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Accumulated Heat Unit and Phenology of Wheat Cultivars as Influenced by Late Sowing Heat Stress Condition

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ABSTRACT

Accumulated heat unit and phenology of wheat (Triticum aestivum L.) cultivars were studied under normal and late sowing heat stress conditions by seeding them on November 30 and December 30, 2006. November 30 sowing was considered as normal sowing condition, whereas December 30 sowing was regarded as late sowing heat stress condition. Four heat tolerant wheat cultivars, Gourab, Sourav, Kanchan and Shatabdi and two heat sensitive cultivars, Sonora and Kalyansona were used as study materials. The results indicated that the number of days required to attain different phenological stages with late growing condition. For all the phenological stages plants of normal sowing condition needed higher heat units than the late sowing condition. At the earlier phenological stages phenothermal indices decreased with late sowing compared to normal sowing but increased at the later stages. At normal sowing condition all the cultivars showed higher heat use efficiencies compared to late sowing condition. The heat tolerant cultivars, Gourab, Sourav, Kanchan and Shatabdi exihited better performance in phenology, growing degree day, helio-thermal unit and finally used heat more efficiently than the heat sensitive cultivars, Sonora and Kalyansona.

Key words: Wheat, phenology and heat use efficiency.

INTRODUCTION

Temperature is an important environmental factor influencing the growth and development of crop plants. During growth and development of a cereal crop several growth stages are distinguishable in which important physiological processes occur. Influence of temperature on phenology and yield of crop plants can be studied under field condition through accumulated heat units system (Chakravarty and Sastry 1984, Rajput *et al*. 1987 and Bishnoi *et al* 1995). Plants have a definite temperature requirement before they attain certain phenological stages. To forecast the phenology and crop production attributes for large areas, there is need to develop crop model (Doraiswamy and Thompson 1982). The heat unit system was adopted for determining the maturity dates of different crops (Bierhuizen 1973). The accurate prediction develops on the assessment of plant development rate at each growth stage during the growing season. However, the phenology and ambient temperature interaction in wheat under late sowing high temperature growing condition is very important in Bangladesh. Because in Bangladesh 60% of wheat of wheat areas are planted late due to various reasons and the crop faces high temperature during reproductive stages

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(Badaruddin *et al.* 1994). In the present investigation, the effect of ambient temperature on phenological development and accumulated heat unit of wheat grown under normal and late growing heat stress condition was studied.

MATERIALS AND METHODS

The experiment was conducted at the research farm of Crop Physiology and Ecology Department of Hajee Mohammad Danesh Science & Technology University (HSTU), Dinajpur during 2006-07. It was laid out in a split plot design with three replications. The unit plot size was 3m x 2m having a plot to plot and block to block distance of 0.75m and 1m, respectively. Four heat tolerant cultivars (Gourab, Sourav, Kanchan and Shatabdi) and two heat sensitive cultivars (Sonora and Kalyansona) were used as study materials. The seeds were sown on November 30 and December 30 of 2006. November 30 sowing was considered as normal growing condition (average temperature $<23^0$ C), whereas December 30 sowing was regarded as late growing heat stress condition (average temperature $>25^0$ C) (Figure 1). The experiment was replicated thrice in a split plot design when two growing conditions (sowing times) were placed in main plots and six wheat cultivars were in sub-plots. Seeds were sown in rows 20 cm apart at the rate of 120 kg ha^{-1} in a unit plot size of 3m x 2m. A fertilizer dose of 100-60-40-20 kg ha^{-1} N, P_2O_5, K_2O and S was applied in the form of urea, triple super phosphate, muriate of potash and gypsum, respectively. Three irrigations were given at crown root initiation, maximum tillering and grain filling stages. Other inter cultural operations were done accordingly.

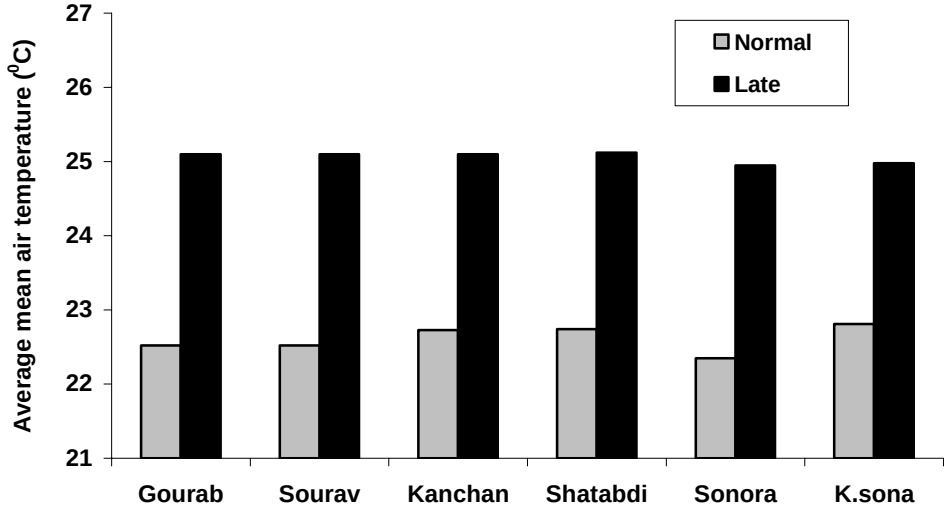

Figure 1. Average mean air temperature (^{0}C) received by different wheat cultivars

The days to crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity were noted when 50% of the plants in all the replications reached the respective stages.

The daily meteorological data were collected from Agro- meteorological centre of Wheat Research Centre, Dinajpur. The various measurements of accumulated heat units were calculated according to the following formulae of Rajput (1980).

1. Growing degree days (GDD) = $\sum[(T_{max} + T_{min})/2 - T_b]$
   (T_b = Base temperature= 10^0C)
2. Helio-thermal unit (HTU) = GDD × Duration of sunshine hour
3. Heat use efficiency (HUE) = Grain yield(kg/ha) ÷ GDD
4. Phenothermal index (PTI) = GDD ÷ Growth days.

Statistical analysis

The findings 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.

RESULTS AND DISCUSSION

Phenology

Results showed that days for attainment of different phenological stages differed significantly from cultivar to cultivar (Table 1). Under normal growing condition, Shatabdi required the highest days to attain crown root initiation (CRI), tillering, booting, heading, anthesis, grain filling and maturity in both the years which was followed by Gourab, Sourav and Kanchan, but Sonora required the lowest number of days for attaining different phenological stages. In this growing condition, Shatabdi required 21 days for CRI, 23 days for tillering, 61 days for booting, 67 days for heading, 72 days for anthesis, 107 days for grain filling and 118 days for maturity, whereas for Sonora the mentioned growth durations were 17, 18, 53, 56, 60, 95 and 105 days, respectively.

Table 1. Phenology (days after sowing) of six wheat cultivars as affected by growing conditions

Cultivar	Crown root initiation stage		Tillering stage		Booting stage		Heading stage	
	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition
Gourab	20 ab	18 cd	21 b	19 cd	60 a	55 c	64 bc	59 f
Sourav	19 bc	18 cd	20 bc	18 de	58 b	54 cd	62 de	58 f
Kanchan	19 bc	17 de	21 b	18 de	61 a	57 b	65 b	61 e
Shatabdi	21 a	19 bc	23 a	20 bc	61 a	58 b	67 a	63 cd
Sonora	17 de	15 f	18 de	16 f	53 d	50 e	56 g	53 h
Kalyansona	18 cd	16 ef	19 cd	17 ef	57 b	54 cd	61 e	58 f

Cultivar	Anthesis stage		Grain filling stage		Maturity stage	
	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition
Gourab	69 b	63 e	104 b	93 fg	114 abc	103 ef
Sourav	67 c	62 e	102 c	92 g	112 bc	102 fg
Kanchan	70 b	65 d	105 b	95 ef	115 ab	105 ef
Shatabdi	72 a	67 c	107 a	97 e	118 a	107 de
Sonora	60 f	56 g	95 f	82 i	105 ef	94 h
Kalyansona	65 d	62 e	100 d	87 h	110 cd	98 gh

Mean followed by the same letter(s) within a phenological stage did not differ significantly at 5 % level by DMRT

At late growing heat stress conditions all the cultivars significantly decreased the requirement of days for attaining different phenological stages of growth. Under late growing condition again the heat tolerant cultivar, Shatabdi needed the highest days for attaining CRI (19 days), tillering (20 days), booting (58 days), heading (63 days), anthesis (67 days), grain filling (97 days) and maturity stages(107 days) closely followed by other heat tolerant cultivars, Gourab, Sourav and Kanchan. On the other hand heat sensitive cultivar, Sonora required the lowest days for attaining all the phenological stages of growth followed by heat sensitive cultivar, Kalyansona. In heat stress condition, the growth duration for Sonora was 15 days for CRI, 16 days for tillering, 50 days for booting, 53 days for heading, 56 days for anthesis, 82 days for grain filling and 105 days for maturity. High temperature at the reproductive phase and low temperature at the early vegetative phase of wheat resulting in reduced number of days for attaining different phenological stages.

Similar results were found by Sandhu *et al.* (1999), Rajput *et al.* (1987), Saini and Nanda (1987), Paul and Sarker (2000), Ghosh *et al.* (2000), Hossain *et al.* (1987) and Saifuzzaman *et al.* (1996) in wheat.

Growing degree days

It was observed that the combined effect of growing conditions and cultivars on heat unit (GDD) was significant at all the phenological stages (Table 2). The lowest heat unit (GDD) requirement was observed in crown root initiation stage, but in the later stages, tillering, booting, heading, anthesis, grain filling and maturity showed increasing trend of heat unit (GDD) requirement for all the cultivars. Finally, the highest heat unit (GDD) requirement was observed at maturity stage for all the cultivars. Under normal growing condition heat tolerant cultivar, Shatabdi needed highest heat unit at all the phenological stages which was followed by Gourab, Sourav and Kanchan, whereas heat sensitive cultivar Sonora required the lowest heat unit (GDD) for attaining different phenological stages closely followed by Kalyansona. Under normal growing condition the GDD values in Shatabdi was 277.9 for CRI, 304.8 for tillering, 731.2 for booting, 809.3 for heading, 876.5 for anthesis, 1375.9 for grain filling and 1560.1 for maturity, whereas the lowest values of GDD for Sonora were 225.1 for CRI, 238.1 for tillering, 634.3 for booting, 666.8 for heading, 717.5 for anthesis, 1192.5 for grain filling and 1345.1 for maturity.

Table 2. Growing degree days (GDD) at different phenological stages of six wheat cultivars as affected by growing conditions

Cultivar	Crown root initiation stage		Tillering stage		Booting stage		Heading stage	
	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition
Gourab	264.9 ab	181.1 f	277.9 b	192.2 ef	717.5 ab	646.8 d	771.4 bc	706.4 ef
Sourav	251.1 bc	181.1 f	264.9 bc	181.0efg	691.7 bc	632.4 d	745.2 cd	691.9 fg
Kanchan	251.1 bc	171.2 fg	277.9 b	181.0efg	731.2 a	676.5 c	783.7 b	734.3 d
Shatabdi	277.9 a	203.3 e	304.8 a	213.5 e	731.2 a	691.9 bc	809.3 a	762.6 bc
Sonora	225.1 de	151.6 g	238.1 d	161.4 g	634.3 d	580.3 e	666.8 g	618.8 h
Kalyansona	238.1 cd	161.4 fg	251.0 cd	171.2 fg	679.0 c	632.4 d	731.2 de	691.9 fg

Cultivar	Anthesis stage		Grain filling stage		Maturity stage	
	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition
Gourab	835.2 bc	762.6 gh	1329.1 b	1252.4 d	1489.3 bc	1433.6 ef
Sourav	809.3 de	747.9 h	1295.0 c	1233.1 d	1451.3 de	1417.2 f
Kanchan	848.5 b	792.4 ef	1345.1 ab	1289.4 c	1509.1 b	1467.2 cd
Shatabdi	876.5 a	820.5 cd	1375.9 a	1326.2 b	1560.1 a	1504.1 b
Sonora	717.5 i	661.6 j	1192.5 e	1051.1 g	1345.1 g	1269.9 h
Kalyansona	783.7 fg	747.9 h	1263.6 cd	1142.8 f	1419.9 ef	1343.7 g

Mean followed by the same letter(s) within a phenological stage did not differ significantly at 5 % level by DMRT

Therefore, at late growing heat stress condition all the cultivars showed reduced heat unit (GDD) requirement for attaining different phenological stages of growth. In late sowing condition again the heat tolerant cultivar Shatabdi showed the highest heat unit (GDD) for attaining all the growth stages which was followed by Gourab, Sourav and Kanchan, whereas heat sensitive cultivar Sonora had the lowest heat unit requirements for attaining different phenological stages which was followed by other heat sensitive cultivar Kalyansona. In heat stress condition the requirements of heat unit (GDD) in Shatabdi were 203.3 for CRI, 213.5 for tillering, 691.9 for booting, 762.6 for heading, 820.5 for anthesis, 1362.2 for grain filling and 1504.2 for maturity. The GDD values for Sonora were 151.6, 161.4, 580.3, 618.8, 661.6, 1051.1 and 1269.0 to attain CRI, tillering, booting, heading, anthesis, grain filling and maturity stages, respectively.

The requirement of heat units (GDD) was higher for normal growing condition than the late growing condition. This was due to longer period for all the phenological stages in the normal growing condition. Late sowing decreased the duration of phenology as compared to normal sowing due to fluctuated unfavourable high temperature during the growing period. So, the requirement of heat units decreased for different phenological stages with late sowing. Comparative heat tolerant cultivars obtained higher GDD than those of heat sensitive ones for their longer phenological stages. Sandhu *et al.* (1999), Rajput *et al.* (1987), Paul and Sarker (2000), Rajput and Sastry (1985), Masnoi *et al.* (1990) and Bishnoi *et al.* (1995) also reported that requirement of heat units decreased for different phenological stages with delay in sowing.

Helio-thermal unit

Helio-thermal unit of a definite phenology is the product of the length of sunshine hour of a day and required days of the phenology accumulated heat unit by plants. The interaction effect of sowing times and cultivars on helio-thermal unit (HTU) was significant for all the phenological stages of growth (Table 3). The highest helio-thermal unit was required for attaining maturity stage, whereas crown root initiation stage required the lowest HTU for all the cultivars. Under normal growing condition, all the cultivars needed higher HTU for attaining different phenological stages compared to late growing condition with few exceptions in grain filling and maturity stages.

Table 3. Helio-thermal unit (HTU) at different phenological stages of six wheat cultivars as affected by growing conditions

Cultivar	Crown root initiation stage		Tillering stage		Booting Stage		Heading stage	
	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition
Gourab	1771.1ab	775.8 f	1888.3 b	861.3 ef	4135.1 a	3123.4 e	4451.1bc	3599.4 f
Sourav	1661.3bc	775.8 f	1771.1 bc	775.8 fg	3927.5 b	3011.1 e	4343.2 c	3472.8 f
Kanchan	1661.3bc	775.8 f	1888.3 b	775.8 fg	4235.6 a	3354.2 d	4525.6ab	3747.3 e
Shatabdi	1888.3 a	940.6 e	2090.2 a	956.2 e	4246.1 a	3472.8 d	4594.1 a	3828.9 e
Sonora	1466.5 d	577.5 g	1583.4 d	662.2 g	3660.1 c	2589.2 f	3847.9 e	2908.3 g
Kalyansona	1583.8cd	662.2 fg	1661.3 cd	721.0 g	3839.2 b	3011.1 e	4135.1 d	3472.8 f

Cultivar	Anthesis stage		Grain filling stage		Maturity stage	
	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition
Gourab	4603.6 ab	3828.9 e	7968.3 c	7952.4 c	9263.1 d	9144.3 e
Sourav	4594.1 b	3779.5 e	7700.1 d	7794.7 d	9000.2 f	9115.3 e
Kanchan	4622.1 ab	4099.6 d	8045.7 c	8272.4 b	9425.9 c	9418.0 c
Shatabdi	4739.5 a	4351.4 c	8326.8 b	8600.5 a	9865.8 a	9418.0 c
Sonora	4135.1 d	3238.6 f	6766.5 g	6304.7 h	8045.1 h	9741.6 b
Kalyansona	4525.6 b	3779.5 e	7430.3 e	7008.6 f	8726.2 g	8721.0 g

Mean followed by the same letter(s) within a phenological stage did not differ significantly at 5 % level by DMRT.

At normal growing condition, heat tolerant cultivar Shatabdi had the highest HTU, whereas heat sensitive cultivar Sonora required the lowest HTU for attaining different phenological stages. In this growing condition the requirements of HTU in Shatabdi were 1888.3 for CRI, 2090.2 for tillering, 4246.1 for booting 4594.1 for heading, 4739.1 for anthesis, 8326.8 for grain filling and 9865.8 for maturity. Under late growing condition, among the cultivars again Shatabdi and Sonora attained the highest and lowest HTU, respectively for attaining different phenological stages of growth.

In the present investigation, the requirement of HTU was higher for normal growing condition compared to late growing condition with few exceptions at the grain filling and maturity stages. It

was reported that HTU for different phenological stages decreased with delay in sowing (Rajput *et al.* (1987), Paul and Sarker (2000), Hauqe *et al.* (2000) and Masnoi *et al.* (1990)).

Phenothermal index

Phenothermal indices (PTI) from sowing to crown root initiation (CRI), CRI to tillering, tillering to booting, booting to heading, heading to anthesis, anthesis to grain filling and grain filling to maturity of six wheat cultivars (Table 4) showed significant influence by the combination of growing conditions and cultivars. Under normal growing condition, all the cultivars had significantly higher PTI up to tillering (CRI to tillering) stage and thereafter late growing condition showed higher phenothermal index compared to normal growing condition in all the cultivars. It was also observed that PTI was highest during grain filling to maturity stage, whereas during crown root initiation to tillering stage it was the lowest. From the overall results it was found that the heat tolerant cultivar Shatabdi had the highest PTI (20.71) at grain filling to maturity stage of late growing condition.

Table 4. Phenothermal index (PTI) at different phenological stages of six wheat cultivars as affected by growing conditions

Cultivar	Sowing to crown root initiation stage		CRI to tillering stage		Tillering to booting stage		Booting to heading stage	
	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition
Gourab	13.24 a	10.05 c	9.88 c	7.00 g	11.13 h	12.39 c	11.97 f	13.40 b
Sourav	13.21 a	10.05 c	9.88 c	7.00 g	11.11 h	12.27 d	11.86 g	13.23 c
Kanchan	13.21 a	10.07 c	10.90 a	6.30 h	11.20 g	12.45 b	11.86 g	13.12 d
Shatabdi	13.23 a	11.23 b	10.96 a	7.52 e	11.10 h	12.62 a	12.12 e	13.18 cd
Sonora	13.24 a	10.11 c	10.05 b	7.35 f	9.34 i	12.04 f	8.96 i	11.06 h
Kalyansona	13.23 a	10.09 c	9.45 d	6.30 h	11.12 h	12.20 e	13.23 c	14.35 a

Cultivar	Heading to anthesis stage		Anthesis to grain filling stage		Grain filling to maturity stage	
	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition	Normal growing condition	Late growing condition
Gourab	11.69 h	12.74 e	13.86 i	16.04 c	15.49 f	17.57 b
Sourav	11.83 g	12.88 d	13.62 j	15.86 d	15.06 g	17.57 b
Kanchan	11.69 h	13.05 c	13.96 h	16.27 b	15.77 e	20.65 a
Shatabdi	13.12 b	14.42 a	14.05 g	16.56 a	15.95 d	20.71 a
Sonora	11.06 i	12.25 f	13.36 l	14.71 f	14.56 i	17.19 c
Kalyansona	11.86 g	12.88 d	13.47 k	15.44 e	14.90 h	17.54 b

Mean followed by the same letter(s) within a phenological stage did not differ significantly at 5 % level by DMRT.

All the cultivars showed higher PTI under normal growing condition compared to late growing condition up to tillering stage and there was decreasing trend of PTI with the advancement of plant age. In this period there was larger variation in PTI between the normal growing condition and the late growing condition of all the cultivars. But after tillering stage, late growing condition showed higher PTI compared to normal growing condition in all the cultivars. But there was minimum variation in PTI between the two growing condition. At the initial stages, the growth duration was lower and then increased with plant age though GDD was increasing with plant age. As a result, at the later stages (from heading to maturity) the values of PTI were closer between the two growing conditions in all the cultivars. Similar results were reported by Rajput *et al.* (1987).

Heat use efficiency

From the results (Table 5) it was observed that all the cultivars used heat more efficiently at normal growing condition compared to late growing condition. Under normal growing condition heat tolerant cultivar Shatabdi had significantly highest HUE (3.07) followed by other three heat tolerant

cultivars Gourab, Sourav and Kanchan, whereas, heat sensitive cultivar Sonora had the lowest HUE (1.95) which was closely followed by other heat sensitive cultivar, Kalyansona.

Table 5. Heat use efficiency (HUE) of six wheat cultivars as affected by growing conditions

Cultivar	Heat use efficiency (HUE)		Reduction (%) at late growing condition
	Normal growing condition	Late growing condition	
Gourab	2.82 b	2.23 de	20.92
Sourav	2.92 b	2.20 e	24.65
Kanchan	2.63 c	2.01 f	23.57
Shatabdi	3.07 a	2.36 d	23.12
Sonora	1.95 f	1.35 h	30.76
Kalyansona	2.22 de	1.59 g	28.37

Mean followed by the same letter(s) did not differ significantly at 5% level by DMRT.

At the late growing heat stress condition all the cultivars significantly reduced their HUE at various magnitude compared to normal growing condition. These reductions for heat tolerant cultivars, Shatabdi, Gourab, Sourav and Kanchan were lower (20.92% to 24.65%) compared to heat sensitive cultivars Sonora and Kalyansona (28.37% to 30.76%). However, in heat stress condition again the cultivar Shatabdi attained highest HUE (2.36), whereas, cultivar Sonora showed the lowest heat use efficiency (1.35).

In the present study, all the cultivars used heat more efficiently under normal growing condition than those of late growing condition. Similar results were reported by Rajput *et al.* (1987), Paul and Sarker (2000), Haque (2000) and Chakravarty *et al.* (1984). The normal growing plants produced higher grain yield by using accumulated heat units efficiently. As the temperature was favourable throughout normal growing condition, it accumulated heat more efficiently and increased physiological activities that confirmed higher grain yield.

CONCLUSION

From the overall results it might be concluded that the heat tolerant cultivars (Gourab, Sourav, Kanchan and Shatabdi) showed greater ability to use solar energy (heat), growing degree day (GDD), and heat use efficiency than the heat sensitive cultivars Sonora and Kalyansona which indicate their (Gourab, Sourav, Kanchan and Shatabdi) lower heat susceptibility than the cultivars Sonora and Kalyansona.

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