AAB BIOFLUX
Advances in Agriculture & Botanics-
International Journal of the Bioflux Society

Variation in plant growth, tiller dynamics and yield components of wheat (*Triticum aestivum* L.) due to high temperature stress

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Abstract. To observe the effect of high temperature stress on the growth and development of five wheat varieties (Sourav, Pradip, Sufi, Shatabdi and Bijoy) an experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh (23°77′N and 90°37′E) from November, 2008 to April, 2009. There were two growing conditions viz. normal sowing (November 30) and another was late sowing (30 December). The late sown wheat plants phased a significant heat stress, especially at the reproductive period that influenced their growth and development pattern. Plant height, tiller number, yield components and yield were compared of all varieties under two environmental conditions. All the varieties performed negatively for all parameters under heat stress condition. Due to heat stress plant height, no. of total tillers, fertile tillers decreased and no. of sterile tillers increases. In the same environment the ear length, no. of spikelet main stem^{-1}, fertile floret main stem^{-1} decreased and no. of sterile floret main stem^{-1} increased. The 1000 grain weight and yield also decreased due to high temperature stress. The performance of Bijoy was the best in respect of yield as the yield reduction was the least (53.42%), whereas Sufi showed worst performance (73.01% yield reduction). Therefore, from this study it may be concluded that under high temperature stress the performance of the variety Bijoy was the best especially regarding the yield components and yield.
Key Words: grain filling, Heat stress, plant growth, , tiller dynamics, sowing time, yield.

Resumen. Para observar el efecto del estrés provocado por la alta temperatura en el crecimiento y desarrollo de cinco variedades de trigo (Sourav, Pradip, Sufi, Shatabdi y Bijoy) se realizó un experimento en el campo de la investigación de Sher-e-Bangla la Universidad Agrícola desde noviembre de 2008 hasta abril de 2009. Se han podido observar dos condiciones de crecimiento: la siembra normal (30 de noviembre) y otro fue la siembra tardía (siembra realizada el 30 de diciembre).En la siembra tardía de trigo se noto una significativa fase, el estrés por el calor, especialmente en el período reproductivo influyo en el crecimiento y desarrollo. La altura de la planta, de los tallos, los componentes del rendimiento y el rendimiento, de todas las variedades, se compararon bajo dos condiciones ambientales. Todas las variedades tuvieron resultados negativa para todos los parámetros en situación de estrés de calor Debido al estrés de calor causado por la altura de la planta, el número total de macollos cambio; el numero de tallos fértiles disminuido y el de tallos estériles aumentos. En el entorno de la misma longitud de mazorca, el número de espiguillas tallo principal-1, fértil tallo principal-1 disminuyó y el número de flor estéril tallo principal-1 aumentó. El peso de 1000 semillas y el rendimiento también se redujo debido a la tensión de alta temperatura. El resultado de Bijoy fue el mejor en relación con el rendimiento, la pérdida fue menor (53,42%), mientras que Sufi mostraron un rendimiento peor (73,01% la reducción del rendimiento). Por lo tanto, a partir de este estudio se puede concluir que bajo el estrés de alta temperatura el rendimiento de la variedad Bijoy es el mejor, especialmente en relación con los componentes del rendimiento y el rendimiento.
Palabras clave: estrés por calor, el crecimiento de plantas, el grano, la dinámica del macollaje, momento de la siembra, rendimiento.

Introduction. Due to global warming the annual mean temperature of Bangladesh which is 25.75°C is expected to rise about 0.21°C by 2050 (Karmakar & Shrestha 2000). This rise of temperature has adverse effect on cultivated crops of Bangladesh especially in winter crops as winter prevails for comparatively shorter period in this country. The winter crop wheat which is the second most important cereal crop in Bangladesh often phase a heat stress due late planting due to unconsciousness of the farmers regarding the sowing times. Without this major wheat area under rice-wheat cropping system is late planted (Badruddin et al 1994). Heat stress adversely affect the whole life cycle of wheat plant including vegetative to reproductive period and it affects the plant height, number of tiller, leaf and stem dry weight, grain number, weight and size (Rahman 2004). Photosynthesis in wheat is maximum between 22 and 25^{o}C (Blum 1986) and decreases sharply above 35oC (Blum 1986; Al-Khatib & Paulsen 1990). Temperature is one of the major environmental factors affecting grain yield of wheat. In parts of Africa, Asia, and Central America yields of wheat and maize could decline by around 20 to 40 percent as temperature rises by 3 to 4°C (Arthur 1988).

Late planted wheat plants face a period of high temperature stress during reproductive stages causing reduced kernel number per spike (Al-Khatib & Paulsen 1990; Islam et al 1993) and reduced kernel weight (Asana & Saini 1962; Acevedo et al 1991). The net effect is the reduction of seed yield (Islam et al 1993).

Therefore, the study was conducted to observe and compare the effect of high temperature stress on plant growth, tiller dynamics and yield attributes of some wheat varieties.

Materials and Methods. The study was conducted at the experimental field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh (23°77 N′ 90°37′ E) during November, 2008 to April, 2009. The soil of the experimental field belongs to the Shallow Red Brown Terrace Soils. Five modern verities of wheat viz. Sourav, Pradip, Sufi, Shatabdi and Bijoy were used as experimental materials. Seeds were collected from Bangladesh Agricultural Research Institute. Performance of these varieties were evaluated under two growing environment one is normal growing environment (sowing at November 30) and another is post anthesis heat stressed environment (sowing at December 30).

The experiment was conducted in randomized complete block design (RCBD) with three replications. Seed were sown in 1.5m×2m sizes plot at rate of 120 kg ha^{-1} maintaining 20 cm line to line and 5 cm plant to plant distance. Fertilizers were applied in recommended dose and method. The dose of cowdung was 7 t ha^{-1}. Urea, triple super phosphate, muriate of potash and gypsum were applied at 180, 140, 40 and 110 kg ha^{-1} as a source of N, P, K and S. The whole amount of all fertilizers and manure and two-third urea were applied during land preparation and the rest amount of urea was applied during first irrigation. The first, second and third irrigation was given 20, 60 and 80 days after sowing. Weeding and other intercultural operation was done when necessary.

Temperature data were recorded regularly from the field by an automatic maximum and minimum thermometer. The number of tillers/plant was recorded at the maximum tillering stage. Ten random hills were collected from each plot for collection of data on plant characters and yield components. Different growth stages were observed carefully and recoreded accordingly. Data on yield components were recorded carefully. The grain yield was adjusted at 12% moisture level. The data was analyzed using MSTAT-C (Russell 1994) programme. The mean differences among the treatments were compared by multiple comparison tests using Duncan's Multiple Range Test (DMRT).

Results and Discussion. Under moderate to medium estimates of rising global temperatures negative impacts are posses on global agricultural production including tropical to temperate region. In tropical countries even moderate warming (1°C for wheat and maize and 2°C for rice) can negatively affect different traits and reduce yields significantly because many crops are already at the limit of their heat tolerance (IPCC 2007). In the experiment the effect of high temperature on wheat was tried to understand and for which two sowing dates were selected as two treatments and a graph was made by the ranges of temperatures prevailed during those period. From the graph it is evident that the maximum temperature was near 25°C at the preliminary stages of plant growth and above 25°C in maximum time throughout the rest growing period.

The temperature was near or above 30°C in all the growing period except a small period from period from mid December to few first days of January. So, the late planted set of plants of wheat plants obviously phased high temperature stress in their growing period. And the ranges of temperatures significantly affect different attributes of different varieties of wheat differently. Some of them are discussed here.

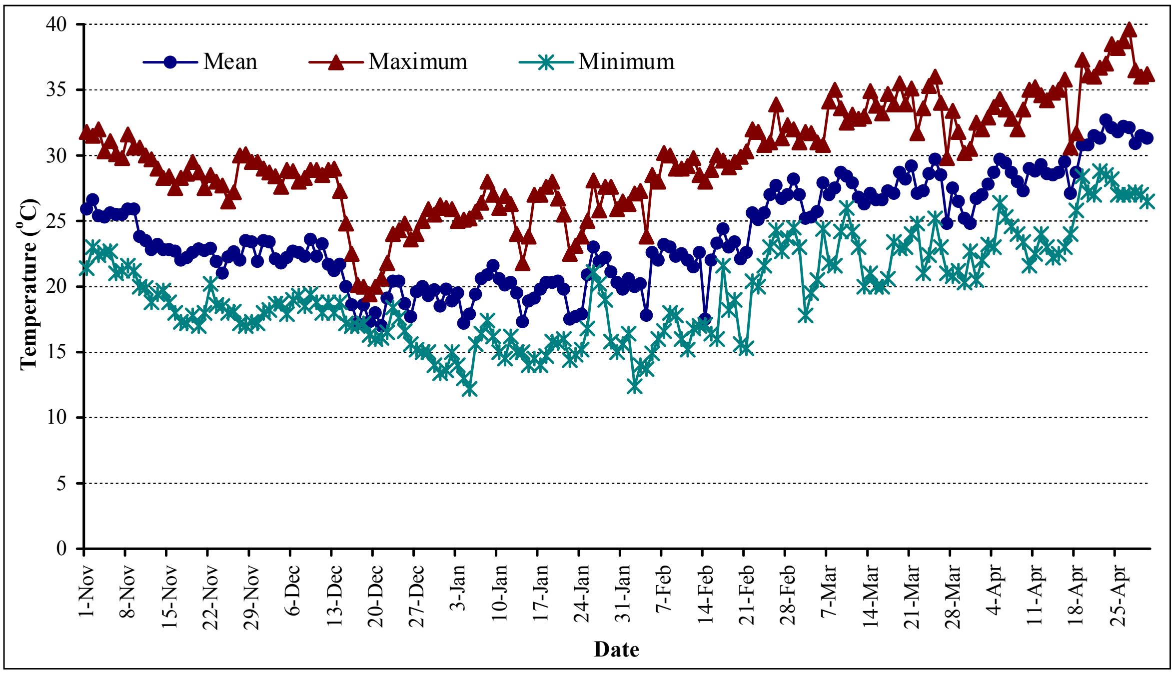

Figure 1. Maximum, minimum and mean temperature during the experimental period.

Plant height

Heat stressed affected plant height modification is a common phenomena in the region where high temperature prevails for while. In comparison to normal temperature range for a plant or variety high temperature always reduces the plant height. Ubaidullah et al (2006) observed that generally late sowing imposed negative effects on all traits and data showed that minimum difference between early and late sowing was 6.3 cm for plant height.

Major impact of high temperatures on shoot growth is a severe reduction in the first internode length resulting in premature death of plants (Hall 1992). In our present study the plant height of Shatabdi (85.63 cm) was highest and it is followed by Sourav (83.75 cm), Pradip (81.92 cm), Bijoy (81.00 cm) and Sufi (80.33 cm) under normal sowing condition (Fig. 2). The plant height were statistically different except Sufi and Pradip. In late sowing the plant heights of the variety ranges from 64.87 cm (in Pradip) to 78.37 cm (in Shatabdi). The plant height of Shatabdi and Bijoy were statistically identical. The performance of of Sufi and Sourav were also similar. Parallel result was reported by Rahman (2004) as he reported that plant height of wheat plant ranges from 66.4-97.3 cm and 55.7-82.3 cm in normal and heat stress condition respectively. The obtained plant heights from the present study are within the same ranges as per Rahman (2004).

Under late sowing condition high temperature stress reduced plant height of all varieties. But this reduction was the lowest in the variety Bijoy (6.85%) and the highest was in the variety Pradip (20.80%). This reduction for other varieties was 16.33% for Sourav, 13.69% for Sufi and 8.47% for Shatabdi. It indicates that there is a less variation in plant height in these two varieties Bijoy and Shatabdi in late sowing heat stress.

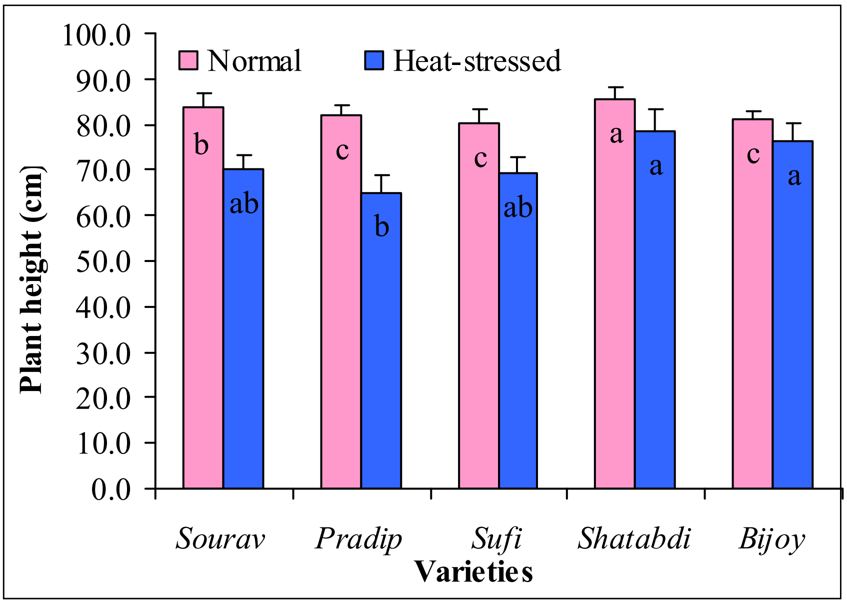

Figure 2. Plant height of different wheat varieties under normal and heat stressed condition. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at P < 0.05 applying LSD test.

Number of tillers

Number of tiller is a very important character for determining the yield of crop. Moreover the fertility or sterility of tillers is also important for determining the so. Number of total tiller plant^{-1} was found highest in Bijoy (6.1), which was followed by Shatabdi (5.2), Sufi (4.2), Pradip (4.1) and Sourav (3.2) in normal environment and in heat stress condition this sequence was Bijoy (5.2), Shatabdi (4.2), Pradip (3.1), Sufi (2.7) and Sourav (2.3). The results of both treatments are more or less significant statistically (Fig. 3). The comparable result was obtained by Rahman (2004) as the result show that the tiller number per plant ranges from 4-8 and 3-6 in normal and heat stress condition respectively. As shown in Fig. 3the number of total tiller in plant reduced due to heat stress and there is a significant difference among the values in both treatments. For late sowing heat stress the no. of total tiller of the variety Sourav, Pradip, Sufi, Shatabdi and Bijoy was reduced by 28.13, 24.39, 35.71, 19.23 and 14.75% respectively.

Fertile tiller plant^{-1} in normal and late sowing condition of the variety Bijoy were 4.2 and 3.2, Shatabdi were 4.1 and 3.0, Sufi were 3.2 and 1.5, Pradip were 3.3 and 2.1, Sourav were 2.2 and 1.2 (Fig. 4). But the results are not statistically significant in both cases. In the variety Sourav, Pradip, Sufi, Shatabdi and Bijoy the no. of fertile tiller plant^{-1} was reduced by 45.45, 36.36, 53.13, 26.83 and 23.81% respectively because of high temperature beyond the normal level. Unlike fertile tillers the no. of sterile tillers increased (Fig. 5) due to high temperature stress in case of all the varieties. Late sowing heat stress increased the percentage of sterile tiller plant^{-1} in the variety Sourav, Pradip, Sufi, Shatabdi and Bijoy by 10.0, 25.0, 20.0, 9.09 and 5.26% respectively.

The decrease in the number of fertile tillers and increase of sterile tillers may be due to the sensitivity of tiller fertility to temperatures and in fact, fertility is determined by a specific temperature range below or above that temperature decrease of fertility or sterility increase is the ultimate result as the ear does not emerge beyond that temperature range. From the literature it can be found that higher temperature enhances leaf senescence causing reduction in green leaf area during reproductive stages. The rapid leaf senescence ultimately resulted in less productive tillers plant^{-1}, which is one of the major causes of yield loss of wheat (Al-Khatib & Paulsen 1984; Randall & Moss 1990; Stone et al 1995; Wardlaw & Moncur 1995; Altenbach et al 2003).

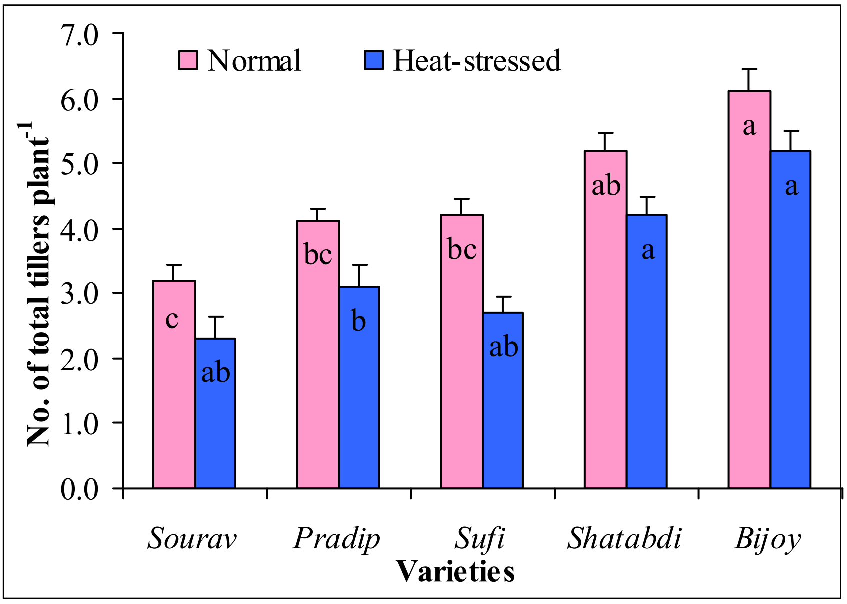

Figure 3. Number of total tiller plant^{-1} of different wheat varieties under normal and heat stressed condition. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at P < 0.05 applying LSD test.

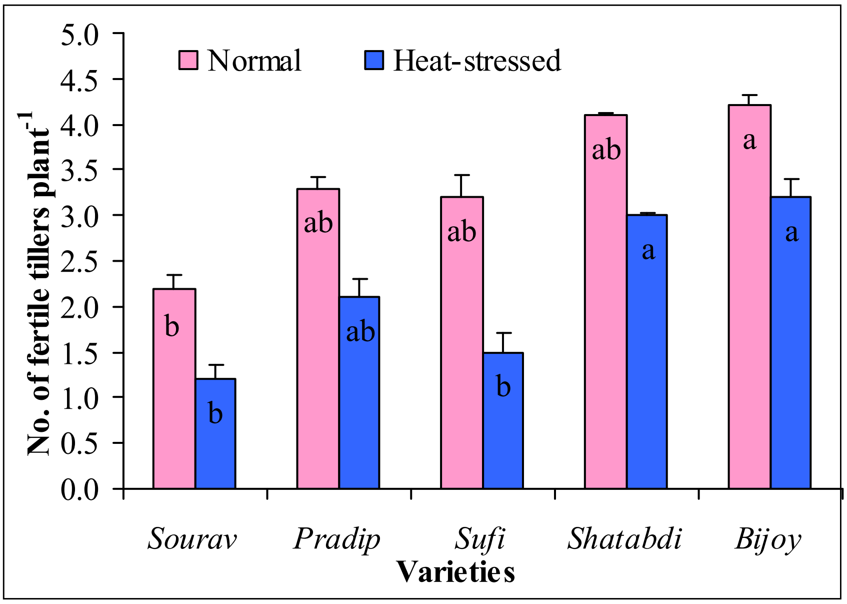

Figure 4. Number of fertile tiller plant^{-1} of different wheat varieties under normal and heat stressed condition. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at P < 0.05 applying LSD test.

Yield components

Yield contributing characters are directly correlated with economic yield of plant. In this study a significant response of treatments was observed on the yield attributes viz. ear length, spikelets per main stem, fertile floret main stem^{-1}, and sterile floret main stem^{-1}. Correlation studies indicates that flag leaf sheath length, extrusion length, plant height, spike length, kernel per spike are important determinants of grain yield in wheat (Fischer & Maurer 1976). Ear length, spike and spikelet characteristics of different wheat varieties have been presented in the Figs 6-8.

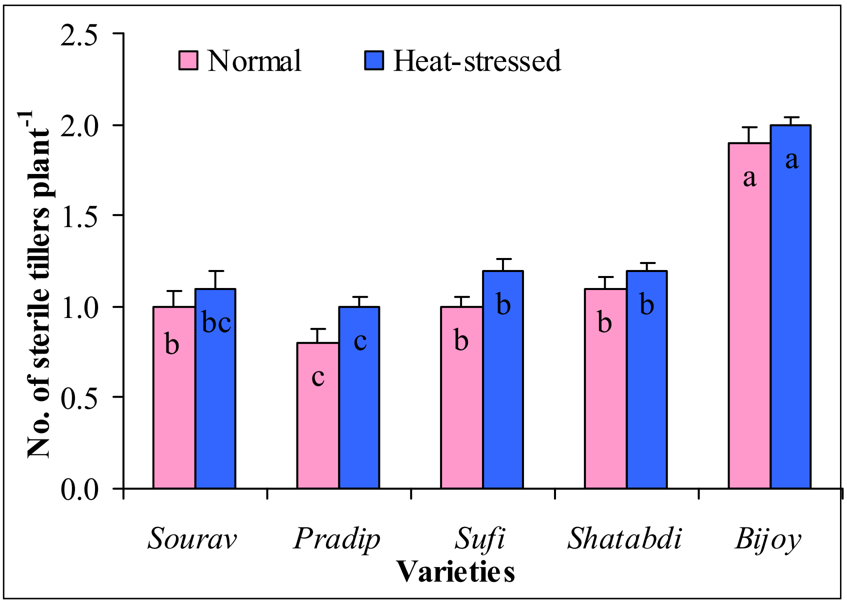

Figure 5. Number of sterile tiller plant^{-1} of different wheat varieties under normal and heat stressed condition. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at $P < 0.05$ applying LSD test.

In the experiment the ear length was found highest in the variety Bijoy (15.5 cm) both in normal and late sowing. Pradip (14.2 cm), Shatabdi (14.1cm), Sourav (13.8 cm) and Sufi (13.6 cm) is the second, third, fourth and fifth in respect to ear length in normal sowing. Bijoy was statistically superior to all and rest others are similar statistically. Ear length of Bijoy is the highest (15.2 cm); Shatabdi is the second highest (14.0 cm); 13.8, 13.6 and 13.5 cm ear length were found in Pradip, Sourav and Sufi respectively in this case in late sowing. Bijoy was statistically superior to all in late sowing also and Sourav, Pradip and Sufi are statistically indifferent. Due to late sowing heat stress the ear length (cm) main stem^{-1} of the variety Sourav, Pradip, Sufi, Shatabdi and Bijoy was reduced by 1.44, 2.814, 0.73, 0.70 and 1.93%, respectively.

Number of spikelet main stem^{-1} was found highest in the variety Bijoy (20.2 and 19.5 in normal and late sowing) and the second highest in the variety Shatabdi (18.7 and 18.2 in normal and late sowing). The no. of spikelet in all other varieties are 17.0 or a little above this. So, Bijoy is statistically highest than to all, after that the variety Shatabdi was the highest where they overlap each other and all others have no differences.

In late sowing heat stress condition the no. of spikelet main stem^{-1} of the variety Sourav, Pradip, Sufi, Shatabdi and Bijoy was reduced by 2.84, 1.71, 1.73, 2.67 and 1.48%, respectively. No. of fertile floret is an important character determining the ultimate yield of a variety. Rawson (1988) examined the hypothesis that sterility is one of the major factors leading to the poor yields in wheat grown from sowing to maturity at high temperatures. The no. of fertile floret main stem^{-1} was found highest in the variety Bijoy in normal (2.7) condition. Second highest no. of fertile floret main stem^{-1} in normal sowing was 2.5 and 2.3 in Sufi and Shatabdi respectively. The lowest no. of fertile floret main stem^{-1} was 2.0 in both Sourav and Pradip in normal sowing. The no of fertile floret main stem^{-1} was also higher in the Bijoy and Shatabdi compared to other varieties in late seeding heat stressed environment. Due to late sowing heat stress the no. of fertile floret main stem^{-1} of the variety Sourav, Pradip, Sufi, Shatabdi and Bijoy was reduced by 20, 15, 28, 17.39 and 18.5% respectively. Here Bijoy can be said as best the performing one. Rahman (2004) reported that the grain number per spike ranges from 45-84 and 20-63 in normal and heat stress condition. If we multiply the no. of fertile floret per spikelet with no. of spikelet the similar results like Rahman (2004) can be found.

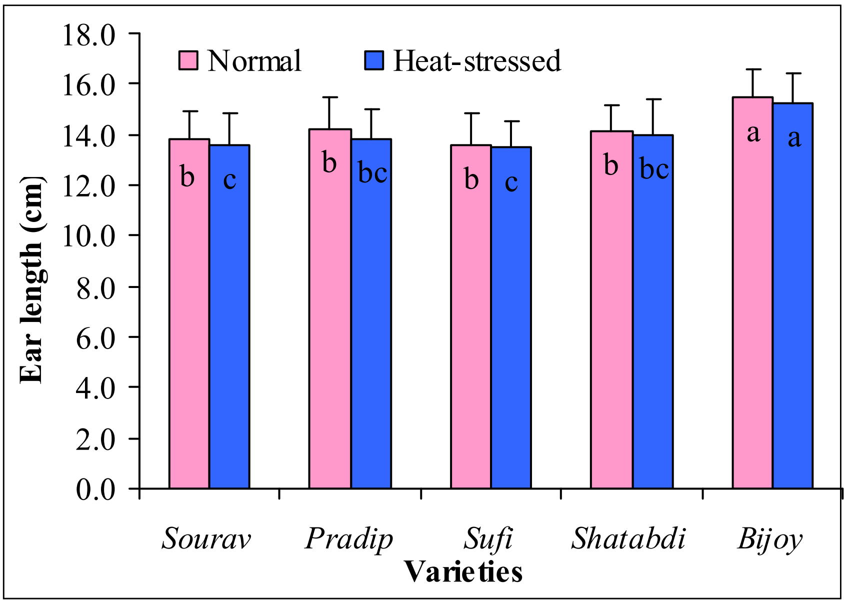

Figure 6. Ear length (cm) main stem^{-1} of different wheat varieties under normal and heat stressed condition. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at $P < 0.05$ applying LSD test.

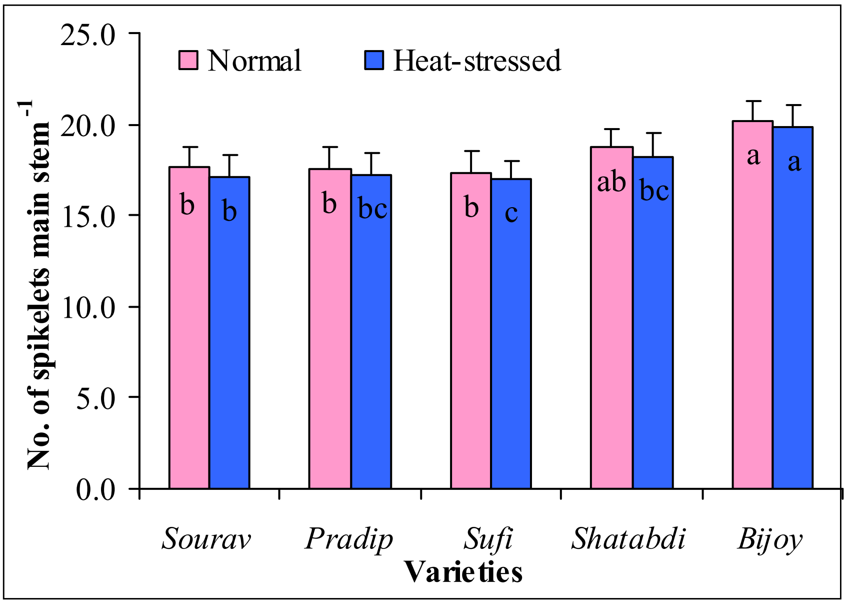

Figure 7. Number of spikelet main stem^{-1} of different wheat varieties under normal and heat stressed condition. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at $P < 0.05$ applying LSD test.

In late seeded heat stress condition the number of sterile floret increases in all cases. The performance of Pradip can said to be the worst as they produced the highest no. of sterile floret main stem^{-1} (3.7) in high temperature stress and the performance of Bijoy can said to be the best as it produced the lowest no. (2.8) of sterile floret per main stem (Fig. 9).

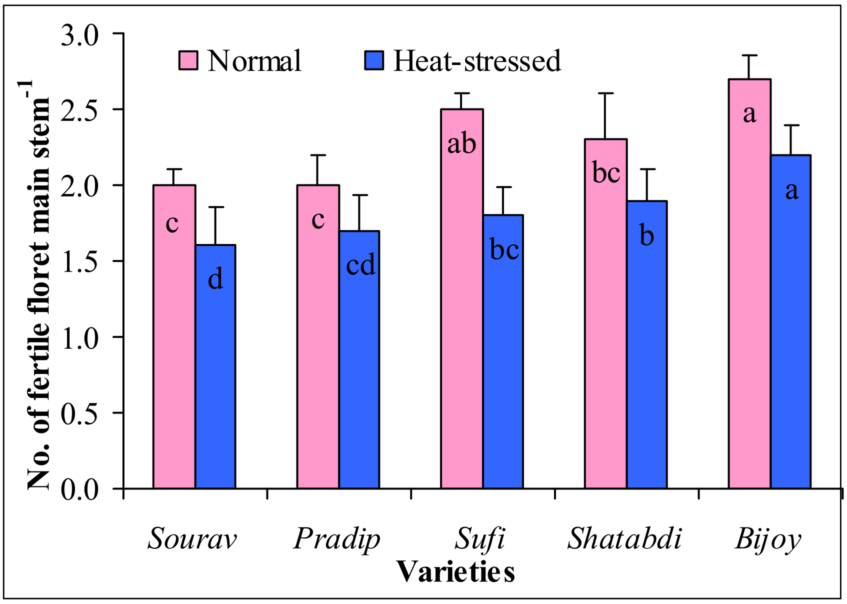

Figure 8. Number of fertile floret main stem^{-1} of different wheat varieties under normal and heat stressed condition. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at $P < 0.05$ applying LSD test.

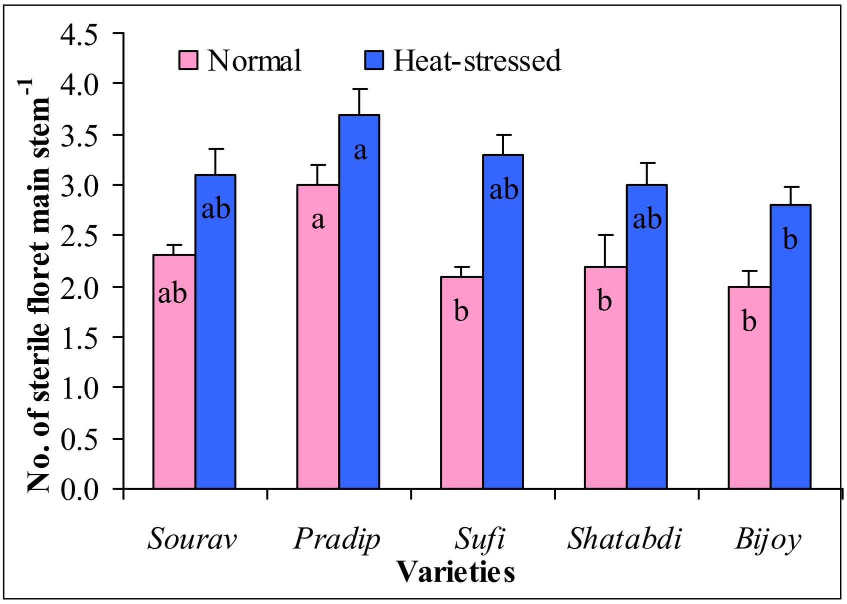

Figure 9. Number of sterile floret main stem^{-1} of different wheat varieties under normal and heat stressed condition. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at $P < 0.05$ applying LSD test.

During reproduction, a short period of heat stress can cause significant increases in floral buds and opened flowers abortion; however, there are great variations in sensitivity within and among plant species and varity (Guilioni et al 1997; Young et al 2004). Because of heat stress 34.78, 23.33, 57.14, 36.36 and 40% no. of sterile floret main stem^{-1} was increased in the variety Sourav, Pradip, Sufi, Shatabdi and Bijoy respectively in the present experiment. The reasons for increasing sterility are reproductive processes were adversely affected by high temperature, which included meiosis in both male and female organs, pollen germination and pollen tube growth, ovule viability, stigmatic and style positions, number of pollen grains retained by the stigma, fertilization and post-fertilization processes, growth of the endosperm, proembryo and fertilized embryo (Foolad 2005). Impairment of pollen and anther development by elevated temperatures is another important factor contributing to decreased fruit set in many crops at moderate to-high temperatures (Peet et al 1998; Sato et al 2006).

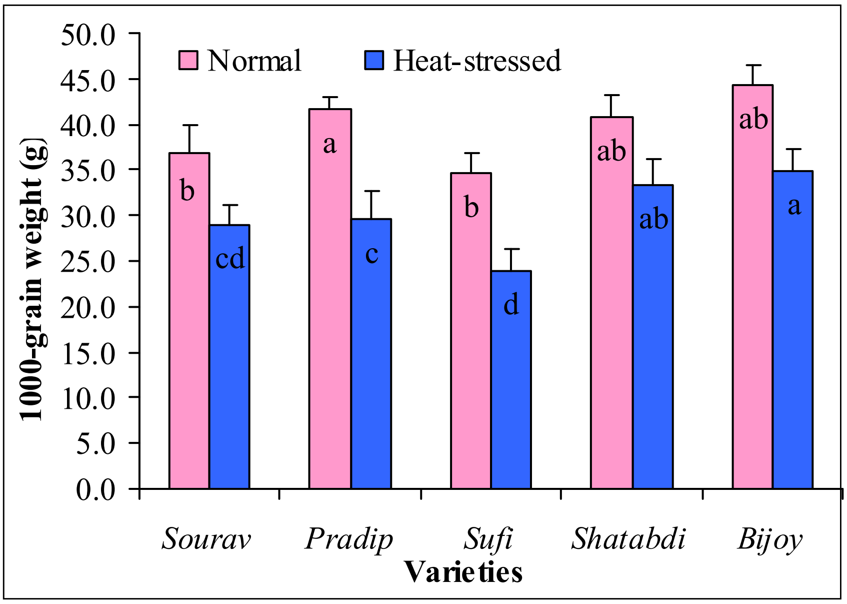

Figure 10. 1000 grain weight of different wheat varieties under normal and heat stressed condition. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at $P < 0.05$ applying LSD test.

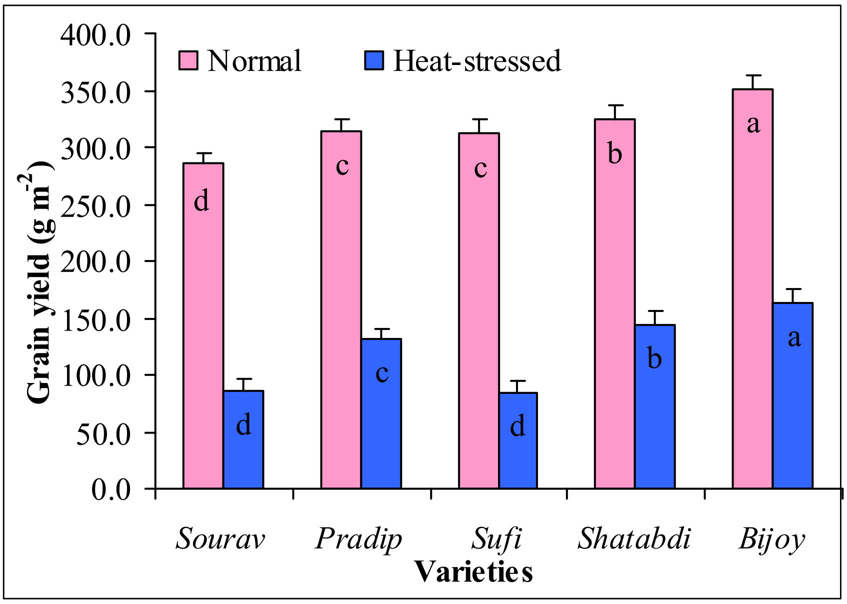

Figure 11. Grain yield of different wheat varieties under normal and heat stressed condition. Mean (±SD) was calculated from three replicates for each treatment. Bars with different letters are significantly different at $P < 0.05$ applying LSD test

Grain yield

The staple cereal crops can tolerate only narrow temperature ranges, which if exceeded during the flowering phase can damage fertilization and seed production, resulting in reduced yield (Porter 2005). The variety Bijoy produced the significantly highest grain yield 350.6 g m^{-2}, whereas the variety (Shatabdi) producing the second highest yield (324.5 g m^{-2}) in normal sowing date. These two verities also produced the highest yield in late sowing (163.3 and 144.5 g m^{-2}, respectively). Sourav had the lowest yield (285.3 g m^{-2}) and Pradip and Sufi produced 314.5 and 312.5 g m^{-2} in normal sowing. But in late sowing the performance of Sufi was the worst and it yielded 84.33 g m^{-2}. In the high temperature stress condition the yield reduction was 69.53% in Sourav, 58.41% in Pradip, 73.01% in Sufi, 55.46% in Shatabdi and 53.42% in Bijoy. So, the performance of Bijoy was the best in respect of yield as the yield reduction was the least (53.42%) and it was the worst in Sufi that showed 73.01% yield reduction. The similar findings were obtained by Hasan (2002) and he reported that grain yield was found to be reduced by about 2.6 to 5.8% in heat tolerant and 7.2% in heat sensitive genotype for each 1°C rise in average mean air temperature from normal growing condition during anthesis to maturity.

Conclusions. From our study it was observed that heat stress significantly affects the growth and development of wheat plant. Considering plant height in heat stress condition the reduction in plant height was lowest in the variety Bijoy and it was highest in case of variety Pradip. The no. of total tiller and fertile tiller was found higher in the variety Bijoy and Shatabdi both in normal and late sowing. Yield components and yield was also better in these two varieties. The yield and 1000 grain of Bijoy was the highest and Sufi was lowest in the heat stressed environment. The percentage of yield reduction was the lowest in Bijoy. So, Bijoy can be considered as the best performing variety among the all studied varieties under heat stress condition.

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Received: 09 May 2010. Accepted: 29 August 2010. Published online: 29 August 2010.
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How to cite this article:
Ahamed K.-U., Nahar K., Fujita M., Hasanuzzaman M., 2010 Variation in plant growth, tiller dynamics and yield components of wheat (*Triticum aestivum* L.) due to high temperature stress. AAB Bioflux **2**(3):213-224.