern indicates that soon after attaining the highest rate, a stage of internal starvation occured which caused initiation of declining growth rate. At this stage, the grain growth depends chiefly on its store food materials mobilized from stem. Under normal condition, all genotypes delayed to initiate the phase of internal starvation and as a result, had longer duration of growth rate than heat stress condition. At post anthesis heat stress condition, the heat tolerant genotypes initiated starvation phase 4 days earlier. But in heat susceptible genotypes internal starvation phase was initiated 12 days earlier than normal condition. Because of their earliest initiation of internal starvation phase heat susceptible genotypes had minimum rapid growth duration due to heat stress.

Elevated temperature encouraged a theatrical resetting of physiological and molecular mechanisms

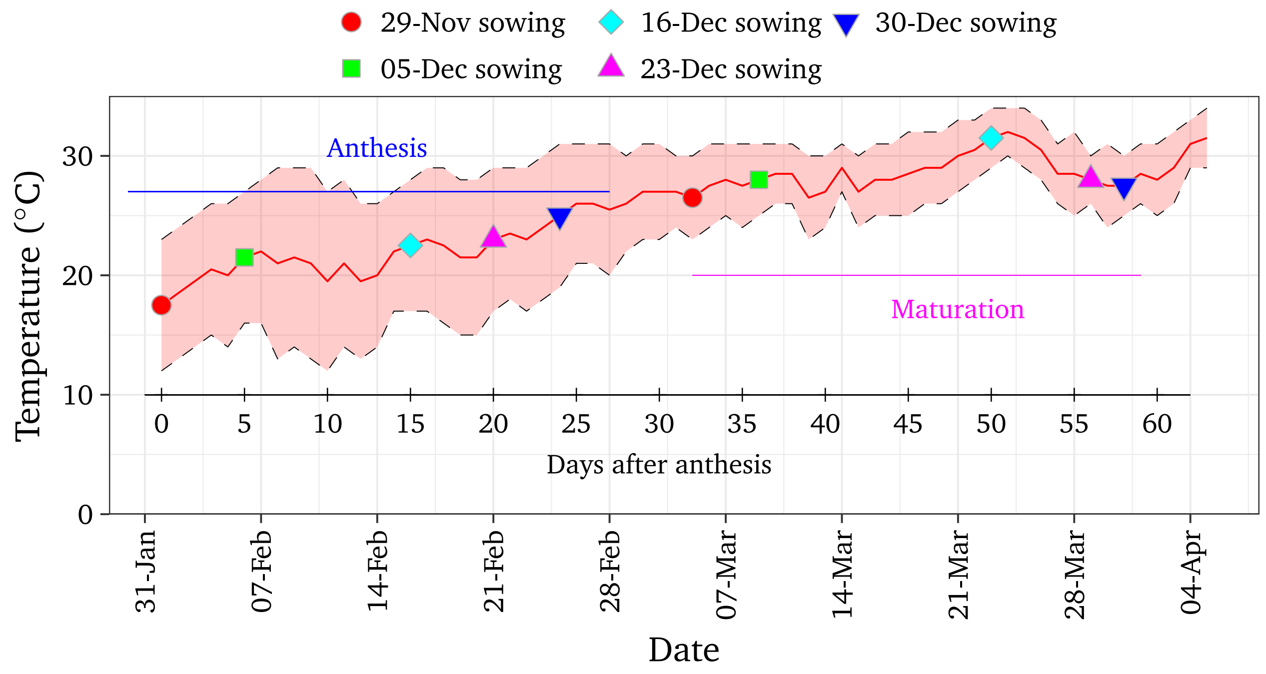

Figure 1. Air temperature during anthesis and maturity periods of wheat sown at five different dates. Red line indicates mean air temperature and the ribbon shows the range between maximum and minimum air temperature.

in order to help sustained homeostasis and survival (Mishkind et al., 2009). Heat induced oxidative stress is the consequence of production of reactive oxygen species that are formed as a result of damage to membrane and proteins (Larkindale and Knight, 2002). Heat can also endorse programmed cell death. Overall these damages may result in reduced photosynthetic rate, impaired translocation of assimilates and reduced carbon gain that ultimately lead to distorted growth and abnormal reproduction (Berry and Bjorkman, 1980).

3.3 Grain weight

Individual grain weight differed significantly due to the combined effect of growing conditions and wheat genotypes (Fig. 3). Under normal growing condition, maximum grain weight was recorded in BARI gom 25 (55.33 mg) which was statistically similar with BARI gom 26 (51.33 mg) and minimum grain weight was recorded in Pavon 76 (35.0 mg) followed by BAW 1135 (49.0 mg) which was statistically differed from all other genotypes. Wheat seeding on 30 December had the lowest grain weight in all of the genotypes, but reduction was maximum in genotypes Pavon 76 and minimum in BARI gom 26. At post anthesis heat stress condition, grain weight reduced significantly in all wheat genotypes. Reduced grain weight under heat stress condition might be due to the reduction in rapid kernel growth duration and reduced starch deposition. Lower grain weight and altered grain quality are the two reported manifestations of heat stress during the postanthesis grain-filling stage by affecting availability and translocation of photosynthates to the developing kernel, and starch synthesis and deposition within the kernel (Bhullar and Jenner, 1985).

3.4 Spike number

Number of spike m^{-2} was significantly influenced in different genotypes by the sowing dates (Table 1). The highest spike number m^{-2} was observed in Pavon 76 (528) followed by BAW 1135 (393.2) which was statistically different from each other. The lowest number of spike was recorded in genotype BARI gom 25 (317.2) followed by BARI gom 26 (340.2) which was statistically similar with each other but different from BAW 1135 and Pavon 76 under normal growing condition. Under post anthesis heat stress condition, the minimum spike number was recorded in BARI gom 25 (278.3) followed by BARI gom 26 (320.0), BAW 1135 (320.8) which was statistically similar with each other but statistically different with Pavon 76 (337.8). Spike number reduced gradually with delaying sowing dates by a weekly distance though their reduction varied from genotype to genotype. Relative to normal seeding dates, the spike number in 30 December seeding was maximum in BARI gom 26 (0.92), followed by BARI gom 25 (0.87), BAW 1135 (0.83) and Pavon 76 (0.75) (Table 1). Bhatta et al. (1994) and Islam et al. (1993) also reported the results of decreasing spike

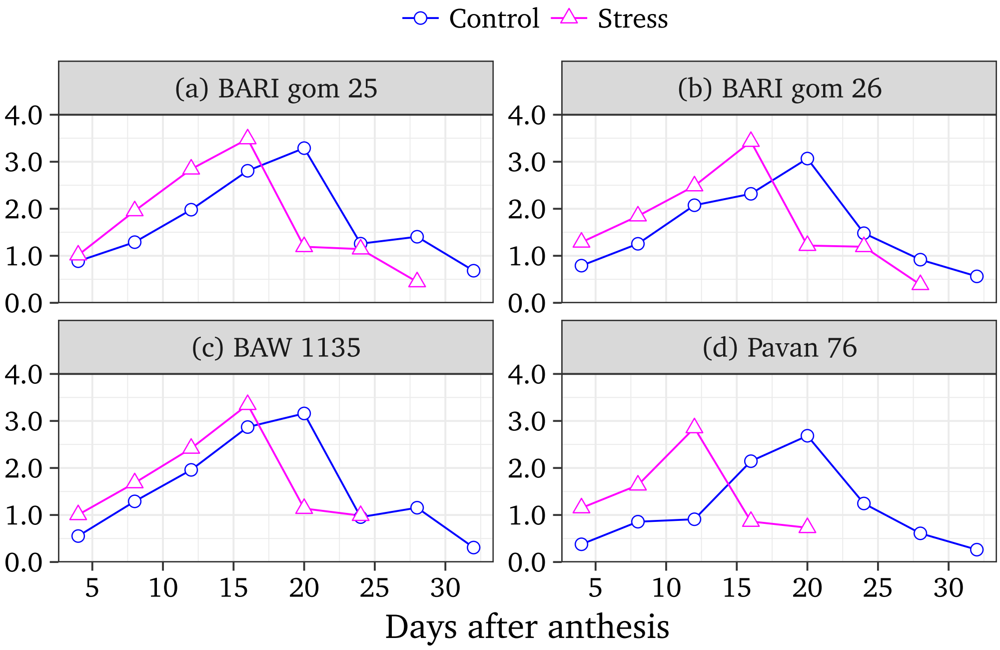

Figure 2. Absolute grain growth (AGR) of four wheat genotypes at different days after anthesis under control (sown at 29 November) and heat stressed (sown at 30 December) condition

number in delay seeded wheat.

3.5 Grain count

Grain number per spike is one of the dominant yield contributing characters. Grain number per spike was influenced significantly by the effect of different sowing dates (Table 1). Under normal growing environment, Pavon 76 produced higher number of grain per spike (60.73) followed by BAW 1135 (57.41) and BARI gom 26 (57.10). BARI gom 25 produced lower number of grain per spike (42.70) which was statistically different from other genotypes. Reduction in grain number was found with delaying sowing dates in all genotypes except BARI gom 25. In BARI gom 25, grain number per spike was increased in 5 December (44.83) and 16 December sowing (45.93) and then the number was reduced in 23 December (44.30) and 30 December (39.63) sowing. Under post anthesis heat stress condition, minimum grain number was recorded in BARI gom 25 (39.63) which were statistically different from other three genotypes, BARI gom 26 (50.80), BAW 1135 (46.90) and Pavon 76 (47.27). Grain number was reduced with increasing sowing dates in all genotypes but their reduction relative to normal was different among the genotypes. The relative grain number per spike at 30 December sowing was higher in BARI gom 25 (0.93) followed by BARI gom 26 (0.92), BAW 1135 (0.82) and lower in Pavon 76 (0.78) (Table 1).

Anthesis stage is considered very crucial with respect to heat stress because the induction of heat stress just before and at this stage showed significant increase in floral abortion and lower number of seeds in peanut, wheat, rice and maize (Saini et al., 1983; Matsui et al., 2001). Significant variation among different wheat genotypes in the reduction in number of grain spike^{-1} under heat stress was found by Sial et al. (2005), Wollenweber et al. (2003) and Karim et al. (1999).

3.6 Grain yield

Grain yield (t ha^{-1}) was greatly influenced by sowing dates and wheat genotypes. Under normal condition the highest value was recorded in BAW 1135 (5.66) followed by Pavon 76 (5.5), BARI gom 26 (5.35) and BARI gom 25 (5.25) which was statistically insignificant with each other (Table 1). Grain yield did not reduce with delaying sowing dates until mid December in BARI gom 25, BARI gom 26 and BAW 1135 except Pavon 76. In Pavon 76, grain yield reduction was found significant after 6 December seeding and lowest yield was recorded in 30 December seeding. Relative yield was higher when seeds were sown on 30 December in BARI gom 26 (0.89) followed by BARI gom 25 (0.81), BAW 1135 (0.66) and lowest in Pavon 76 (0.56) (Table 1).

Reduced number of spike m^{-2} and reduced grain size were the major factors for reducing the grain yield under late planting heat stress condition in the present experiment compared to normal growing period. Reduction of grain number per spike with delay sowing largely contributed to reduce the correspond-

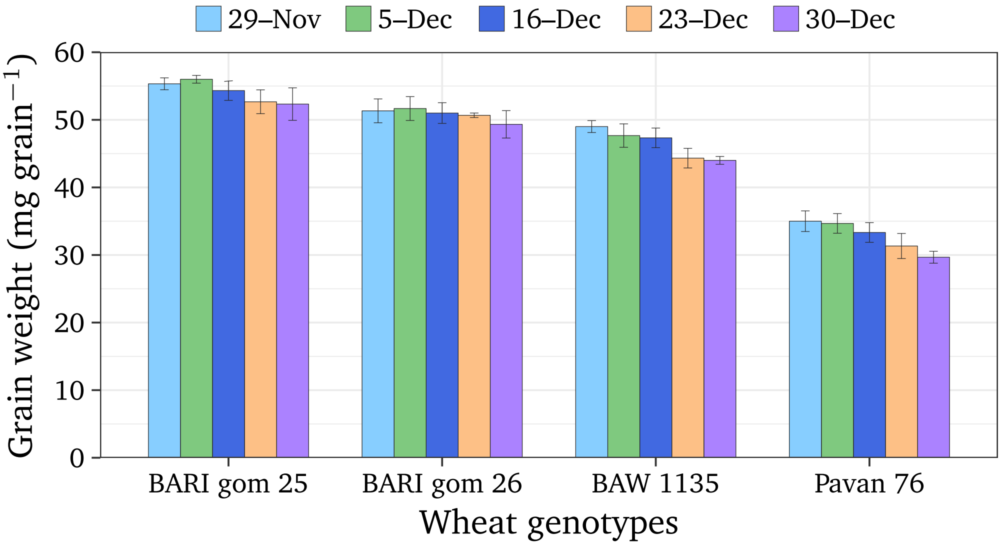

Figure 3. Individual grain weight of wheat genotypes at different sowing dates (starting from 29 November to 30 December)

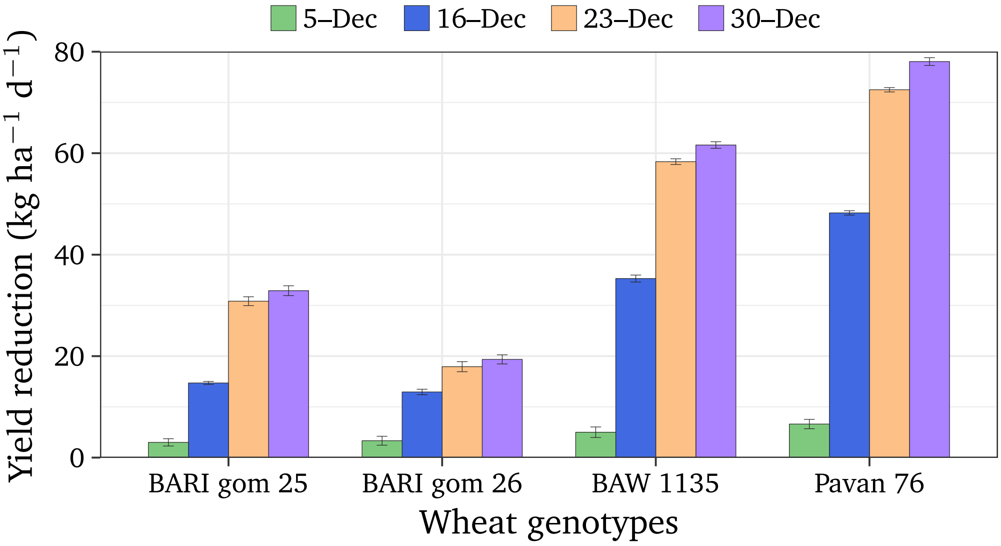

Figure 4. Yield reduction (kg ha^{-1} d^{-1}) of four wheat genotypes under 5, 16, 23 and 30 December sowing compared to 29 November sowing

ing grain yield largely in Pavon 76 and BAW 1135 but a smaller decrease in grains number per spike support the tolerance in terms of grain yield in BARI gom 25 and BARI gom 26. Studies also have shown that late planting heat stress caused lower grain yield in wheat compared to optimum sowing (Islam et al., 1993; Bhatta et al., 1994; Rasal et al., 2006; Sial et al., 2005; Wollenweber et al., 2003; Sharma-Natu et al., 2006). Significant variation due to heat stress in different wheat genotypes was also found by Rasal et al. (2006), Hasan and Ahmed (2005). They concluded that the high relative grain yield which was the results of stable and/or long duration of phosynthetic activity under heat stress condition and the character can be used as a selection criterion for heat tolerance of wheat genotypes.

3.7 Harvest index

Harvest index was significantly influenced by the effects of sowing dates (Table 1). Under normal growing condition, higher value of harvest index was found in BARI gom 26 (47.22%) followed by BARI gom 25 (47.17%), BAW 1135 (46.0%) and Pavon 76 (45.83%) which was statistically similar with each other. Under post anthesis heat stress condition, harvest index value was reduced in all genotypes. Lower value of harvest index was observed in Pavon 76

Table 1. Spike m^{-2}, grains spike^{-1}, grain yield and harvest index of wheat genotypes at different sowing dates

Genotypes	Sowing date	Spikes m^{-2}		No. of grains spike^{-1}		Grain yield t ha^{-1}		HI (%)
		Actual	Relative	Actual	Relative	Actual	Relative	
BARI gom 25	29–Nov	317.2 ef	–	42.70 fg	–	5.25 abc	–	47.17 a
	5–Dec	313.3 ef	0.98	44.83 defg	1.05	5.23 abc	0.99	47.07 a
	16–Dec	312.5 ef	0.97	45.93 def	1.07	5.00 abcd	0.95	47.40 a
	23–Dec	284.5 f	0.9	44.30 efg	1.04	4.51 de	0.86	45.5 ab
	30–Dec	278.3 f	0.87	39.63 g	0.93	4.23 ef	0.81	45.19 ab
BARI gom 26	29–Nov	340.2 de	–	57.10 ab	–	5.35 abc	–	47.22 a
	5–Dec	342.2 de	0.98	57.13 ab	1	5.33 abc	0.99	47.16 a
	16–Dec	330.8 ef	0.97	56.73 ab	0.99	5.13 abc	0.96	46.72 a
	23–Dec	322.3 ef	0.95	52.73 bc	0.94	4.90 bcde	0.62	45.67 ab
	30–Dec	320.0 ef	0.92	50.80 cd	0.92	4.75 cde	0.89	45.59 ab
BAW 1135	29–Nov	393.2 bc	–	57.40 ab	–	5.66 a	–	46.60 a
	5–Dec	387.8 bcd	0.98	56.53 ab	0.98	5.63 a	0.99	46.27 a
	16–Dec	365.2 cde	0.92	51.10 cde	0.89	5.06 abcd	0.89	45.53 ab
	23–Dec	340.5 de	0.87	48.73 cdef	0.84	4.26 ef	0.75	42.05 bc
	30–Dec	320.8 ef	0.83	46.90 cdef	0.82	3.75 fg	0.66	38.14 d
Pavon 76	29–Nov	528.0 a	–	60.73 a	–	5.50 ab	–	45.83 ab
	5–Dec	514.2 a	0.98	56.97 ab	0.94	5.47 ab	0.99	45.69 ab
	16–Dec	447.0 b	0.86	51.57 cd	0.86	4.68 cde	0.85	44.87 ab
	23–Dec	423.0 b	0.8	48.90 cdef	0.81	3.76 fg	0.68	41.87 cd
	30–Dec	397.8 bc	0.75	47.27 cdef	0.78	3.08 h	0.56	37.57 d
CV (%)		7.49		6.3		7.47		4.58

(37.57%) which was statistically similar with that of BAW 1135 (38.14%) but significantly different from BARI gom 25 (45.19%) and BARI gom 26 (45.59%). Due to lower grain yield and biological yield, Pavon 76 and BAW 1135 gave lower harvest index than other genotype as they affected more under post anthesis heat stress growing condition. A considerable decrease in the number of grains was observed on exposure of floral initiation stage and spikelet development to high temperature conditions thus adversely impacting the maximum yield potential. Sink strength and source capacity are considered two vital factors in modifying the grain yield and quality of wheat genotypes exposed to chronic heat as well as a heat shock which ultimately results in lower harvest index in heat sensitive genotype (Yang et al., 1996).

3.8 Yield reduction

Yield of all genotypes was reduced with delaying seeding time (Figure 1.4). Significant amount of yield was reduced per day. Compare to normal sowing time (29 November), yield reduction was not remarkable in 5 December sowing (ranges from 3 kg/ha/day in BARI gom 25 to 6.61 kg/ha/day in Pavon 76). Rapid reduction of yield was recorded from 16 December sowing (ranges from 12.94 kg/ha/day in BARI gom 26 to 48.23 kg/ha/day in Pavon 76). Highest amount yield reduction was found in Pavon 76 (78.06 kg/ha/day) when sown on 30 December. Yield reduction was minimum in BARI gom 26 (19.36 kg/ha/day) followed by BARI gom 25 (32.90 kg/ha/day) and BAW 1135 (61.61 kg/ha/day). Thus minimum yield reduction was recorded on 5 December sowing compare to normal sowing and remarkable yield reduction was started from 16 December sowing. Pavon 76 and BAW 1135 suffered more in post anthesis heat stress growing condition because of its susceptibility to heat stress than other two genotypes which resulted poor spike/ m2, less no of grain per spike and finally lower grain yield in heat stressed condition in relative to normal growing condition. High temperature decreased the photosynthetic rate, viable leaf area, shoot and grain mass, kernel weight and sugar content at maturity and reduced water use efficiency as demonstrated by Shah and Paulsen (2005). During grain development of wheat heat stress badly affect the starch content of grain which fallout in poor grain quality, grain size and yield as evaluated by Chinnusamy and Khanna-Chopra (2003).

3.9 Heat susceptibility index for grain yield

Heat susceptibility index based on grain yield varied in different wheat genotypes. According to the susceptibility index, BARI gom 26 (0.41) and BARI gom 25 (0.71) was found as heat tolerant genotype, between them BARI gom 26 was highly heat tolerant than other and Pavon 76 (1.61) and BAW 1135 (1.23) was observed as heat susceptible genotype. The heat susceptible index for grain yield revealed that grain yield was affected when temperature raises. Sharma et al. (2013) also found that heat susceptibility index values reduced more in grain yield in case of heat sensitive genotype (Raj 4014) than heat tolerant genotypes (DBW 14).

4 Conclusions

Under post anthesis heat stressed environment, negligible reduction of yield attributes *viz*. Number of number per m^{-2} and grain per spike finally has been reflected through higher relative seed yield in BARI gom 26 (89%) than Pavon 76 (56%). In major wheat growing areas where wheat cannot be accommodated due to short and warmer winter, the potentiality of BARI gom 26 can be tested.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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