INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 3, No. 11, p. 8-19, 2013

RESEARCH PAPER

Late planting heat stress on ear growth physiology of wheat

Tapos Kumar Roy[1], Md. Hafizur Rahman Hafiz[1*], Md. Robiul Islam[1], Md. Abu Hasan[1], Md. Nurealam Siddiqui[2]

[1]*Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh*

[2]*Department of Biochemistry and Molecular Biology, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur-1706, Bangladesh*

Key words: Chlorophyll content, ear growth, heat stress, proline content, wheat.

doi: http://dx.doi.org/10.12692/ijb/3.11.8-19 Article published on November 02, 2013

Abstract

Grain yield of wheat in Bangladesh is low as it is severely affected by various biotic and abiotic stresses, among them; heat stress (terminal high temperature) is one of the major causes of lower wheat yield in Bangladesh. This paper focuses on the assessment and performance of some wheat genotypes under different temperature regimes and to fix up of suitable potential lines, for high temperature-stressed environments. Four wheat genotypes (Bijoy, BAW 1059, BAW 1064, and Sonora) were tested under normal and heat stress condition to study the influence of late planting heat stress on ear growth physiology of wheat. In membrane thermostability (MT) test, Bijoy, BAW 1059 and BAW 1064 showed less than 50% membrane injury and were considered as heat tolerant (HT) genotypes and Sonora showed more than 50% membrane injury and was considered as heat sensitive genotype (HS). The HT genotypes maintained higher level of proline both in flag leaf and kernel in late planting heat stress condition than that of normal growing condition but HS Sonora produced reverse result. In late planting heat stress condition, Sonora exhibited greater decrease in flag leaf chlorophyll (98%) than that of HT genotypes, Bijoy and BAW 1064 (64%) and BAW 1059 (70%). Due to late planting heat stress, the quantity of ear dry matter accumulation at peak and duration required to attain peak was higher in HT genotypes than the sensitive one. The HT genotypes showed longer ear growth duration, higher stem reserve utilization, higher relative grain yield and low heat susceptibility index (HSI) for grain yield under late planting heat stress condition compared to HS genotype.

* **Corresponding Author:** Md. Hafizur Rahman Hafiz ✉ hafizhstu@hotmail.com

Introduction

In Bangladesh, generally, wheat is sown in mid November to ensure optimal crop growth and avoid high temperature stress however, about 60% of the wheat is cultivated at late sowing condition after harvesting the transplanted aman rice (Badaruddin *et al.*, 1994). An important limitation to wheat productivity is the heat stress that, affect different growth stages specially anthesis and grain filling. It has already been proved that heat stress can be a significant aspect in dropping the yield and quality of wheat (Stone and Nicolas, 1995)**.** Late planting wheat exposed to high temperature (mean air temperature of >26°C) at reproductive stage (terminal heat stress) causing reduction in yield and it is one of the major reasons of yield gap (2 t ha^{-1}) in Bangladesh (Islam *et al.*, 1993). Similarly terminal heat stress is a major reason of yield decline in wheat due to delayed planting in Pakistan (Rehman *et al.*, 2009) and a major challenge to wheat productivity in India (Joshi *et al.*, 2007).

During the reproductive growth of wheat, heat stress damaged the photosynthetic apparatus causing lessen Photosynthetic movement and sink capability which leads to reduced output (Harding *et al.*, 1990). Source activity is injured by heat because of both leaf area (Herzog, 1982,) and photosynthesis is diminished (Kuroyanagi and Paulsen, 1985). High temperature stress during reproductive development stage resulting accelerate maturity with a reduction in both individual kernel weight and kernel number (Hays *et al.*, 2007; Kosina *et al.*, 2007), furthermore high temperature episodes occurring near to anthesis can reduce the number of grains per ear and resulted in smaller grain yields (Fokar *et al.*, 1998; Rehman *et al.*, 2009).

In spite of low yield of wheat due to terminal heat stress, its cultivation cannot be avoided totally. Therefore, effort have to be made to minimize the late sown yield diminution by screening or developing high temperature tolerant wheat varieties or by ameliorating the consequence of heat stress through agronomic approaches. Membrane thermostability (MT) test is a widely used and acceptable method to evaluate heat tolerance and heat susceptibility index is used to evaluate yield parameters (Hossain *et al.*, 1995). At high temperature stress under late planting condition the genotypes that retain normal flag leaf chlorophyll for a longer period may be considered as heat tolerant (Gupta *et al.*, 2006) and proline which accumulates in plants under supra optimal temperature (Hossain *et al.*, 1995) is a useful component for evaluating the tolerance of a crop to high temperature (Chaitanya *et al.*, 2001).

Terminal heat stressed environments in wheat brings numerous physiological disorders which ultimately results in early onset of senescence or retards conversion of sucrose to starch in developing grains of wheat resulting in smaller kernel size due to shortened grain filling period (Ishag and Mohammad, 1996) and lower grain filling rate (Wardlaw and Moncur, 1995) or combination of both (Tashiro and Wardlaw, 1989). However the physiological and biochemical mechanisms involved in the temperature dependent grain growth are yet to be studied. Considering the above importance the main objective of this study was to evaluate some improved wheat genotypes facing high temperatures during and after anthesis under field conditions on ear growth physiology and yield.

Materials and methods

The experiment was set up at the research farm of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur during November 2010 to April 2011 on a medium high land belonging to the non-calcarious dark gray floodplain soil. The experiment was conducted in a split plot design with three replications. The two growing conditions-normal growing condition (sowing on November 30) and post anthesis heat stress condition (sowing on December 30) were placed in the main plots as main plot treatments whereas four wheat genotypes such as Bijoy, BAW 1059, BAW 1064 and Sonora were placed randomly in the sub-plots as sub-plot treatments. Seeds of four wheat genotypes were sown in rows of

20 cm apart, at the rate of 120 kg ha^{-1} in a unit plot size was 3m x 2m. A fertilizer dose of 90-85-66-20-2-0.5 kg ha^{-1} N, P, K, S, Zn and B was applied in the form of Urea, Triple Supper phosphate (TSP), Murate of potash (MP), Gypsum and Boric acid respectively. Other intercultural operations were done uniformly.

Membrane thermostability (MT) test

Procedure used for measuring membrane injury (%) to high temperature was the same as describe by Blum and Ebercon (1981). Flag leaf samples were collected at anthesis from five randomly selected plants of each genotypes and replication. Two leaf discs (10 mm in diameter) were collected from a flag leaf using a leaf puncher (CAT 162 model, Ronnd Open Industry Co. Ltd., Japan). Paired sets of leaf discs were collected in separate test tubes (25 mm x 200 mm). Leaf discs were washed thoroughly with three changes of deionized water to remove electrolytes adhering to leaf tissue, as well as electrolytes released from cut ends of the leaf segments. After rinsing, tubes were drained, retaining 4 ml of water to prevent desiccation of tissue during heat treatment. For heat treatment test tubes were covered with aluminum foil and incubated in a controlled temperature water bath (J. P. SELECTA, Ctra-Nil-Km- 585.1, Abrera, SPAIN) at 44°C for one hour, while control test tubes were maintained at 25°C during the same period of time. After the treatment period, 16 ml of deionized water was added to both control and treated test tubes. Test tubes were heated at 10°C for 24 hours to allow diffusion of electrolytes from the leaf segments. Then the test tubes were brought to 25°C and shaken to mix the contents. An initial conductance of the test tube contents was determined with an electrical conductivity meter (Model HI 8083, HANNA instruments, Portugal). The test tubes were then placed in an autoclave at 0.10 MPa pressure for 10 minutes to kill leaf tissue completely and release all of the electrolytes. Subsequently, test tubes were cooled to 25°C, the contents were mixed and a final conductance measurement was made. The level of injury was determined as relative injury (RI) from the following equation-

$$RI\ (\%) = 1- [\{1- (T_1/T_2)\}/\{1-(C_1/C_2)\}] \times 100$$

Where T and C refer to conductance values for treatment and control test tubes, respectively, and subscripts 1 and 2 refer to initial and final conductance values, respectively.

Estimation of proline

Proline content of flag leaf and kernel at 16 days after anthesis in all wheat genotypes grown in two different growing conditions were estimated as Bates (1973). At first Ninhydrin reagent was prepared in such a way so that it was utilized for proline estimation within two hours of preparation. 0.5g of fresh sample was crushed in mortar and pastte and homogenized the material in 10 ml 3% sulphosalicylic acid until no large segments of plant material remained. Homogenate was filtered through Whatman No. 2 filter paper. Two ml of the filtrate and each standard proline solutions were then reacted with 2 ml of ninhydrin reagent and 2 ml of glacial acetic acid in a pyrex test tube, boiled for one hour at 100°C in water bath covering the tube with aluminium foil to prevent excess evaporation. Subsequently, it was cooled in ice bath and 4 ml of toluene was added to each tube using a dispensor. Each tube was then shaken vigorously for 15 to 20 seconds in an electrical shaker and allowed the layer to separate for 30 minutes. The absorbance of layer was measured through spectrophotometer (SPECTRO UV-VIS RS Spectrophotometer, Labo Med, Inc.) at 520 nm with pure toluene as a blank. The proline content was determined from a standard curve and calculated on a fresh weight basis as follows:

$$\mu\text{moles proline/ g of plant sample} = \{(\mu\text{g proline/ml} \times \text{ml toluene}) / 115.5\ \mu\text{g}/\ \mu\text{moles}\} / (\text{g sample}/5).$$

Estimation of chlorophyll

Chlorophyll content of the flag leaf during anthesis was estimated using a formula according Witham *et al.* (1986). One mg of leaf was taken from different positions of the flag leaf. Chlorophyll was extracted with 80% aqueous acetone by using a mortar and pestle for grinding the tissue and made up to 10 ml with 80% acetone. The suspension was decanted into centrifuge tubes and centrifuged (CENTRIFUGE, DSC-158T,220, RPM 3200,AMPS 2;Made in Taiwan R.OC) for 3 minutes. The clear green solution was then decanted from the colorless residue. The optical density of this solution was determined against 80% acetone as blank using spectrophotometer at 645 and 663 nm. Total chlorophyll of fresh leaf was determined according to Witham *et al.* (1986) using following formulae.

Total chlorophyll (mg/g fresh tissue) = [20.2(D645-8.02(D663)] x [v/(1000 x w)]

Where,

V=Final volume of filtrated extract

W=Weight of fresh leaf

Stem reserve utilization

Stem reserve utilization (g/main shoot) i.e. short space, was calculated using the formula from the model according to Hasan (2009).

Stem reserve utilization= Maximum stem dry weight – Stem dry weight at physiological maturity of grain.

Grain dry weight main stem ear was calculated using the following formula:

Grain dry weight / ear = Maximum ear dry weight – Ear dry weight at anthesis.

Grain yield m^{-2}

The samples were collected from an area of 2m 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 (2´ X 1.5´). The samples were dried in sun, threshed and cleaned manually and fresh weight of grain was taken. Grain and straw yield were expressed in t/ha, grain yield also adjusted to 12% moisture.

Relative performance

The relative performance was calculated as Asana and Williams (1965) by the following formula: Variable measured under stress condition/Variable measured under normal condition× 100

Heat susceptibility index

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

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

Where,

Y = Grain yield of genotype in a stress environment

Y_p = Grain yield of genotype in a stress-free environment

X = Mean Y of all genotypes

X_p = Mean Y_p of all genotypes

(Higher HSI indicates greater susceptibility).

Statistical analysis

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

Results and discussion

To expose the wheat genotypes into normal growing temperature and natural heat stress during reproductive development, all wheat genotypes were sown in the field on November 30 and December 30. In this experiment, late sown (December 30) wheat genotypes exposed to heat stress (>26^{o}C) during most of their reproductive growth phase and regarded as post anthesis heat stress condition (Figure 1). But the wheat genotypes sown on November 30 experienced less than 26^{o}C throughout their whole reproductive growth phase and considered as normal growing condition because the optimum temperature for reproductive stage of wheat lies a range of 22 to 26^{o}C (Campbell and Read, 1968). Temperature above 26^{o}C at reproductive growth phase causes harmful premature ripening of wheat (Aborl *et al.*, 1991). Temperatures above 25^{o}C adversely affect flux through the pathway of starch synthesis in developing wheat and limit yield (Keeling *et al.*, 1994).

Membrane injury to high temperature

Cell membrane thermostability of flag leaf at anthesis as expressed by relative membrane injury to high temperature differed significantly among the wheat genotypes tested (Figure 2). The highest membrane injury was found in Sonora (66.5%). Bijoy showed significantly the lowest membrane injury (43.5%) which was followed by BAW 1059 (48%) and BAW 1064 (49%). The membrane injury showed by BAW 1059 and BAW 1064 genotypes were statistically similar and both of the genotypes were moderate based on relative membrane injury among the wheat genotyopes. Three wheat genotypes (Bijoy, BAW 1059 and BAW 1064) showed less than 50% membrane leakage and were considered as heat tolerant (HT) genotypes and Sonora showed more than 50% membrane leakage and was considered as heat sensitive genotype. Shanahan *et al.* (1990) obtained a significant increase in yield of spring wheat in hot locations by selection of membrane-thermostable lines, as determined by measurements on flag leaves at anthesis. By applying the MT test on winter wheat seedlings, Saadalla *et al.* (1990) found a high correlation in MT between seedlings and flag leaves at anthesis for genotypes grown under controlled environmental conditions. Genotypic differences in membrane injury of flag leaf at anthesis of the field grown wheat was also reported by Hasan *et al.* (2007).

Table 1. Flag leaf and kernel proline content of different wheat genotypes as influenced by normal and heat stress condition.

Genotypes	Flag leaf proline (µ mol/g fresh wt.)			Kernel proline (µ mol/g fresh wt.)		
	Normal	Heat stress	Relative performance	Normal	Heat stress	Relative performance
Bijoy	3.15 cd	5.80 b	1.84	2.08c	2.95a	1.41
BAW1059	3.42 c	8.50 a	2.48	2.26c	2.80a	1.23
BAW1064	3.00 de	6.10 b	2.03	1.71 d	2.50 b	1.46
Sonora	2.99 de	2.74 e	0.91	2.80 a	2.77a	0.98
CV (%)	3.92			4.83		

In a column values followed by different letter(s) are significantly different from each other by DMRT at p ≤ 5% level.

Flag leaf and kernel proline content

Proline content in flag leaves and kernels of different wheat genotypes at 16 days after anthesis was significantly influenced by post anthesis heat stress conditons (Table 1). Under normal growing condition the heat tolerant genotypes contained 3.00 to 3.42 µmoles proline /g FW and the HS genotype contained 2.99 µmoles proline /g FW in their flag leaves at 16 days after anthesis. Due to heat stress the proline level was significantly increased in HT genotypes (5.8 to 6.10 µmoles/g FW) but in HS genotype it was even decreased (2.74 µmoles/g FW) but the reduction was not significant.

Table 2. Flag leaf chlorophyll content and stem reserve utilization to grain of different wheat genotypes as influenced by normal and heat stress condition.

Genotypes	Flag leaf chlorophyll content at 24 days after anthesis (mg/g fresh leaf)			Reserve utilization (g/g main stem)		
	Normal	Heat stress	Relative performance	Normal	Heat stress	Relative performance
Bijoy	0.826 a	0.297 b	0.359	0.35 bc	0.27 d	0.76
BAW1059	0.831 a	0.030 c	0.030	0.45 a	0.33 c	0.73
BAW1064	0.808 a	0.287 b	0.355	0.40 ab	0.33 c	0.83
Sonora	0.795a	0.015 c	0.018	0.39 b	0.27 d	0.69
CV (%)	2.20			3.90		

In a column values followed by different letter(s) are significantly different from each other by DMRT at p ≤ 5% level.

From both normal and heat stressed condition, kernel proline level was estimated at 16 days after anthesis in different wheat genotypes and the results were presented in table 1. Under normal growing condition, the kernel proline of HT genotypes was 1.71 to 2.26 µmoles/g FW and it was 2.80 µmoles/g FW in the kernel of HS genotype at 16 days after anthesis. Due to heat stress the kernel proline level increased significantly in HT genotypes (2.5 to 2.95 µmoles/g FW) and it was decreased in HS genotypes (2.77 µmoles/g FW) but the reduction was not significant. Overall results showed that both HT and HS genotypes maintained more or less similar proline level in their flag leaves and kernels under normal condition. Due to post anthesis heat stress this proline level was increased in HT and decreased in HS genotypes.

Table 3. Grain yield of different wheat genotypes as influenced by normal and heat stress condition.

Genotypes	Grain yield (t/ha)		Relative Performance
	Normal	Heat stress	
Bijoy	4.00 a	1.73 f	0.78
BAW 1059	3.38 b	2.75 de	0.81
BAW 1064	3.40 b	2.60 e	0.76
Sonora	3.04 cd	3.12 bc	0.57
CV (%)	5.58		

In a column, values followed by different letter(s) are significantly different from each other by DMRT at p ≤ 5% level.

Increased proline synthesis in heat stressed environment due to loss of feedback regulation in proline biosynthetic pathway (Boggess and Stewart, 1980) might be an adaptive mechanism to reduce the accumulation of NADPH, which increased as result of the decrease in photosynthetic CO_2 reduction rate of the plant (Berry and Bjorkman,1980). Increased proline level both in flag leaf and kernel due to heat stress in HT wheat genotypes could have a protective function. Genotypic difference in proline accumulation pattern due to heat stress has also been reported in six cotton cultivars (Ronde *et al.*, 2001) and different cabbage and Chinese cabbage varieties (Hossain *et al.*, 1995) and mulberry leaves (Chaitanya *et al.*, 2001). Hasan *et al.* (2007) also found heat tolerance in terms of proline accumulation in flag leaf and kernel of different wheat genotypes.

Chlorophyll content

Chlorophyll content in flag leaves of different wheat genotypes at 24 days after anthesis was significantly influenced by post anthesis heat stress conditions (Table 2). Under normal growing condition Sonora showed the lowest chlorophyll content (0.795 mg chlorophyll /g FL) which was followed by BAW 1064 (0.808 mg chlorophyll /g FL), Bijoy (0.826 mg chlorophyll /g FL) and BAW 1059 (0.831mg chlorophyll /g FL).

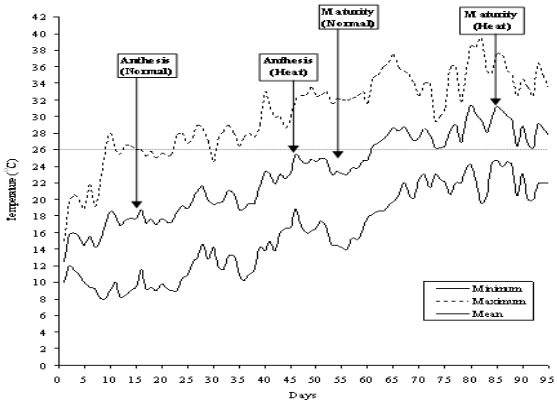

Fig. 1. Maximum, minimum and mean air temperature from 16 January to 16 April 2011 showing the period of anthesis and maturity of normal and late planting wheat.

Due to late planting heat stress, the chlorophyll content at 24 days after anthesis was reduced significantly in all wheat genotypes. Though the reduction was greater in HS genotype (98%) compared to that in HT genotypes Bijoy and BAW 1064 (64%). But another HT genotype BAW 1059 showed greater reduction in flag leaf chlorophyll content as like as HS genotype. This result indicated that HT genotypes normally able to stay green for longer time than the HS genotype. But in present study HT genotype BAW 1059 behaved differently.

Photosynthesis is one of the most sensitive processes to heat stress in wheat (Al-Khatib and Paulsen, 1984; Harding *et al.*, 1990). Whole plant photosynthetic rates decline rapidly when plants were stressed during vegetative and reproductive phases (Gupta *et al.*, 2006).Working with 16 genotypes of wheat Ashraf and Bhatti (1998) **r**eported that chlorophyll contents in all wheat genotypes decreased with late sowing (Hasan *et al.*, 2007 and Sikder *et al.*, 1999).

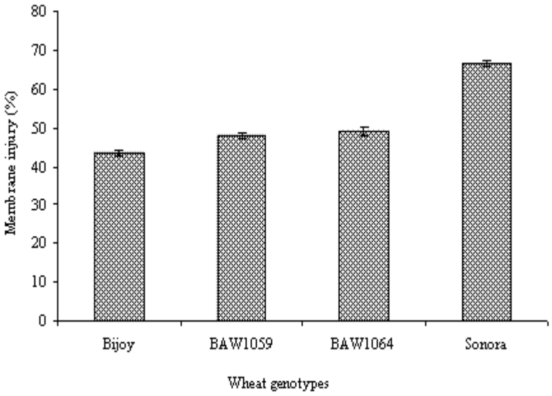

Fig. 2. Membrane injury (%) (mean ± SE) to high temperature of flag leaves at anthesis of different field grown wheat genotypes Values followed by different letter(s) are significantly different from each other by DMRT at 5% level.

Stem reserve utilization

Different wheat genotypes and growing conditions interacted significantly to influence main stem reserve utilization (Table 2). Under normal growing condition, main stem reserve utilization was the highest in BAW 1059 (0.45 g/g main stem) which was statistically identical with that in BAW 1064 (0.40 g/g main stem). Main stem reserve utilization was the lowest in Bijoy (0.35 g/g main stem) which was statistically similar to that in Sonora (0.39 g/g main stem).

Due to late planting heat stress, the stem reserve utilization was significantly reduced in all wheat genotypes though the reduction was higher (30.43%) in HS genotype compared to that in HT genotypes (16.28 to 26.23%). The relative value (in heat stress condition compared to normal condition) indicated that the HT genotypes (0.73 to 0.83) had greater ability to utilize stem reserve compared to HS genotype (0.69). Shukla *et al.,* (1997) indicated greater stem reserve mobilization in tolerant genotypes to support grain filling during critical stages of dry matter accumulation in the grain compared to heat sensitive genotypes. Blum *et al.*, (1994) also concluded that the superior capacity of heat tolerant genotype for grain filling from mobilized stem reserves is a constitutive trait which supports grain filling under heat stress.

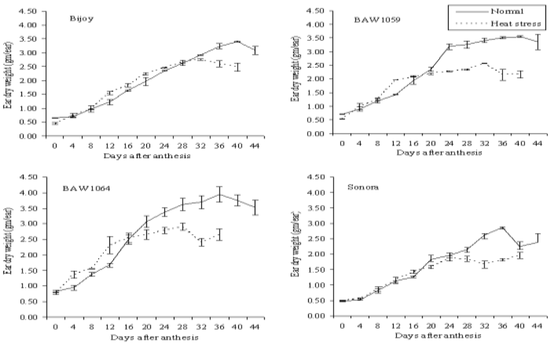

Fig. 3. Ear dry weight (mean ± SE) of different wheat genotypes at different days after anthesis as influenced by normal and heat stress condition.

Ear dry matter accumulation

Both under normal and post anthesis heat stress conditions, a typical sigmoid pattern of dry matter accumulation in ear were discernible in all wheat genotypes (Figure 3). Under normal growing condition, the ear dry weight in HT genotypes was observed to be increased up to 3.40 g in Bijoy and 3.55 g in BAW 1059 at 40 days after anthesis and decline thereafter slowly. In another HT genotype BAW 1064 it was observed to be increased up to 3.94 g at 36 days after anthesis. But ear dry weight in HS genotype Sonora was increased up to 2.86 g at 36 days after anthesis.

Under post anthesis heat stress condition, maximum dry matter accumulation in ear and days required to attain maximum dry weight were reduced in all wheat genotypes. The reduction in maximum ear dry weight in heat tolerant, Bijoy (18.86%), BAW 1059 (27.43%) and BAW 1064 (26.24%) were lower than that in heat sensitive Sonora (34.90%). Again the duration required to attain maximum ear dry weight was reduced 8 days in HT genotypes whereas it was 12 days in HS genotype, Sonora.

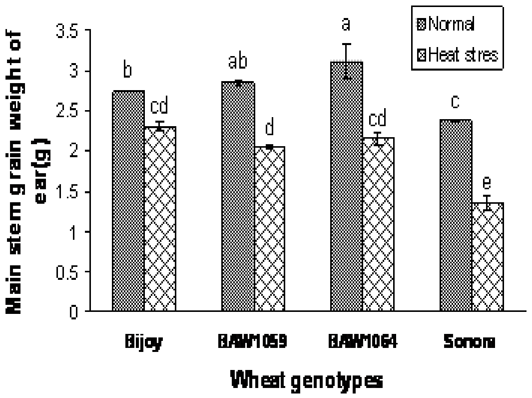

Fig. 4. Main stem grain dry weight of different field grown wheat genotypes as influenced by normal and heat stress condition. In a column values followed by different letter(s) are significantly different from each other by DMRT at 5% level.

The reduction in duration required to attain the maximum kernel dry weight was 4 days in HT genotypes whereas it was 12 days in HS wheat genotypes. The declining tendency in kernel dry weight after attaining the peak could be due to respiratory loss of kernel after physiological maturity. Sigmoid pattern of kernel dry matter accumulation was also found in wheat by Chanda *et al.* (1999); Sikder *et al.* (1999) and Hasan and Ahmed (2005). Hays *et al.* (2007) and Hasan and Ahmed (2005) also found high temperature stress at grain filling period resulted in reduced grain size and grain filling period but reductions were lower in heat tolerant genotypes than those in sensitive genotypes.

Grain dry weight per main stem ear

Significant variation was found in grain dry weight per main stem ear by the interaction effect of growing conditions and wheat genotypes (Figure 3). Under normal growing condition, BAW 1064 obtained the highest grain dry weight per main stem ear (3.11 g/ear) which was followed by BAW 1059 (2.85 g/ear) and Bijoy (2.74 g/ear). Sonora produced significantly the lowest grain dry weight per main stem ear (2.38 g/ear). Due to late planting heat stress, the grain dry weight per main stem ear was reduced in all wheat genotypes. But different genotypes showed different degree of responses to heat stress. The reduction in grain dry weight per main stem ear was the least in Bijoy (16.10%) which was followed by BAW 1059 (28.31%) and BAW 1064 (30.85%) whereas the reduction was the highest in Sonora (42.86%). Fokar *et al.* (1998) observed significant variation among five wheat cultivars in the reduction in grain weight per ear, kernel number and single kennel weight under heat stress. Differences in grain weight per ear among cultivars were ascribed to the variation in the reduction in both kernel number and kernel weight under heat stress. Shpiler and Blum (1986) observed that the cultivars that sustained the highest yield in hot environments were able to maintain the longest duration of GS_2 and had higher number of grain per spike.

Grain yield

Growing conditions and wheat genotypes interacted significantly to govern the grain yield (Table 3). Under normal growing condition, Bijoy attained the highest grain yield (4.0 t/ha) which was followed by BAW 1064 (3.4 t/ha) and BAW 1059 (3.38 t/ha) whereas Sonora gave the significantly lowest grain yield (3.04 t/ha).

Due to heat stress, the grain yield was reduced in all wheat genotypes. But different genotypes showed different degree of responses to heat stress. The reduction in grain yield was least in BAW 1059 (18.63%) which was followed by Bijoy (22%) and BAW 1064 (23%) Whereas the reduction was the highest in Sonora (43%).

Reduced number of ears per m^2, number of grains per ear and reduced grain size were the major responsible factors for reducing the grain yield under heat stress condition in the present experiment. Results from other studies showed that late planting heat stress caused lower grain yield in wheat compared to optimum sowing (Ishag and Mohammad, 1996; Rasal *et al.*, 2006; Kosina *et al.*, 2007; Rehman *et al.*, 2009). Significant variation due to heat stress in different wheat genotypes was also found by Rasal *et al.* (2006), Hasan and Ahmed (2005).

Heat susceptibility index

Heat susceptibility index based on grain yield varied in different wheat genotypes (Figure 4). According to the susceptibility index, BAW1059 (0.71), Bijoy (0.84) and BAW1059 (0.89) was found as heat tolerant and Sonora (1.64) was found as heat susceptible genotype. Hasan and Ahmed (2005) found that the heat tolerant genotypes showed lower susceptibility index (0.346 to 0.962) than the heat sensitive genotype (1.721). Heat stress reduced the grain yield but low heat susceptibility indexes for grain yield were found in heat tolerant genotypes (Rasal *et al.,* 2006).

The results of the present study indicate that distinct changes in kernel proline level between HT and HS wheat genotypes was found at early reproductive development and in flag leaf, it was found at later reproductive growth due to heat stress. Flag leaf longevity reduced in all wheat genotypes due to late planting heat stress but the reduction was inconsistent between HT and HS wheat genotypes. The heat tolerant wheat genotypes showed greater ear and grain growth duration, longer duration rapid grain growth rate, higher stem reserve utilization and consequently maintained lesser reduction in grain dry weight per ear and grain yield under heat stress condition than those showed by heat sensitive wheat genotypes.

Conclusion

The overall result indicated that determination of heat tolerance in wheat genotypes based on lower membrane injury percentage, longer grain filling duration, longer stay in green, higher proline level, greater utilization of stem reserve and lesser reduction of grain dry weight per main stem ear and better yield contributed to heat tolerance in Bijoy, BAW 1059 and BAW 1064 compared to Sonora. However, based on heat susceptibility index for grain yield, BAW 1059 was found as the most tolerant and Sonora was most susceptible genotype to late planting heat stress condition.

References

Abrol YP, Bagga AK, Chakravarty NVK, Wattal PN. 1991. Impact of rise in temperature on the productivity of wheat in India. In: Abrol YP *et al.*, editors. Impact of global climatic change on photosynthesis and plant productivity. India: Oxford and IBH Publishers, 787-98.

Al-Khatib K, Paulsen GM. 1984. Mode of high temperature injury to wheat during grain development. Physiologia Plantarum **61,** 363- 68. http://dx.doi.org/ 10.1111/j.13993054.1984.tb06341.x

Asana RD, Williams RF. 1965. The effect of temperature stress on grain development in wheat. Australian Journal of Agricultural Research **16(1),** 1-13.
http://dx.doi.org/10.1071/AR9650001

Ashraf MY, Bhatti AS. 1998. Effect of delayed sowing on some parameters of photosynthesis in wheat. Wheat information service **86,** 46-48.

Badruddin M, Sauders DA, Siddique AB, Hossain MA, Ahmed MO, Rahman MM, Parveen S. 1994. Determining yield constraints for wheat production in Bangaldesh. In: Saunders DA Hettel GP, editors. Wheat in heat stressed environments; irrigated, dry areas and rice-wheat farming systems. Mexico CIMMYT, 265-71.

Bates LS. Waldren RP, Teare ID. 1973. Rapid determination of free proline for water-stress studies. Plant and Soil **39(1),** 205-07.
http://dx.doi.org/10.1007/BF00018060

Berry J, Bjorkman O. 1980. Photosynthetic response and adaptation to temperature in higher plants. Annual Review of Plant Physiology **31,** 491-543.
http://dx.doi.org/10.1146/annurev.pp.31.060180.002423

Blum A, Ebercon A. 1981. Cell membrane stability as a measure of drought and heat tolerance in wheat. Crop Science **21,** 43-47.
http://dx.doi.org/10.2135/cropsci1981.0011183X002100010013x

Bogess SF, Stewart CR. 1980. The relationship between water stress induced proline accumulation and inhibition of protein synthesis in tobacco leaves. Plant Science Letter **17(2),** 245-52.

Campbell CA, Read DWL. 1968. Influence of air temperature, light intensity and soil moisture on the growth, yield and some growth analysis characteristics of chioiolo wheat grown in the growth chamber. Canadian Journal of Plant Science **48,** 299-11.

Chaitanya KV, Sundar D Reddy AR. 2001. Mulberry leaf metabolism under high temperature stress. Biology of Plants **44(3),** 379-84.
http://dx.doi.org/10.1023/A:1012446811036

Chanda SV, Narmada K Singh YD. 1999. Dry matter accumulation and associated changes in biochemical parameters during wheat grain development. Journal of Agronomy and Crop Science **182(3),** 153-60.
http://dx.doi.org/10.1046/j.1439-037x.1999.00277.x

De Ronde JA, Van Der Mescht A, Steyn HSF. 2000. Proline accumulation in response to drought and heat stress in cotton. African Crop Science Journal **8(1),** 85-91.

Fisher RA, Maurer R. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. Australian Journal of Agricultural Research **29(5),** 897-12.
http://dx.doi.org/10.1071/AR9780897

Fokar M, Blum A, Nguyen HT. 1998. Heat tolerance in spring wheat. II. Grain filling. Euphytica **104(1),** 9-15.
http://dx.doi.org/10.1023/A:1018322502271

Gupta NK, Gupta S, Shukla DS, Desshmukh PS. 2006. Post anthesis high temperature influences photosynthesis, grain growth and dry matter accumulation in contrasting wheat genotypes. Physiology and Molecular Biology of Plants **12(2),** 151-56.

Harding SA, Guikema JA, Paulsen GM. 1990. Photosynthetic decline from high temperature stress during maturation of wheat. II Interaction with source and sink processes. Plant Physiology **92(3),** 654-58.
http://dx.doi.org/10.1104/pp.92.3.654

Hasan MA, Ahmed JU, Bahadur MM, Haque MM, Sikder S. 2007. Effect of late planting heat stress on membrane thermostability, proline content and heat susceptibility index of different wheat cultivars. Journal of National Science Foundation Sril lanka **35(2),** 109-17.
http://dx.doi.org/10.4038/jnsfsr.v35i2.3675

Hasan MA, Ahmed JU. 2005. Kernel growth physiology of wheat under late planting heat stress. Journal of National Science Foundation Sri Lanka **33(3),** 193-04.
http://dx.doi.org/10.4038/jnsfsr.v33i3.2325

Hasan MA. 2009. Physiology of sustaining wheat yield under late planting hest stress. PhD thesis. Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh.

Hays DB, Do JH, Mason RE Finlayson SA, Morgan G. 2007. Heat stress induced ethylene during early grain development induces kernel abortion and early desiccation in a susceptible cultivar. Plant Scince **172,** 1113-23.

Herzog H. 1982. Relation of source and sink during the grain filling period in wheat and some aspects of its regulation. Physiologia plantarum **56(2),** 155-60.
http://dx.doi.org/10.1111/j.1399-3054.1982.tb00318.x

Hossain MM, Takeda H, Senboku T. 1995. Proline content in Brassica under high temperature stress. Japan International Research Center for Agricultural Science **2,** 87-93.

Ishag HM, Mohamed BA. 1996. Phasic development of spring wheat and stability of yield and yield components in hot environments. Field Crops Research **46(1-3),** 169-76.

Islam N, Ahmed SM, Razzaque MA, Sufian A, Hossain MA. 1993. A study on the effect of seeding dates on the yield of wheat varieties. Bangladesh Journal of Agricultural Research **18(1),** 102-7.

Joshi AK, Mishra B, Chatrath R, Ferrara GO, Singh RP. 2007. Wheat improvement in India: Present status, emerging challenges and future prospects. Euphytica **157(3),** 431-46.
http://dx.doi.org/10.1007/s10681-007-9385-7

Keeling PL, Banisadr R, Barone L, Wasserman BP, Singletary GW. 1994. Effect of temperature on enzymes in the pathway of starch biosynthesis in developing wheat and maize grain. Australian Journal of Plant Physiology **21(6),** 807-27.
http://dx.doi.org/10.1071/PP9940807

Kosina P, Reynolds MP, Dixon J, Joshi A. 2007. Stakeholder perception of wheat production constraints, capacity building needs and research partnerships in the developing countries. Euphytica **157(3),** 475-83.
http://dx.doi.org/10.1007/s10681-007-9529-9

Kuroyanagi T, Paulsen GM. 1985. Mode of high temperature injury to wheat. II. Comparison of wheat and rice with and without inflorescences. Physiologa plantarum **65(2),** 203-08.
http://dx.doi.org/10.1111/j.13993054.1985.tb02383.x

Mason RE, Mondal S, Beecher FW, Pacheco A, Jampala B, Ibrahim AMH, Hays DB. 2010. QTL associated with heat susceptibility index in wheat (*Triticum aestivum* L.) under short-term reproductive stage heat stress. Euphytica **174(3),** 423-36.
http://dx.doi.org/10.1007/s10681-010-0151-x

Rehman AU, Habib I, Ahmad N, Hussain M, Khan MA, Farooq J, Ali MA. 2009. Screening wheat germplasm for heat tolerance at terminal growth stage. Plant Omics Journal **2(1),** 9-19.

Saadalla MM, Quick JS, Shanahan JF. 1990. Heat tolerance in winter wheat. II. Membrane thermostability and field performance. Crop Science **30(6),** 1248-51.
http://dx.doi.org/10.2135/cropsci1990.0011183X003000060018x

Shanahan JF, Edwards IB, Quick JB, Fenwick JR. 1990. Membrane thermostability and heat tolerance of spring wheat. Crop Science **30 (2),** 247-51.
http://dx.doi.org/10.2135/cropsci1990.0011183X003000020001x

Shpiler L, Blum A. 1986. Differential reaction of wheat cultivars to hot environments. Euphytica **35 (2),** 483-92.
http://dx.doi.org/10.1007/BF00021856

Shpiler L, Blum A. 1990. Heat tolerance for yield and its components in different wheat cultivars . Euphytica **51 (3),** 257-63.
http://dx.doi.org/ 10.1007/BF00039727

Shukla DS, Gupta NK, Kapashi SB, Deshmukh PS, Sairam RK, Pande PC. 1997. Relationship between stem reserves and grain development in terminal heat stress susceptible and tolerant wheat genotypes. Indian Journal of plant physiology 2(1), 36-40.

Sikder S, Ahmed JU, Hossain T, Miah MAK, Hossain MM. 1999. Membrane thermostability, grain growth and contribution of pre-anthesis stem reserve to grain weight under late seeded condition. Thai Journal of Agricultural Science **32(4),** 465-73.

Stone PJ, Nicolas ME. 1995.Effect of timing of heat stress during grain filling on two wheat varieties differing in heat tolerance. I. grain growth. Australian Journal of Plant Physiology **22(2),** 927-34. http://dx.doi.org/10.1071/PP9950927

Tashiro T, Wardlaw IF. 1989. A comparison of the effect of high temperature on grain development in wheat and rice. Annals of Botany **64(1),** 59-65.

Wardlaw IF, Moncur L. 1995. The response of wheat to temperature following anthesis. I. The rate and duration of kernel filling. Australian Journal of Plant. Physiology **22(3),** 391-97. http://dx.doi.org/10.1071/PP9950391

Witham FW, Blydes DF, Devlin RH. 1986. Exercise in plant physiology, (2nd edition). Bonton: PWS publishers 128- 31.