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PERFORMANCE OF KERNEL DRY MATTER ACCUMULATION AND YIELD ATTRIBUTES OF WHEAT CULTIVARS UNDER NORMAL AND HEAT-STRESSED ENVIRONMENTS

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ABSTRACT

An experiment was conducted with two wheat cultivars viz. a relatively heat tolerant (HT) Kanchan and a heat sensitive (HS) Sonora to elucidate differences in yield attributes and kernel dry matter accumulation under normal and late planting heat-stressed environments. Results clearly depicted that irrespective of cultivars, all the tested spike, spikelet and kernel attributes were affected due to late planting heat stress, but the extent of reduction was significant and relatively higher in HS Sonora under heat-stressed environment. A typical sigmoidal pattern of kernel dry matter accumulation was observed in both wheat cultivars under normal and heat-stressed environment. Days to attain peak of kernel dry matter accumulation was reduced by 5 days in Kanchan, whereas it was reduced by 10 days in Sonora due to heat stress. Seed yield from Kanchan and Sonora was recorded as 4.89 t ha^{-1} and 4.78 t ha^{-1}, respectively under normal environment. But it was reduced more in Sonora (32.0%) than Kanchan (18.8%) under heat-stressed environment. Finally, it was found that seed yield reduced by about 5.8% for each 1°C rise in average mean air temperature from normal growing environment during anthesis to maturity in Kanchan but it was about 1.6 times higher i.e. 9.3% in Sonora.

Key words: Heat stress, kernel dry matter accumulation, seed yield, heat susceptibility index, wheat

INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important cereal crop ranking number one globally and the second most important cereal crop next to rice in Bangladesh. The national average wheat yield in Bangladesh is quite low (2.2 t ha^{-1}) compared to other wheat growing countries (Anon., 2007a and Anon., 2007b) and even lower compared to its attainable yield potential in this country. This is about one-third of the attainable yield potential of 6.6 t ha^{-1} of Kanchan, the most extensively cultivated wheat cultivar in Bangladesh. Like many parts of the Asian subcontinent, in Bangladesh, as a result of the rice-wheat cropping system, crop damage due to heat stress under late planted (after 15 December) condition has become an important limiting factor for wheat yields (Aslam *et al.*, 1989). Increasing demand for food, global warming and climatic change will in future push wheat crops further into heat-stressed environment. Late planted wheat plants face a period of high temperature stress during reproductive stages causing reduced kernel number spike^{-1} (Al-Khatib and Paulsen, 1990), reduced kernel weight (Acevedo *et al.*, 1991), shortened kernel filling duration (Stone and Nicholas, 1998) and reduced kernel growth rate (Tashiro and Wardlaw, 1990). The net effect is the reduced seed yield (Islam *et al.*, 1993). Wheat and other cereals characteristically have an approximately linear grain filling phase, within the overall sigmoidal pattern, that begins a few days after anthesis and lasts until physiological maturity (Evans and Wardlaw, 1976). The rate of grain growth during this linear period increases moderately with increasing temperature (Chowdhury and Wardlaw, 1978). Duration of

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grain filling, the other determinant of kernel size is strongly responsible to temperature. Each degree increase in temperature during grain filling resulting in about a 3 day decrease in duration of grain filling regardless of cultivars (Wiegand and Cueller, 1981). Temperature can often be related directly to kernel weight because a common response among wheat cultivars to increase temperature is a continuous reduction in kernel weight at temperatures above 15 °C (Chowdhury and Wardlaw, 1978). Elevated temperatures during grain filling period have detrimental effect on kernel weight and subsequently on grain yield through a shortening of the grain filling duration (Asana, 1968). Work has been carried out on the response of the wheat cultivars in relation to vegetative growth, floral development and fertilization and to perhaps a smaller extent during the post-anthesis period. However, relatively little comparative assessment has been made of the effect of temperature on kernel development and dry matter accumulation in wheat, specifically in Bangladesh condition. Hence, the present study was designed to study the differences in yield attributes, kernel development and dry matter accumulation that would be used as the basis to screen HT wheat cultivars for Bangladesh environment.

MATERIALS AND METHODS

The experiment was carried out at the research farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh on an upland soil. Two wheat cultivars, Kanchan (a late, HYV, heat tolerant and extensively cultivated cultivar) and Sonora (an early and heat sensitive cultivar) were used as seed materials. On the basis of membrane thermostability test, the cultivar Kanchan was considered as relatively heat tolerant (HT) cultivar as compared to Sonora (Mohi-Ud-Din *et al.*, 2007). A fertilizer dose of 100-38-25-20 kg ha^{-1} N, P, K and S was applied in the form of urea, triple supper phosphate (TSP), muriate of potash (MP) and gypsum, respectively. Full dose of P, K and S, and one third of N were incorporated thoroughly into the soil as basal dose. The remaining amount of N was applied at 25 and 40 days after seedling emergence splitting into two equal amounts. Seeds were sown on November 30 (as normal) and December 30 (as late planting heat-stressed) in rows of 20 cm apart (at the rate of 120 kg ha^{-1}). Irrigation was given to avoid the drought stress when necessary. The crop was kept weed free and for controlling diseases Tilt 250 EC was sprayed regularly @ 1 ml L^{-1} at 10-day interval after 25 days of seedling emergence. The experimental design was a split-plot allocating two sowing times in main plots and two wheat cultivars in sub plots with four replications.

Kernel dry matter accumulation: At anthesis randomly selected 70 ears were tagged from each plot. Five tagged ears were harvested to quantify kernel growth at every 5^{th} day beginning from anthesis. The harvesting of ears in all cultivars was continued up to 40 days after anthesis (DAA) for normal growing environment (November 30 sowing) and 35 DAA for post-anthesis heat-stressed environment (December 30 sowing). The harvested ears were kept in oven at 70 °C for 72 hours. 20 kernels of each cultivar were separated from the middle two spikelets of every five ear. During separation only first and second kernel of a spikelet were collected. Then weight of 20 kernels of each cultivar was taken with an analytical balance (AND Electronic Balance, Model ER 180A, A & D Company Limited, Tokyo, Japan). The samples were shored in a desiccator to avoid moisture absorption.

Kernel density: Kernel density was measured at 12% moisture basis and calculated by using the following formula:

$$\text{Kernel density}\,(\text{g cm}^{-3}) = \frac{\text{Kernel weight (g)}}{\text{Kernel volume}\,(\text{cm}^3)}$$

Effective tillers plant^{-1}: The number of effective tillers plant^{-1} was recorded at harvest. In that case ten plant samples from each treatment were taken randomly and means were calculated.

Spike characters: Five spikes from the main shoot were collected randomly from each plot to collect spike characters data.
Number of spikelets spike^{-1}, number of florets spike^{-1} and number of kernels spike^{-1} were counted manually and floret sterility (%) was calculated by using the following formula:

$$\text{Floret sterility (\%)} = \frac{\text{No. of Kernels spike}^{-1}}{\text{No. of Florets spike}^{-1}} \times 100$$

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

Number of spikes, kernel and straw dry weight: The samples were collected from an area of 1m x 1m from the center of each plot by cutting the plant at ground level. Then ears were counted and collected in a cloth bag. The samples were dried in sun, threshed and cleaned manually and fresh weight of kernel was taken. The husk, straw and representative samples of kernel were dried in an oven at 70 °C for 72 hours to obtain kernel and straw dry weight. Total dry weight m^{-2} was calculated by adding kernel, husk and straw dry weight.

Straw and seed yield: The straw yield and seed yield were expressed in t ha^{-1}, seed yield also adjusted to 12% moisture.
Relative performance: The relative performance was calculated as Asana and Williams (1965) by the following formula:

$$\text{Relative performance (\%)} = \frac{\text{Variable measured under stressed environment}}{\text{Variable measured under normal environment}} \times 100$$

Heat susceptibility index: Heat susceptibility index (S) was calculated for seed yield as described by Fisher and Maurer (1978) using the following formula:

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

Where, Y = Seed yield of cultivar in a stress environment
Y_p = Seed yield of cultivar in a stress-free environment
X = Mean Y of all cultivars
X_p = Mean Y_p of all cultivars
($S< 0.5$, highly stress tolerant; $S>0.5<1.0$, moderately stress tolerant and $S > 1.0$, stress susceptible).

Statistical analysis: The findings were analyzed by partitioning the total variance with the help of computer by using MSTAT-C program. The treatment means were compared using Duncun's Multiple Range Test (DMRT) at 5% level of significance. SE values were calculated and used as and where necessary.

RESULTS AND DISCUSSION

In this experiment, the late sown (December 30) wheat crop experienced mostly heat stress during reproductive development than the crop sown at the normal time (November 30). Both wheat cultivars were sown in the field at November 30 exposed to < 26 °C during the reproductive growth phase (Fig. 1). This was within the range of normal temperature (22-26 °C) required for reproductive growth phase of wheat (Al-Khatib and Paulsen, 1990; Campbell and Read, 1968) and considered as "normal growing environment". On the other hand, they experienced high temperature (>26 °C) during the reproductive growth phase, when seeds were sown at December 30 (Fig. 1) and regarded as "post-anthesis heat-stressed environment". Temperature above 26 °C at reproductive growth phase causes harmful premature ripening of wheat and similar results have also been supported by Abrol *et al.* (1991).

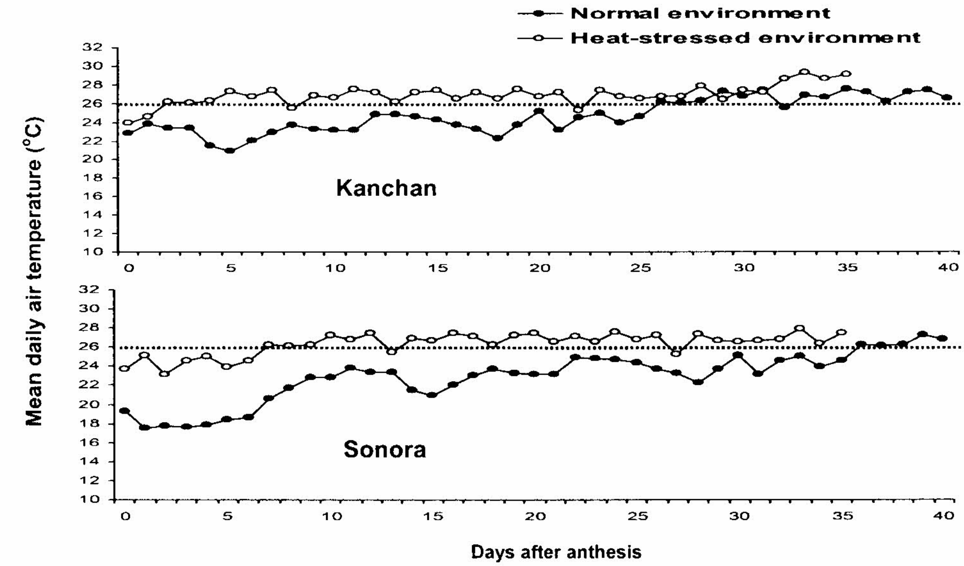

Figure. 1. Mean daily air temperature received by two wheat cultivars from anthesis to maturity under normal and post-anthesis heat-stressed environments

Spike and spikelet attributes

Kanchan produced significantly higher number of effective tillers plant^{-1} than Sonora (Table 1). Heat stress in either case did not create any significant reduction in effective tillers plant^{-1}. Results thus indicate that wheat plants in the present experiment did not receive heat stress before anthesis i.e. tillering was completed before start of heat stress. Results from other studies showed that the spike number plant^{-1} was not influenced by late sowing environment (Sikder *et al.*, 1999).

Table 1. Spike and spikelet attributes of two wheat cultivars under normal and post-anthesis heat-stressed environments

Cultivars	Growing environment	No. of effective tillers plant^{-1}	Spike dry wt. (g spike^{-1})	No. of spikelets spike^{-1}	No. of florets spike^{-1}	Floret sterility (%)
Kanchan	Normal	6.63 a*	2.72 b	19.75 a	79.68 b	37.94 b
	Heat- stressed	6.15 a	2.34 b	19.02 a	72.37 c	39.58 b
		(7.2)**	(14.0)	(3.7)	(9.2)	
Sonora	Normal	5.03 b	3.56 a	18.30 b	84.33 a	38.01 b
	Heat- stressed	4.65 b	2.78 b	16.92 c	80.31 b	41.92 a
		(7.6)	(21.9)	(7.5)	(4.8)	
CV (%)		6.71	9.02	3.64	6.17	2.96

*Means in a column followed by the same letter(s) did not differ significantly at 5% level by DMRT; ** Figures in parentheses indicate per cent decrease relative to normal environment

He and Rajaram (1993) reported that the ear number m^{-2} was less sensitive while yield, kernels ear^{-1}, biomass and plant height were more heat sensitive. Shanahan *et al.* (1990) mentioned that heat tolerant wheat cultivars were associated with productivity only under extreme temperature.
The combined effect of growing environments and cultivars on spike dry weight was significant (Table 1). At normal growing environment, Sonora produced the heaviest spike (3.56 g), which was statistically different from that of Kanchan (2.72 g). In post-anthesis heat-stressed environment, spike dry weight was reduced in both wheat cultivars though the reduction was insignificant in Kanchan. Sonora showed the lower relative spike dry weight to normal (78.1%) compared to that in Kanchan (86.0%).
Results of the present experiment suggest that spike dry matter accumulation was adversely affected by heat stress as because during dry matter accumulation in spike the temperature was appeared to be too higher enough to slow down sink activity in Sonora. The post anthesis development in Sonora was thus found to be more sensitive than Kanchan in the present experiment.
Under both normal and heat-stressed environment, Kanchan showed significantly higher spikelets $spike^{-1}$ than that of Sonora (Table 1). Under post-anthesis heat-stressed environment, this number remained more or less same in Kanchan. But it was reduced by 7.5% in Sonora due to heat stress and the reduction was significant. The spikelets number $spike^{-1}$ was determined during GS_2 phase (double ridge to anthesis) and it was reduced under heat stress (Shpiler and Blum, 1986).
Number of florets $spike^{-1}$ varied significantly by the combined effect of growing conditions and wheat cultivars (Table 1). Under normal growing environment Sonora contained the higher number of florets $spike^{-1}$ (84.33), which was statistically different from that of Kanchan (79.68). Under post-anthesis heat-stressed environment, the floret number $spike^{-1}$ was reduced significantly both in Kanchan and Sonora. Significant reduction in the number of florets $spike^{-1}$ in wheat under heat stress was also reported by Zeng *et al.* (1985) and Shpiler and Blum (1986).

The floret sterility was influenced significantly only in Sonora by growing environments (Table 1). Both wheat cultivars showed statistically similar per cent sterility (37.94% in Kanchan and 38.01% in Sonora) in normal growing environment. Post-anthesis heat-stressed environment increased the sterility in both wheat cultivars though the increment was significant only for Sonora. From the results of other studies it was found that high temperature resulted in wheat floret sterility (Rawson, 1986), late planting wheat experienced high temperature at reproductive stage causing abortion of florets (Warrington *et al.,* 1977).

Kernel Attributes

Kernel number of mother shoot spike: Kernel number per mother shoot spike is one of the dominant yield contributing characters. Kernel number $spike^{-1}$ was influenced significantly by the interaction effect of growing environments and cultivars (Table 2). Under normal growing environment, Sonora had the higher number of kernels $spike^{-1}$ (52.72) than that of Kanchan (49.47). Under heat-stressed environment, this number was reduced in both the cultivars though the reduction was significant only for Sonora. Heat stress caused lower relative kernels $spike^{-1}$ to normal in Sonora (88.87%) than Kanchan (95.27%). Reduced kernels $spike^{-1}$ under heat stress environment was due to the reduced florets $spike^{-1}$ and increased floret sterility. Reduction in number of kernels $spike^{-1}$ with different magnitude were also observed by Al-Khatib and Paulsen (1990), Bhatta *et al.* (1993), He and Rajaram (1993), Islam *et al.* (1993), and Karim *et al.* (1999) under late sowing or high temperature environment compared to optimum sowing temperature.

Table 2. Kernel attributes of two wheat cultivars under normal and post-anthesis heat-stressed environments

Cultivars	Growing environment	No. of kernels spike^{-1}	Kernel dry wt. (g spike^{-1})	Kernel to spike dry wt. ratio	Kernel Density (g cm^{-3})
Kanchan	Normal	49.47 b*	2.09 b	0.76 ab	1.395 a
	Heat-stressed	47.13 b	1.73 d	0.74 ab	1.110 b
		(4.7)**	(17.2)	(2.6)	(20.4)
Sonora	Normal	52.72 a	2.63 a	0.78 a	1.463 a
	Heat-stressed	46.85 b	1.93 c	0.70 b	1.044 b
		(11.1)	(26.6)	(10.3)	(28.6)
CV (%)		3.41	2.71	6.10	4.28

* Means in a column followed by the same letter(s) did not differ significantly at 5% level by DMRT;
** Figures in parentheses indicate per cent decrease relative to normal environment

Physiological maturity of kernel: Physiological maturity of kernel is indicated by its attainment of maximum dry weight. Dry matter accumulation in kernel started slowly after anthesis, gradually became faster near about 10 DAA and reached to peak at 35 DAA under normal environment both in Kanchan and Sonora (Fig. 2).

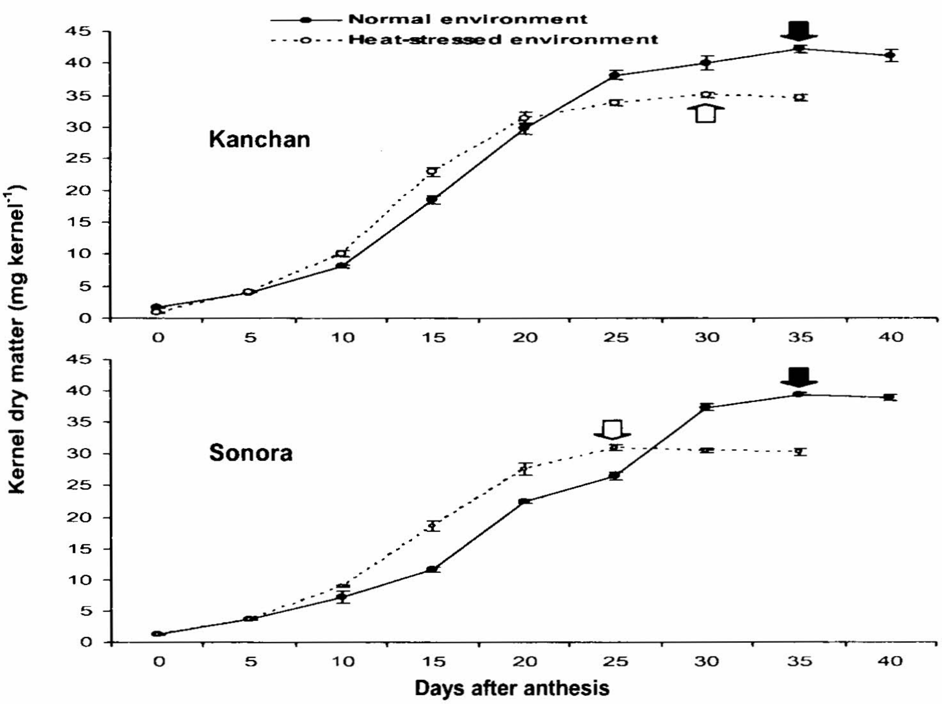

Figure 2. Kernel dry matter accumulation in two wheat cultivars at different days after anthesis under normal and heat-stressed environments. (Filled and unfilled arrows indicate physiological maturity under normal and heat-stressed environments, respectively)

That is, kernel dry matter accumulation followed a more or less sigmoidal pattern. But under post-anthesis heat-stressed environment the peak of sigmoidal pattern was reduced by 5-day in Kanchan, which was as high as 10-day in Sonora. As a result, larger reduction in kernel dry matter accumulation recorded in Sonora (26.6%) compared to Kanchan (17.2%). Thus, the results suggested that early attainment of physiological maturity contributed to larger reduction of kernel dry matter in Sonora.

The declining tendency in dry matter accumulation rate after attaining the highest level could be due to respiratory loss of kernel as experienced with high temperature. Sigmoidal pattern of seed dry matter accumulation was also found by Chanda *et al.* (1999), Karim *et al.* (1999) and Sikder *et al.* (1999) in wheat. Reduction in kernel weight was associated with the reduced duration of kernel growth (Warrington *et al.*, 1977 and Karim *et al.*, 1999).

Mohi-Ud-Din *et al.* (2007) reported that under heat-stressed environment the onset of flag leaf senescence commenced at 5 days earlier in Sonora (20 DAA) compared to Kanchan (25 DAA). It might be one of the causes of shorter kernel filling duration under heat-stressed environment. Attainment of physiological maturity was recorded in the present experiment 5-day later than onset of flag leaf senescence in both the cultivars (Kanchan- 30 DAA and Sonora- 25 DAA) under post-anthesis heat-stressed environment.

Kernel dry weight of mother shoot spike: Significant variation was observed in kernel dry weight of mother shoot spike by the interaction effect of growing environments and cultivars (Table 2). Cultivar Sonora had kernel dry weight of 2.63 g spike^{-1}, which was higher as compared to Kanchan (2.09 g spike^{-1}) under normal growing environment. Although under heat-stressed environment, both the cultivars experienced significant loss of kernel dry weight of mother shoot spike, but there were differences in the extent of loss. A larger reduction in kernel dry weight of mother shoot spike was 26.6% in Sonora compared to 17.2% in Kanchan. As a result of greater reduction of kernel number spike^{-1} as well as individual kernel size in Sonora apparently caused larger reduction in kernel dry matter per mother shoot spike in Sonora than that in Kanchan in the present experiment. Asana and Williams (1965) also reported reduction in kernel dry weight of mother shoot spike of wheat due to heat stress.

The kernel to spike dry weight ratio was higher in Sonora (0.78) than that of Kanchan (0.76) though these values were not significantly different at normal growing environment (Table 2). Under heat-stressed environment, this ratio was reduced significantly only in Sonora (10.3%) but not in Kanchan (2.6%). The varied magnitude of reduction in kernel to spike dry weight ratio was due to varied degree of reduction in spike dry weight and kernels dry weight of mother shoot spike under post-anthesis heat-stressed environment.

The combined effect of growing environments and cultivars on kernel density was significant (Table 2). Under normal growing environment, Sonora although produced higher kernel density (1.463 g cm^{-3}), which did not differ significantly with Kanchan (1.395 g cm^{-3}). Under post-anthesis heat-stressed environment, kernel density was reduced significantly in both wheat cultivars. But the extent of reduction was lower in Kanchan (20.4%) than in Sonora (28.6%).

Pande *et al.* (1995) reported that higher reduction in kernel density of heat sensitive wheat cultivars was due to drastic declined rate of flag leaf photosynthesis at post-anthesis stages. As a result of drastic decline in flag leaf photosynthesis, osmotically active components such as sugar, protein, ash etc. were decreased in the kernels and causing lower kernel density.

In the case of Sonora, relatively poor ratio of kernel to total spike dry weight along with significantly reduced kernel number as well as mother shoot spike dry weight clearly suggested that kernel dry matter was more severely reduced than the whole spike dry matter reduction. From these results of the present experiment, it was clear that poor distribution of dry matter occurred to kernel than to choppy matters of spike: Poor kernel density also suggests improper kernel filling under heat-stressed environment more pronounced in Sonora than Kanchan. All these indicate poor sink capacity to accumulate dry matter in kernel of the cultivars and this was more clearly appeared in Sonora.

Straw and seed yield

Straw yield of Kanchan (5.02 t ha^{-1}) was statistically similar to that of Sonora (4.99 t ha^{-1}) under normal growing environment (Table 3). On the other hand, under heat-stressed environment straw yield was reduced significantly in both wheat cultivars. Straw yields of Kanchan and Sonora were reduced by 13.2% and 14.4%, respectively due to heat stress.

Under normal growing environment, Kanchan attained the highest seed yield (4.89 t ha^{-1}), whereas Sonora gave the lowest (4.78 t ha^{-1}) (Table 3). Post-anthesis heat-stressed environment decreased the seed yield significantly in both wheat cultivars. Seed yield was reduced more in Sonora (32.0%) than Kanchan (18.8%). In the present study, finally, it was found that seed yield reduced by about 5.8% for each 1°C rise in average mean air temperature from normal growing environment during anthesis to maturity in Kanchan but it was about 1.6 times higher i.e. 9.3% in Sonora.

Table 3. Seed and straw yield and heat susceptibility index of two wheat cultivars under normal and post-anthesis heat-stressed environments

Cultivars	Growing Environment	Straw yield (t ha^{-1})	Seed yield (t ha^{-1})	Heat susceptibility index
Kanchan	Normal	5.02 a*	4.89 a	
	Heat-stressed	4.36 b	3.97 b	0.74
		(13.2)**	(18.8)	
Sonora	Normal	4.99 a	4.78 a	
	Heat-stressed	4.27 b	3.25 b	1.26
		(14.4)	(32.0)	
CV(%)		3.02	10.69	

* Means in a column followed by the same letter(s) did not differ significantly at 5% level by DMRT

** Figures in parentheses indicate per cent decrease relative to normal environment

Reduced number of kernels $spike^{-1}$ and reduced kernel weight were the major responsible factors for reducing the seed yield under heat-stressed environment. Results from other studies showed that late sowing caused lower seed yield in wheat compared to optimum sowing (Bhatta *et al.*, 1993; Islam *et al.*, 1993; Karim *et al.*, 1999. Al-Khatib and Paulsen (1990) concluded the high relative seed yield, which was the result of stable and/or long duration of photosynthetic activity at heat-stressed environment as a selection criterion for heat tolerance of wheat cultivars.

Heat susceptibility index based on seed yield varied between HT and HS cultivars (Table 3). According to the susceptibility index, Kanchan (0.74) was found as moderately heat tolerant and Sonora (1.26) was found as heat susceptible cultivar. Hasan *et al.* (2007) also observed similar result in another study with Kanchan and Sonora in Bangladesh condition.

Therefore, considering all the studied attributes, Kanchan was found to be late planting heat-stress tolerant cultivar. The characters contributing to heat tolerance can be used to compare the efficiency of wheat cultivars for late planting heat stress tolerance and also for genetic strengthening of wheat in Bangladesh.

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