

Yield Contributing Characters of Wheat under Normal and Heat Stress Conditions

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Received August 30, 2023

This study was conducted to identify yield and yield contributing attributes of wheat genotypes in response to heat stress. In this respect, eight wheat genotypes viz., Pavon-76, Prodip, BARI Gom-25, BARI Gom-26, BAW-1143, BAW-1146, BAW-1147 and BAW-118 were used as study materials. The experiment was evaluated in relation to heat tolerance in field condition by seeding them at November 27 (normal), December 17 (late) and January 7 (very late growing condition) over two successive years. Spike length, spike number per plant, floret number per spike and grain number per spike, floret/spike, spike dry weight and individual seed weight (seed size), grain yield, biological yield and harvest index were observed highest at normal growing condition. At late and very late growing heat stress conditions, all the genotypes showed reduced performance in those parameters at different magnitudes. Heat tolerant genotypes had higher relative values in those attributes than the MHT and heat sensitive genotype at late growing condition. Late and very late growing heat stress conditions increased the sterility in all the genotypes. HSI calculated in stress environments to assess their stress potential on the basis of grain yield. The HSI values of Prodip, BAW-1146, BAW-1147, BAW-1148 and Pavon-76 were higher than 1.0, indicating that these genotypes were susceptible to heat stress. The HSI values of the remaining three wheat genotypes indicate their various levels of tolerance to high temperature. Among them BARI Gom-25, BARI Gom-26 and BAW-1143 were tolerant to heat stress.

Key words: Heat stress, wheat, yield related characters

Wheat (*Triticum aestivum* L.) is a cereal crop, which belongs to the family Gramineae has grown worldwide for edible grains. Among cereals, wheat used by more than 36% of the world's population. Wheat has been grown in many countries for its versatile nature in adaptation and utility in innumerable ways (Singh *et al.*, 2020). Different yield related characters were identified as contributing to heat tolerance in wheat. The most responsive yield components are grain number per spike, grains per spikelet, grain weight, rate of grain filling, biomass at harvest (Zhong-hu and Rajaram 1994). In addition to these characters, other physiological characters like chlorophyll retention, stem reserves mobilization (Blum *et al.* 1994, Sikder and Paul 2010), canopy temperature depression (Reynolds *et al.* 1994; Sikder and Paul 2010) and stomatal conductance (Reynolds *et al.*, 1994) have been associated with performance of irrigated wheat under high temperature level which would be used as to identify comparatively tolerate genotypes. Heat stress due to late planting is the main reason for the lower yield per unit area in wheat (Hura, 2020; Tahir *et al.*, 2022). Heat stress during post-anthesis (grain-filling stage) affects availability and translocation of photosynthates to the development of kernels and starch synthesis and deposition within the kernel, thus resulting in lower grain weight and altered grain quality (Mohammadi *et al.* 2004). It has been observed that each degree rise in ambient temperature reduces the yield by 3-4% (Mishra 2007). In this regard, the present study was carried with the aim out to identify the wheat genotypes with tolerance to late planting heat under genotype by environment interactions, yield traits under different planting regimes.

MATERIALS AND METHODS

The experiment was conducted in the research field of Crop physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh from November to April of 2011-12 and 2012-2013. Eight genotypes viz. Prodip, BARI Gom-25, BARI Gom-26, BAW-1143, BAW-1146, BAW-1147, BAW-1148 and Pavon-76, was used as

experimental materials. The experimental design was a split plot with three sowing dates. Three main plots were considered as treatment plots. Each main plot was subdivided into three replication plots each of 4×2.5 m² containing all the eight genotypes assorted randomly. Seeds were sown on 27 November (Normal), 17 December (Late) and 7 January (Very late). Three irrigations were applied atCRI, flowering and grain filling stage. In each year, there were 9, 8 and 8 harvests for normal, late and very late growing conditions, respectively with equal intervals of 10 days and the first harvest was taken at 20 days after sowing (DAS). At each harvest, the plants were cut off at the ground level and the tops were separated into leaves, stem and panicle (if present).The harvested plant parts were kept in an electrical oven at about at 70° C for 72 hours and the dry weights of these parts were taken by an electrical balance and expressed in grams. Different yield characters were measured in following ways:

Number of spikes per plant

Number of spikes counted from ten random selected plants in each plot at harvest and the mean value was calculated.

Spike characteristics

Ten spikes were collected randomly from each plot and mean value was calculated to record the spike characteristics.

1. Spike length (excluding awn) -was measured manually using scale.

2. Number of spikelets per spike- number of florets per spike and spikelet, number of grains per spike and spikelet were counted manually and floret sterility (%) was calculated by using the following formula (Sikder 2011).

Floret sterility (%) = $[1 - (\text{No. of kernels/spike}) / (\text{No. of florets/spike})] \times 100$

3. Then the collected spikes were dried in an oven at 70° C for 72 hours. After drying the spikes were weighed and grains were separated from husk and weighed.

Spikelets spike⁻¹

Total number of spikelets spike⁻¹ was calculated and averaged from ten randomly selected plants from each

plot.

Number of kernel per spike

Number of kernel per spike was counted manually. Ten spikes were selected randomly from each plot and the average number of kernel per spike was calculated.

Seed size

From each plot a sub-sample of thousand grains were taken randomly from dried samples and the total weight was recorded by an electric balance. From the grain weight average seed size was calculated.

Biological yield and grain yield

The samples were collected from an area of 1 meter \times 1 meter from the centre of each plot by cutting the plant at the ground level and was collected in a cloth bag. The samples were dried in the sun, threshed and cleansed and dry weights of grain, straw and husk were recorded. The biological yield and grain yield were expressed in ton per hectare (t/ha). Grain yield was also adjusted to 12% moisture content.

Biological yield (t/ha) = straw yield + seed yield+ husk

Harvest index

Harvest index was calculated as the ratio of grain yield to biological yield (Donald and Hamblin 1976) and expressed in percentage. The harvest index was worked out as indicated below.

HI (%) = Grain Yield/Biological Yield \times 100

Heat susceptibility index

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

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

Where,

Y = Yield of a genotype in a stress environment

Y_p = Yield of a genotype in a stress-free environment

X = Mean of Y of all the genotypes

X_p = Mean of Y_p of all the genotypes.

(S < 1.0, stress tolerant and S > 1.0, stress susceptible)

Statistical analysis

The data were analyzed by partitioning the total variance with the help of computer by using MSTAT-C

computer package (Russell, 1994). The treatment means were compared using Duncan's Multiple Range Test (DMRT) (Duncan, 1955) at $P \leq 0.05$. Correlation and Regression analysis was also done and level of significance was tested with t-test (Singh and Choudhary 1985).

RESULTS AND DISCUSSION

Spike length

The spike length of eight wheat genotypes at different growing conditions is presented in Tables 1 and 2 for 2011-12 and 2012-13, respectively. Under normal growing condition, the highest spike length was found in BAW 1143 (11.21cm and 12.17 cm for first and second year, respectively). Pavon-76 obtained the lowest value of spike length (9.80cm) for first year and 9.85 cm was in second year.

Under very late growing condition, HT genotype BAW-1143 showed the highest spike length (9.88 cm and 9.90 cm for first and second year, respectively) which was statistically similar with the other HT genotypes (BARI Gom-26, BARI Gom-25 and Prodig). HS genotype Pavon-76 had the lowest spike length (6.42cm and 7.50 cm for first and second year, respectively).

Under late and very late growing conditions, the spike length of all the genotypes was significantly more reduced compared to normal and late growing conditions. But the magnitudes of reduction were different among the genotypes.

Spike length was reduced when it was grown in high temperature and high temperature resulted in smaller organs. Hossain *et al.* (2012a) found that in stress conditions all the genotypes had shorter spikes. It was due to low air and soil temperature from sowing to vegetative stages of the normal sowing crop and high temperature to reproductive stages of the late and very late sowing conditions. This reduction was occurred due to high temperature as it reduces the life span of wheat.

Number of spikes per plant

The number of spikes per plant of eight wheat genotypes at different growing conditions is shown in Tables 3 and 4 for first and second year, respectively. The interaction effect of growing conditions and genotypes significantly influenced the spike number per

plant.

Under normal growing condition, HT genotype BAW-1143 had the highest spike number per plant (7.53 and 7.63 for first and second year, respectively), which was statistically similar to BARI Gom-26, BARI Gom-25 and Prodip for both the years. Genotypes BAW-1146, BAW-1147 and BAW-1148 were statistically similar for both the years. However, Pavon-76 attained the lowest spike number (4.70 and 5.02 for first and second year, respectively).

Under late growing condition, HT genotype BAW-1143 had the highest spike number per plant (7.12 and 6.53 for the first and the second year, respectively), which was statistically similar to BARI Gom-26 for first year and for second year it was at par with all genotypes except Pavon-76. Pavon-76 attained the lowest spike number (4.11 and 4.45 for the first and second year, respectively).

At very late growing condition, the spike number per plant of all the genotypes was decreased. In this heat stress condition, the HT genotype BAW-1143 attained height number of spike per plant (6.60 and 5.72 for the first and second year, respectively). Whereas, genotype Pavon-76 had the lowest number of spike per plant (3.72 and 3.74 for the first and second year, respectively). At this heat stress condition, all the genotypes reduced their number. But these values were highest in Pavon-76 (20.85% and 25.50 % for the first and second year, respectively).

The economic yield of most cereals is determined by the number of productive spikes. Number of spikes depends on the genotype and on the conditions to which the crop is exposed during growth. The general hypothesis is that plants in their initial stages of development may adapt more easily to their environment.

The significant difference in number of spikes among genotypes is the genetic background of the varieties and the conditions to which the crop is exposed during growth. Late planting suffered mostly due to a drastic reduction in ear. Hossain *et al.* (2011) observed that number of spikes of wheat genotypes was reduced in Late sowing date and very late sowing date due to low temperature stress at the tillering stage (vegetative

stage).

Results from other studies showed that spike number per plant was not significantly influenced by late sowing (Hasan *et al.* 2007). Hu and Rajaram (1994) reported that ear number per plant was less sensitive while the yield, grain per ear, biomass and plant height were more sensitive to high temperature. Shanahan *et al.* (1990) stated that heat tolerant genotypes were associated with productivity under extreme temperature.

Number of florets per spikelet

Results showed that number of florets per spikelet varied significantly by the combined effect of sowing times and genotypes (Tables 5 and 6) for the first year and the second year, respectively). Under normal growing condition, there were no significant differences among

However, the HT genotype BAW-1143 had the highest floret number per spikelet (4.98 for first year and 4.90 for second year) and the lowest in Pavon-76 (4.15 for first and 4.17 for second year).

At late growing condition, floret number per spikelet in genotypes Prodip, BARI Gom-25, BARI Gom-26, BAW-1143 and BAW-1146 were statistically similar but it was highest in BAW-1143 (4.75 for first year and 4.78 for second year) and genotype Pavon-76 had the lowest value (3.75 for first year and 3.76 for second year).

Under very late growing condition, all the genotypes reduced their floret number per spikelet at different degrees. But only the HS genotype Pavon-76 significant reduced their floret number per spikelet (3.20 for first year and 3.29 for second year).

Reduction from normal to late growing condition Pavon-76 showed the highest value (21.69% and 21.10% for first and second year, respectively). Genotype BAW-1143 reduced the lowest (13.65% and 11.63% for first and second year, respectively).

In relative performance to normal growing condition, HT genotypes BAW-1143, BARI Gom-25, BARI Gom-26 and Prodip showed the higher relative value for florets number per spikelet (86.35% to 80.85% and 88.37% to 81.09% for the first and second year, respectively).

This trial extremely reduced by delayed planting. Significant reduction in floret number per spikelet in wheat was reported by Shpilar and Blum (1991). A

similar response has been reported for wheat by Mohammad *et al.* (2011).

Number of florets per spike

The interaction effect of growing condition and genotype on floret number per spike was significant for both the years. The floret number per spike of eight genotypes at different growing conditions is shown in Table 7 and 8 for the first and second year, respectively. Under normal growing condition, BAW-1143 had the highest floret number per spike (92.50 and 92.22 for the first year and second year, respectively) Statistically similar data was found in genotypes BARI gom-25, BARI gom-26 and Prodip (89.88, 90.13; 89.21 for the first year) and in second year it was 89.03, 91.31 and 86.87 respectively). The lowest value was found in HS genotype Pavon-76 (72.09 and 73.27 for the first and second year, respectively).

Under late growing condition all the wheat genotypes showed reduced floret number per spike compared to normal growing condition. At this growing condition, the floret number per spike BAW-1143 (87.02 and 88.72 for the first and second year, respectively) had the highest floret number per spike and Pavon-76 showed the lowest value (64.10 and 62.04 for the first and second year, respectively).

Under very late growing condition, the floret number per spike of all genotypes (both HT and the HS) significantly reduced compared to normal and late growing conditions. The reduction of floret number per spike of HT genotypes BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip were lower compared to HS genotype. At this heat stress growing condition, the HT genotype BAW-1143 attained the highest floret number per spike (75.55 and 77.16 for the first and second year, respectively) while the HS genotype Pavon-76 had the lowest floret number spike (48.56 and 50.50 for the first and second year, respectively). In this heat stress condition, HS genotype Pavon-76 showed the highest (32.64) reduction for both the first and second year. Other MHT genotypes reduced at the same rate such as BAW-1146 (32.54% and 26.50% for the first and second year respectively), BAW-1147 (31.56% and 25.06% for the first and second year, respectively).

In relative performance HT genotype BAW-1143, BARI Gom-25, BARI Gom-26 and Prodip attained higher

relative values for both the years (81.68% to 71.98% and 83.67% to 73.18% for the first and second year, respectively; Figure 1) compared to HS genotypes Pavon-76 and MHT genotypes BAW-1148 (67.36% to 71.65% and 71.65 % to 70.64% for the first and second year, respectively).

Spike condition is one of the yield components that have most affect on grain yield. Floret per spike extremely reduces by delayed planting. Significant reduction in floret number per spike in wheat was reported by Shpilar and Blum (1991). A similar wheat response has been reported for winter wheat by Blue *et al.* (1990). Floret per spike showed significant variations among the genotypes of wheat (Mohammad *et al.* 2011).

Number of grains per spikelet

The number of grains per spikelet of eight wheat genotypes at different growing conditions is shown in Tables 9 and 10 for the first and second year, respectively. Results showed that the growing conditions significantly influenced grain number per spikelet. Under normal growing condition, the heat tolerant genotypes BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip performed better compared to the MHT genotypes BAW-1146, BAW-1147, BAW-1148 and HS genotype Pavon-76 for both the years. In this growing condition, genotype BAW-1143 attained the heigher number of grains per spikelet (3.23 and 3.30 for the first and the second year, respectively) which was followed by BARI gom-26 BARI gom-25 and Prodip in both the years (3.15, 3.16, 3.10 and 3.13, 3.05, 3.08 for the first and the second year, respectively) and the lowest number of grains per spikelet was in Pavon-76 (2.60, 2.63 for the first and the second year, respectively).

Under late growing condition, number of grains per spikelet was reduced in HT, MHT and HS genotype. Genotype BAW-1143 attained the highest grain number per spikelet (3.13 and 3.16 for first and second year, respectively) and it was the lowest in Pavon-76 (2.40 and 2.44 for first and second year, respectively).

Under very late growing condition, both the HT and HS genotypes showed much reduced their grain number per spikelet compared to normal and late growing condition. This reduction was not statistically significant but there were wide variations among the different

genotypes 8.05 to 12.69% and 8.54 to 12.93% for the first and the second year, respectively).

In this heat stress condition, all the four HT genotypes showed statistically higher grain number per spikelet compared to HS genotype Pavon-76.

In relative performance HT genotypes BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip attained higher relative value in grain number per spikelet for both the years (87.31% to 91.95% and 90.30 % to 91.46% for the first and the second year respectively).

The yield reduction of wheat under high temperatures is associated with a less number of grains/spike and smaller grain size (Gibson and Paulsen, 1999). In late and very late conditions, higher temperature during anthesis and maturity period reduced the number of grains spikelet¹.

Floret sterility

Results of floret sterility with interaction effect of growing conditions and genotypes is shown in Tables 11 and 12 for first and second year, respectively. In normal growing condition, the HS Pavon-76 had comparatively higher (41.05% and 36.93 % for first and second year, respectively) floret sterility than the heat tolerant genotypes BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip. Therefore, the late and very late growing condition increased the sterility in all the genotypes (both the HT and HS). But the degree of increment among the genotypes was varied. These increments were significant for all the genotypes. In case of relative change to normal sowing, the HS genotypes Pavon-76 had higher value compared to the HT genotypes BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip

There were wide variations in floret sterility among the eight genotypes. This was due to their genetic character. Late growing post-anthesis heat stress condition increased the sterility in all the genotypes. But the degree of increment was higher in the HS genotype (Pavon-76) and MHT genotypes (BAW-1146, BAW-1147 and BAW-1148) compared to the heat tolerant genotypes (BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip). At late planting wheat floret fertility was increased because stress during microspirogenesis is due to loss of pollen viability. Similar results were observed in several grain crops (Djanaguiraman *et al.*

2014). High temperature causes structural and functional abnormalities in reproductive organs, which leads to failure of fertilization or premature abortion of seed (Saini and Aspinall (1982). Late sowing showed higher grain abortion than the optimum sowing because of comparatively higher temperature at the grain filling stage. The decreased floret fertility may be due to poor pollen tube growth, leading to unsuccessful fertilization. Higher temperature affects translocation of nutrients to the developing pollen grains, leading to loss of pollen viability (Hess and Hesse 1994).

Seed size

The individual seed size of eight wheat genotypes at different growing conditions is presented in Table 13 and 14 for the first and second year, respectively. The interaction effect of growing conditions and genotypes statistically influenced the individual grain size. Heat tolerant genotypes attained higher grain size than the heat sensitive genotypes in both the growing conditions. Under normal growing condition, BAW-1143 had the highest grain size (49.90 mg/grain and 49.95 mg/grain for the first and second year, respectively) and Pavon-76 obtained the lowest grain size (41.40 mg/grain and 41.42 mg/grain for the first and the second year, respectively). Genotypes BARI Gom-26, BARI Gom-25 and Prodip attained statistically similar grain size but in the second year it was slightly higher than the first year because at second year the temperature was lower than first year and yield was higher.

At late and very late growing conditions, all the genotypes significantly reduced their grain size compared to normal growing condition. In this heat stress growing condition, again the HT genotype BAW-1143 had the highest seed size and HS genotype Pavon-76 showed the lowest grain size. BARI Gom-26, BARI Gom-25 and Prodip gave statistically similar grain size at heat stress condition. Though all the genotypes reduced their grain size at heat stress condition but the degree of reduction varied among the genotypes. Comparatively HT genotypes (BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip) showed lower reduction than the heat sensitive genotypes BAW-1146, BAW-1147, BAW-1148 and Pavon-76 .

Regarding reduction for individual seed size, the HT genotypes had lower value than the HS ones. Seed size of wheat genotypes decreased when exposed to heat stress due to high temperature stress (Hossain *et al.* 2012a and 2012b).

Reduced grain size under heat stress condition might be due to the rapid reduction in grain growth duration. Net effect of heat stress in the grain filling period was lower grain weight due to the reduction in grain filling period, grain filling rate or combined effect of both (Tashiro and Wardlaw, 1989).

Delayed sowing shortens the duration of each developmental phase, which ultimately reduces grain filling period and lowers the grain weight (Spink *et al.*, 2000).

Grain yield

Grain yield of eight wheat genotypes at different growing conditions is shown in Tables 15 and 16 for the first and second year, respectively. The interaction effect of growing conditions and genotypes significantly influenced the grain yield. HT genotype BAW-1143 showed statistically highest grain yield, whereas HS genotype Pavon-76 had the lowest grain yield in each growing condition. The highest grain yields of BAW-1143 were 4.5, 3.82, and 2.61 t ha⁻¹ at the normal, late and very late growing conditions, respectively for the first year. And second year these were 4.80, 3.87 and 2.75 t ha⁻¹ at the normal, late and very late growing conditions, respectively. Whereas, the lowest grain yields of Pavon-76 were 3.15, 2.62 and 1.13 t ha⁻¹ at the normal, late and very late growing conditions, respectively for the first and at the second year these were 3.25, 2.65 and 1.16 t ha⁻¹ at the normal, late and very late growing, respectively. Genotypes BARI Gom-26, BARI Gom-25 and Prodip attained statistically similar grain yield in each the growing conditions at first year. In second year statistically similar grain yields were found in genotypes BARI Gom-25 and Prodip.

At late growing condition, all the genotypes showed reduced grain yield but the magnitude of reductions were different among the genotypes. Comparatively HT genotypes BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip showed lower reduction in grain yield than the MHT genotypes BAW-1146, BAW-1147 and BAW-1148 and HS genotype Pavon-76.

At very late growing condition, the grain yield of all the genotypes was reduced more. Comparatively HT genotypes BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip (42.00% to 50.97 and 42.71% to 50.59% for the first and second year, respectively) showed lower reduction of grain yield than the MHT genotypes and HS genotype Pavon-76.

Regarding relative performance, HT genotypes BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip also attained higher relative grain yield (49 to 58 % for both the year) than the HS genotypes Pavon-76.

In the present study, yield components were significantly affected by growing conditions. In high temperature, the yield reduction was found the higher in all genotypes compared to optimum sowing. Results from other studies showed that in case of late sowing climate and soil moisture were unfavourable (high temperature, low relative humidity in the air and low soil moisture) for crop production, which ultimately affected crop growth and yield (Hossain *et al.*, 2012 d). This assumption is also supported by Grigorova *et al.*, (2011) who stated that the combined effects of drought and high temperature on physiology, growth, water relations, and yield are significantly higher than the individual effects. Bhatta *et al.*, (1994) reported that some genotypes of wheat showed stability in grain yield between optimum and late planting. In sub-tropical climates like Bangladesh, excess radiation and high temperatures are often the most limiting factors affecting plant growth and final grain yield (Wahid *et al.*, 2007; Hossain *et al.*, 2009; Nahar *et al.*, 2010; Hossain *et al.*, 2011; Sikder, 2011 and Hakim *et al.*, 2012).

However, genetic effects are not independent of environmental effects; most genotypes do not perform satisfactorily in all environments. When an interaction between a genotype and the environment occurs, the relative ranking of genotypes for yield often differs when genotypes are compared over a series of environments and/or years (Al-Otayk, 2010).

In Bangladesh, early wheat faces high temperature stress at the vegetative stage and late sowing wheat is affected at two stages: germination by low temperature stress (<10°C) and at the reproductive stage by high temperature (>25°C), which ultimately affects grain yield (Hossain *et al.*, 2011; 2012a).

A negative linear relationship between grain yield and mean temperature was found in the present study (Figure 1). The results; therefore, show the dramatic effect to high temperature. This decline was associated with a decrease in grain yield from 0.50 t/ha by increasing 1°C temperature in first year and in second year it was 0.343 t/ha. Grain yield was reduced by 3-4% per spike for each 1°C rise in average mean air temperature above the optimum (15°C) (Wardlaw *et al.*, 1989).

Biological yield

Growing conditions and genotypes interacted significantly to govern the biological yield results are presented in Tables 17 and 18 for the first and second year, respectively. Irrespective of growing conditions there were significant variations among the genotypes. Under normal growing condition, genotype BAW-1148 had the highest biological yield (14.50 t/ha and 14.65 t/ha for the first and second year, respectively) followed by BAW-1147 (14.27 t/ha and 14.51 t/ha for the first and second year, respectively) and BAW-1146 (14.24 t ha-1 and 14.22 t ha-1 for the first and second year, respectively). Genotypes BARI Gom-26, BARI Gom-25 and Prodip showed statistically similar value of biological yield for the first year and in second year, BARI Gom-26 and BARI Gom-25 were statistically similar. In this growing condition, HS genotype Pavon-76 had the lowest biological yield (10.88 t ha-1 and 12.15 t ha-1 for the first and second year, respectively).

Under late growing condition, the genotype BAW-1146 had the highest biological yield (12.76 t/ha) for the first year which was at par with BAW-1147(12.65 t ha-1) and BAW-1148 (11.80 t ha-1) but in second year BAW-1148 (12.75 t ha-1) had the highest value. In this growing condition, HS genotype Pavon-76 also had the lowest biological yield (8.15 t ha-1 and 9.95 t ha-1 for the first and second year, respectively) like normal growing condition.

Under very late growing condition, biological yields of all genotypes were reduced by different magnitude. The genotype BAW-1148 had the highest biological yield (7.96 t/ha) for the first year which was at par with BAW-1147(7.91 t ha-1 a) and BAW-1146 (7.76 t ha-1). In second year BAW-1147 had the highest biological yield

(8.05 t ha-1) which was at par with BAW-1146, BAW-1143 and BAW-1148. In this heat stress growing condition, HS genotype Pavon-76 also had the lowest biological yield (5.03 t ha-1 and 5.15 t ha-1 for the first and second year, respectively).

From the observed data it was found that at very late growing condition, the biological yield of all the genotypes was significantly reduced at different magnitudes. This reduction was lower (34.52% to 44.45% and 33.74 % to 44.05% for the first and second year, respectively) in heat tolerant genotypes compared to heat sensitive genotype (56.36 % and 57.61% for the first and second year, respectively).

Higher relative performances were in heat tolerant genotypes to MHT and heat sensitive genotypes.

From the observed data, it was found that at late sowing condition the biological yield of all the varieties are significantly reduced at different degrees. Early sowing resulted in higher straw yield due to more number of tillers. These results are in agreement with those of Matuz and Aziz (1991). Kumar *et al.*, (1994) reported that the straw yield decreased probably due to the fact that plant got unfavorable environment (high temperature) at vegetative stage, as a result crop became thinned and produced less tillers which in turn decreased the straw yield. Bhatta *et al.* (1994) reported reduced biological yield under high temperature. Hu and Rajaram (1994) concluded that biomass could be considered as a potential criterion for heat tolerance of wheat. Hossain and Teixeira da Silva (2012); Hossain *et al.* (2012a); Hossain *et al.* (2012b) Hossain *et al.*(2012c) and Hossain *et al.* (2012d) noticed that when wheat was grown from sowing to maturity at high temperatures, phenological development was rapid, leading to poor biomass production and consequently poor biological yield.

Harvest index (HI)

As a useful index of assessing the phytomass converted into useful economic yield, the harvest index was significantly influenced by the combined effect of growing conditions and genotypes and it is presented in Table 19 and 20 for first and second year, respectively. There existed significant variation among the different genotypes in each growing conditions.

Under normal growing condition, the heat tolerant genotypes BARI Gom-26, BARI Gom-25 and Prodip attained statistically similar harvest index. However, BAW-1143 had the highest HI (40.13% and 42.29 % for first and second year, respectively), whereas heat sensitive genotype Pavon-76 showed the lowest HI (28.96% and 29.15 % for first and second year, respectively).

Under late growing heat stress condition the harvest index of all the genotypes were reduced compared to normal and late growing conditions. But the reductions were different among the genotypes.

Under very late growing heat stress growing condition, the harvest index of all the genotypes was reduced compared to normal growing condition. But the degrees of reductions were different among the different genotypes. In this heat stress condition, the HI values for BAW-1143, BARI Gom-26, BARI Gom-25, Prodip, BAW-1146, BAW-1147, BAW-1148 and Pavon-76 were 36.135, 32.03, 31.56, 28.20, 25.17, 24.12, 23.16 and 24.85%, respectively in first year and in the second year the corresponding values were 28.61, 31.87, 32.54, 36.57, 26.72, 24.82, 23.40, and 22.52 %, respectively.

Table 1: Spike length of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	Spike length (cm)			Reduction (%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	10.35b	9.25def	8.40g	18.84
BARI Gom-25	10.4b	9.30de	8.44fg	10.58
BARI Gom-26	10.5ab	9.35ce	8.75eg	16.67
BAW-1143	11.21a	10.25b	9.88bd	11.86
BAW-1146	10.25b	8.22g	7.30h	28.78
BAW-1147	10.15bc	8.25g	7.25h	28.57
BAW-1148	10.05bd	8.30g	7.20h	28.36
Pavon-76	9.80bd	8.21g	7.12i	27.35
CV (%)	5.00			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 2: Spike length of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	Spike length (cm)			Reduction (%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	11.25b	10.05ef	8.92gh	20.71
BARI Gom-25	11.06bc	10.25ef	8.86gi	19.89
BARI Gom-26	11.17b	10.12ef	9.25g	17.19
BAW-1143	12.17a	10.87bd	9.90ef	18.65
BAW-1146	10.50ce	8.75gi	7.65j	27.14
BAW-1147	10.35df	8.5hi	7.62j	26.38
BAW-1148	10.15ef	8.47hi	7.55j	25.62
Pavon-76	9.85f	8.27i	7.50j	23.86
CV (%)	5.21			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 3: Number of spike per plant of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	Number of spike per plant			Reduction (%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	7.00ab	6.76b	5.80ef	17.14
BARI Gom-25	7.05ab	6.82b	5.85ef	17.02
BARI Gom-26	7.12ab	6.85ab	5.90df	17.13
BAW-1143	7.53a	7.12ab	6.60bd	12.35
BAW-1146	6.70bc	5.71ef	5.58ef	16.77
BAW-1147	6.60bd	5.62ef	5.48ef	16.97
BAW-1148	6.50bd	5.78ef	5.28fg	18.77
Pavon-76	4.70gh	4.11hi	3.72i	20.85
CV (%)	6.00			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 4: Number of spike per plant of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	Number of spike per plant			Reduction (%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	7.05ab	5.95ad	5.32bd	24.54
BARI Gom-25	7.15ab	6.05ac	5.35bd	25.17
BARI Gom-26	7.25ab	6.15ac	5.55ad	23.45
BAW-1143	7.63a	6.53ac	5.72ad	25.03
BAW-1146	6.82ab	5.83ad	5.25bd	23.02
BAW-1147	6.72ac	5.72ad	5.15bd	23.36
BAW-1148	6.55ac	5.81ad	5.00bd	23.66
Pavon-76	5.02bd	4.45cd	3.74d	25.50
CV (%)	6.25			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 5: Number of floret per spikelet of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	No. of floret per spikelet			Reduction(%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	4.75ac	4.60ac	3.84eh	19.15
BARI Gom-25	4.80ac	4.63ac	3.88eh	19.16
BARI Gom-26	4.88ab	4.68ac	3.92dh	19.67
BAW-1143	4.98a	4.75ac	4.30bf	13.65
BAW-1146	4.55ad	4.35af	3.65gi	19.78
BAW-1147	4.43ae	4.31bf	3.60hi	18.74
BAW-1148	4.35af	4.25bg	3.55hi	18.39
Pavon-76	4.15ch	3.75fi	3.20i	21.69
CV (%)	7.82			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 6: Number of floret per spikelet of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	No. of floret per spikelet			Reduction(%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	4.76a	4.63ab	3.86fg	18.91
BARI Gom-25	4.82a	4.66ab	3.90eg	19.09
BARI Gom-26	4.87a	4.72a	3.93bg	19.30
BAW-1143	4.90a	4.78a	4.33ad	11.63
BAW-1146	4.66ab	4.37ad	3.85cg	17.38
BAW-1147	4.52ac	4.32ad	3.82cg	15.49
BAW-1148	4.45ad	4.27ae	3.50eg	21.35
Pavon-76	4.17af	3.76dg	3.29g	21.10
CV (%)	6.56			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 7: Number of floret per spike of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	No. of floret per spike			Reduction(%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	89.21b	80.78ef	62.82kl	29.58
BARI Gom-25	89.88b	83.78d	63.83jk	28.98
BARI Gom-26	90.13b	85.13d	64.88j	28.02
BAW-1143	92.50a	87.02c	75.55h	18.32
BAW-1146	85.22d	80.60g	57.49m	32.54
BAW-1147	82.22e	77.32g	56.27m	31.56
BAW-1148	80.38f	75.48k	54.24n	32.52
Pavon-76	72.09i	64.10l	48.56o	32.64
CV (%)	3.27			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 8: Number of floret per spike of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	No. of floret per spike			Reduction(%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	86.87cd	81.63ef	63.57km	26.82
BARI Gom-25	89.03bc	84.30de	64.82kl	27.19
BARI Gom-26	91.31ab	86.23cd	65.91k	27.82
BAW-1143	92.22a	88.72bc	77.16hi	16.33
BAW-1146	84.58de	78.31gh	62.17lm	26.50
BAW-1147	81.81ef	76.81hi	61.31m	25.06
BAW-1148	80.32fg	74.98ij	60.74n	24.38
Pavon-76	73.27j	62.04lm	50.50o	31.08
CV (%)	4.23			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 9: Number of grains per spikelet of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	No. of grains per spikelet			Reduction(%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	3.05ad	2.90bf	2.76dh	9.51
BARIGom-25	3.10ac	2.96ae	2.82cg	9.03
BARIGom-26	3.15ab	2.98ae	2.87bf	8.89
BAW-1143	3.23a	3.13abc	2.97ae	8.05
BAW-1146	2.85bg	2.76dh	2.54gj	10.88
BAW-1147	2.82cg	2.73eh	2.55gj	11.35
BAW-1148	2.83cg	2.70eh	2.50hj	12.50
Pavon-76	2.60fi	2.40ij	2.27j	12.69
CV (%)	5.71			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 10: Number of grains per spikelet of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	No. of grains per spikelet			Reduction(%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	3.08ab	2.96ab	2.77ab	10.06
BARIGom-25	3.13ab	2.98ab	2.84ab	9.27
BARIGom-26	3.16ab	3.00ab	2.89ab	8.54
BAW-1143	3.30a	3.16ab	2.98ab	9.70
BAW-1146	2.90ab	2.80ab	2.57ab	12.59
BAW-1147	2.94ab	2.78ab	2.56ab	11.72
BAW-1148	2.89ab	2.73ab	2.54ab	12.11
Pavon-76	2.63ab	2.44ab	2.29b	12.93
CV (%)	6.77			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 11: Floret sterility (%) percentages of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	Floret sterility (%)			Differences of sterility (%)
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	34.85 fi	35.65hj	37.74bc	+3.00
BARI Gom-25	36.20ij	37.60gi	40.38cd	+3.31
BARI Gom-26	35.49ij	36.73 fi	42.94 de	+2.65
BAW-1143	33.84l	34.62k	36.32jk	+2.48
BAW-1146	38.51eh	39.35de	40.67b	+3.17
BAW-1147	36.39jk	39.50de	39.58de	+3.19
BAW-1148	35.62k	38.91eg	39.16df	+3.57
Pavon-76	41.05bc	41.34bc	45.43a	+4.38
CV (%)	3.74			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 12: Floret sterility (%) percentages of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	Floret sterility (%)			Differences of sterility (%)
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	35.29df	36.08cf	38.32be	+3.03
BARI Gom-25	35.31df	36.05cf	37.49bf	+2.18
BARI Gom-26	35.11df	36.44cf	36.75cf	+1.64
BAW-1143	32.59f	33.89f	35.07ef	+2.48
BAW-1146	37.76bf	35.10ef	41.50ab	+3.74
BAW-1147	34.03ef	34.85ef	41.33ab	+7.30
BAW-1148	35.68df	35.20df	42.08ab	+6.40
Pavon-76	36.93bf	34.72ef	44.73a	+7.80
CV (%)	6.55			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 13: Seed size of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	Seed size(mg/grain)			Reduction(%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	48.00d	43.55n	37.25r	22.40
BARI Gom-25	48.25c	43.60ij	37.56h	22.16
BARI Gom-26	48.60b	43.70ij	38.15p	21.50
BAW-1143	49.90a	44.30h	40.00o	19.84
BAW-1146	47.50e	43.40j	36.25s	23.68
BAW-1147	46.80f	42.40k	35.40t	24.36
BAW-1148	46.50g	41.80l	35.00u	24.73
Pavon-76	41.40m	38.50p	30.20t	27.05
CV (%)	1.35			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 14: Seed size of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	Seed size(mg/grain)			Reduction(%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	48.15ab	43.57ad	37.29be	22.55
BARI Gom-25	48.30ab	43.62ad	37.58be	22.19
BARI Gom-26	48.62ab	43.73ad	38.17be	21.49
BAW-1143	49.95a	44.32ad	40.10be	19.72
BAW-1146	47.56abc	43.47ad	36.35ce	23.57
BAW-1147	46.82ad	42.45ae	35.47de	24.24
BAW-1148	46.52ad	41.86ae	35.05de	24.66
Pavon-76	41.42ae	38.53ae	30.24e	26.99
CV (%)	9.29			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 15: Grain yield of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	Grain yield (t/ha)			Reduction (%) at very late growing condition compared to normal	Heat susceptibility index (S)
	Normal growing condition	Late growing condition	Very late growing condition		
Prodip	4.14abcd	3.52fh	2.03j	50.97	1.01
BARI Gom-25	4.23abc	3.68eg	2.13j	49.65	0.98
BARI Gom-26	4.32ab	3.71eg	2.21j	48.84	0.97
BAW-1143	4.50a	3.82df	2.61i	42.00	0.81
BAW-1146	4.05be	3.50fh	1.95j	51.85	1.02
BAW-1147	3.96be	3.41gh	1.91j	51.77	1.02
BAW-1148	3.87cf	3.36gh	1.85j	52.20	1.03
Pavon-76	3.15h	2.62i	1.13k	64.13	1.27
CV (%)	6.93				

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 16: Grain yield of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	Grain yield (t/ha)			Reduction(%) at very late growing condition compared to normal	Heat susceptibility index (S)
	Normal growing condition	Late growing condition	Very late growing condition		
Prodip	4.25bc	3.55fg	2.10kl	50.59	1.00
BARI Gom-25	4.32bc	3.70ef	2.25jk	47.92	0.95
BARI Gom-26	4.38b	3.75e	2.31j	47.26	0.94
BAW-1143	4.80a	3.87de	2.75i	42.71	0.85
BAW-1146	4.25bc	3.52g	2.10kl	50.59	1.00
BAW-1147	4.15c	3.43g	1.95lm	53.01	1.05
BAW-1148	3.95d	3.38gh	1.87m	52.66	1.04
Pavon-76	3.25h	2.65i	1.16n	64.31	1.27
CV (%)	3.05				

Mean followed by same letter(s) did not differ significantly at 5% level of significance

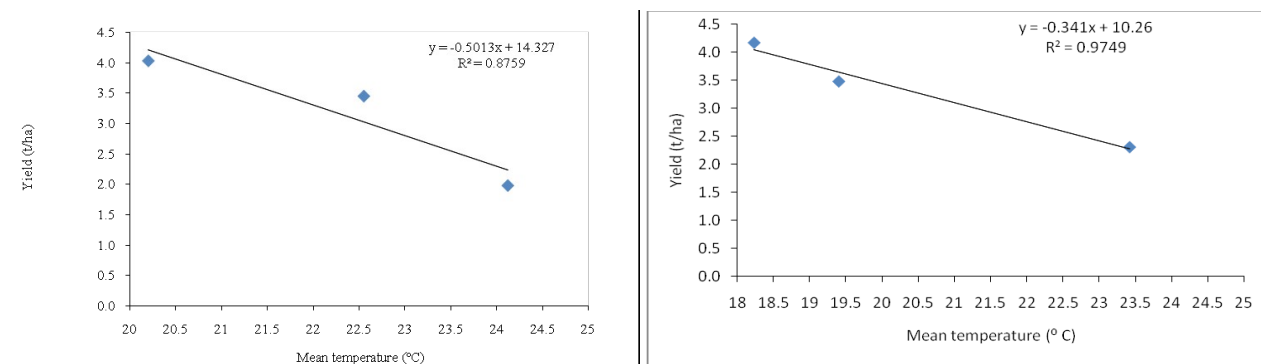
**Figure 1.** Effect of mean temperature on grain yield (left graph for 2011-12 and right for 2012-13).

Table 17: Biological yield of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	Biological yield (t/ha)			Reduction(%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	12.90bd	10.01fg	7.40h	42.63
BARI Gom-25	12.17ce	10.15fg	6.76hi	44.45
BARI Gom-26	12.23cd	10.76ef	6.88hi	43.74
BAW-1143	11.21cf	9.56h	7.31h	34.52
BAW-1146	14.24ab	12.76ac	7.76h	45.50
BAW-1147	14.27ab	12.65ad	7.91h	44.56
BAW-1148	14.50a	11.80gh	7.96h	45.10
Pavon-76	10.88df	8.15h	5.03j	56.36
CV (%)	9.12			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 18: Biological yield of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	Biological yield(t/ha)			Reduction(%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	13.12b	11.82de	7.34gh	44.05
BARI Gom-25	12.30cd	11.76de	7.06h	42.60
BARI Gom-26	12.26cd	11.65de	7.10h	42.09
BAW-1143	11.35e	10.52f	7.52gh	33.74
BAW-1146	14.22a	11.75de	7.86g	44.73
BAW-1147	14.51a	12.25cd	8.05g	44.52
BAW-1148	14.65a	12.75bc	8.00g	45.39
Pavon-76	12.15cd	9.95f	5.15i	57.61
CV (%)	3.85			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 19: Harvest index (%) of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	Harvest index (%)			Relative change to normal (%)
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	32.09e	29.30de	28.23de	-12.06
BARI Gom-25	34.75b	33.65c	31.56c	-9.15
BARI Gom-26	35.32b	34.47b	32.03c	-9.31
BAW-1143	40.13a	37.26b	36.15b	-7.41
BAW-1146	28.43de	27.41de	25.17fg	-11.47
BAW-1147	27.74de	26.96df	24.12g	-13.05
BAW-1148	26.67ef	24.35g	23.16g	-13.16
Pavon-76	28.96d	25.81fg	22.47fg	-14.19
CV (%)	3.80			

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Table 20: Harvest index (%) of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	Harvest index (%)			Relative change to normal (%)	Differences of harvest index (%)
	Normal growing condition	Late growing condition	Very late growing condition		
Prodip	32.39cde	30.03ef	28.61eg	-11.67	-3.78
BARI Gom-25	35.12bd	31.46de	31.87de	-9.25	-3.25
BARI Gom-26	35.73bd	32.19ce	32.54be	-8.93	-3.19
BAW-1143	42.29a	36.79b	36.57bc	-13.53	-5.72
BAW-1146	29.89ef	29.96ef	26.72fh	-10.61	-3.17
BAW-1147	28.60eg	28.00eg	24.82gh	-13.22	-3.78
BAW-1148	26.96fh	26.51fh	23.40h	-13.20	-3.56
Pavon-76	29.15ef	26.63fh	22.52h	-22.74	-6.63
CV (%)	7.78				

Mean followed by same letter(s) did not differ significantly at 5% level of significance

Harvest index has been reported as a key parameter for crop yield predictions since it determines the physiological efficiency of the crop to mobilize photosynthates and transport it to organs of economic value (Mushtaq *et al.* 2011). It is influenced by genotypic and environmental conditions. In the present study, lower HI at late sowing condition was due to lower grain yield and biological yield at the late sowing condition. These results are similar with the findings of Bahar *et al.* 2011. These results provide a suggestion that harvest index could be used as an indirect selection criterion for wheat genotype under heat stress environments.

Heat susceptibility index (HSI)

HSI calculated separately on the basis of grain yield in different stress environments to assess their stress potential. In this study, the HSI of Prodip, BAW-1146, BAW-1147, BAW-1148 and Pavon-76 were higher than 1.0, indicating that these genotypes were susceptible to heat stress (Tables 15 and 16). The HSI values of the remaining three wheat genotypes indicate their various levels of tolerance to high temperature.

From heat susceptibility index based on grain yield it was found that BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip had lower heat susceptibility ($S < 1.0$) than Pavon-76, BAW-1146 and BAW-1147 ($S > 1.0$) and it was regarded that BAW-1143, BARI Gom-26, BARI Gom-25 and Prodip were comparatively heat tolerant than BAW-1146, BAW-1147, BAW-1148 and Pavon-76.

Among them BARI Gom-25 (HSI = 0.98 for first year

and HSI = 0.95 for second year), BARI Gom-26 (HSI = 0.97 for first year and HSI = 0.94 for second year) and BAW-1143 (HSI = 0.81 for first year and HSI = 0.85 for second year) were tolerant to heat stress.

The importance of HSI in agriculture has been designated by several researchers. It sometimes represents a measure of genotypic yield potential under heat stress (Bruckner and Froberg, 1987). Hossain and Teixeira de Silva (2012) and Hossain *et al.* (2012b) stated HSI to be a measure of yield stability. Therefore, a stress-tolerant genotype as defined by HSI needs not necessarily to have a high yield potential. The ideal wheat genotype should be high yielding under any environmental conditions.

CONCLUSION

Spike length, spike/plant, grain/spike, floret/spike, individual seed size, grain yield, biological yield, harvest index were found higher than late and very late growing condition. HT genotypes showed higher value than MHT and HS genotype in both the year. Floret sterility was increased at late and very late growing conditions, but heat tolerant genotype exhibits lower value. HSI calculated in stress environments to assess their stress potential on the basis of grain yield. In this study, the HSI values of Prodip, BAW-1146, BAW-1147, BAW-1148 and Pavon-76 were higher than 1.0, indicating that these genotypes were susceptible to heat stress. The HSI values of the remaining three wheat genotypes indicate their various levels of tolerance to high

temperature. Among them BARI Gom-25, BARI Gom-26 and BAW-1143 were tolerant to heat stress.

CONFLICTS OF INTEREST

The authors declare that they have no potential conflicts of interest.

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