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Effect of Heat Stress on Phenological Traits of Wheat Genotype

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ABSTRACT

Purpose : *This study was conducted at Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur to identify phenology, growing degree days, phenothermal index and heat use efficiency of wheat genotypes in response to heat stress.*

Research Method : *Eight wheat genotypes viz., Pavon-76, Prodip, BARI Gom-25, BARI Gom-26, BAW-1143, BAW-1146, BAW-1147 and BAW-118 were used and seeding them at November 27 (normal), December 17 (late) and January 7 (very late growing condition) over two successive years of 2011-12 and 2012-13. The experiment was laid out in a split plot design and main plot treatments were sowing time and sub plot design was wheat genotypes.*

Findings : *The number of days for attaining different phenological stages, the requirement of heat unit (GDD), phenothermal index (PTI) and heat use efficiency (HUE) was higher for normal growing condition compared to late and very late growing condition and higher in heat tolerant genotypes than the heat sensitive genotypes in each sowings of every year. The heat tolerant (HT) genotype BAW-1143 needed highest number of days whereas, HS genotype Pavon-76 required the lowest number of days for attaining all the phenological stages .Under normal growing condition, HT genotype BAW-1143 had the significantly highest HUE (2.22 and 2.37 for first and second year, respectively). But HS genotype Pavon-76 had the lowest HUE (1.71 and 2.16 for first and second year, respectively).*

Limitations : *The limitations of the research are apparent to the fact that it was done in a single location.*

Originality/Value : *This research helps the researcher to identify heat tolerance genotypes for further investigation.*

Keywords: *Heat stress, HUE, phenology, PTI*

INTRODUCTION

Wheat is the main source of world's energy and nutrition. Wheat provides 21% of food calories and 20% of protein to more than 4.5 billion people worldwide (Barun *et al*.,2010).The optimum temperature for grain development of wheat lies with a range of 15-18ºC (Modhej *et al*.,2011). This increased uptake is used to fulfill energy requirements for higher rate of evapotranspiration, photosynthesis, respiration and development. The most obvious effect of high temperatures on wheat growth is accelerating plant development (Shpilar and Blum, 1986). Other effects of heat stress on wheat are; respiration increase, photosynthesis

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decrease, inhibition of starch synthesis in developing kernels (Jenner,1994) declining spike number per plant, grain number per spike and grain weight(Zong-hu and Rajaram,1994), acceleration of senescence of grain filling activities (Al-khatib and Paulson,1984) and constriction of carbon assimilation (Stone,2001).

Temperature is a modifying factor in all stages including germination, tillering, booting, ear emergence, anthesis and maturity since it can influence the rate of water supply and other substrate necessary for growth. Under high temperature, the wheat crop completes its life cycle much faster than under normal temperature conditions. All crops stages have a start duration; consequently, there are fewer days to accumulate and assimilate during life cycle and production of biomass is reduced (Fischer and Maurer, 1978). It ultimate affects grain filling and lastly the yield of crop. Responses to high temperature of plant vary with plant species, variety and phenological stages. The accumulative heat units and system are adopted for determining the dates of flowering/heading and maturity of different field crops are different (Sikder, 2009). Reproductive processes are markedly affected by high temperature in most plants; which ultimately affect fertilization and post fertilization processes leading to reduced crop yield (Wahid *et al*., 2007). Therefore, the present study was carried out to evaluate the adaptability of eight wheat genotypes, to examine the response of wheat phenology and other agroclimatological parameters under stressed and non-stressed conditions.

MATERIALS AND METHODS

The experiment was carried out at the research farm of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh during 2011-12 and 2012-13. It was laid out in a split plot design with three replications. The unit plot size was 3m × 2m. The management practice recommended by Wheat Research Centre (WRC) of Bangladesh Agricultural Research Institute was followed for crop cultivation. Sowing time {Normal growing condition at 27 November (S_1), Late growing or post- anthesis heat stress condition at 17 December (S_2) and Very late growing or extreme post-anthesis heat stress condition at 07 January (S_3)} was accommodated in main plot and eight wheat genotypes viz. Prodip, BARI Gom-25, BARI Gom-26, BAW-1143, BAW-1146, BAW-1147, BAW-1148 and Pavon-76 were assigned to sub-plot.

Intercultural operations were done to ensure normal growth of the crop. Three irrigations were applied, the first irrigation after 21 days of sowing (at crown root initiation stage), second irrigation after 55 days of sowing (at heading stage) and the third irrigation after 75 days of sowing (at grain filling stage). Following phenological stages were observed and recorded in days when 50% of plants of each plot that reached a definite stage showed visual signs as the representative of that stage. The number of days were counted from the date of planting as a benchmark.

i. Booting stage- Number of days taken from sowing to stem elongation

ii. Heading stage- Number of days taken from sowing to ear emergence

iii. Anthesis stage- Number of days taken from sowing to anthesis

iv. Physiological maturity- Number of days taken from sowing to physiological maturity

The accumulated heat unit system which is based on the idea that plants have definite temperature requirements before they attain certain phenological stages, has a significant relationship with temperature, plant growth and phenological development of a crop. The following parameters were calculated according to the formulae (Rajput, 1980).

1. Growing degree days (GDD) = $\sum(T_{max} + T_{min}) /2 - T_b$

(T_b = Base temperature= 10°C)

2. Heat use efficiency (HUE) = Grain yield/ ha ÷ GDD (°C day)

3. Phenothermal index (PTI) = GDD ÷ Growth days.

The data were analyzed by partitioning the total variance with the help of computer by using MSTAT-C computer package. The treatment means were compared using Duncan's Multiple Range Test (DMRT) (Duncan, 1955) at P≤0.05. Correlation and Regression analysis were also done and level of significance was tested with t-test (Singh and Choudhary, 1985).

RESULTS AND DISCUSSION

Phenology

Phenology of eight wheat genotypes is presented in Tables 01 and 02 for the first year (2011-12) and the second year (2012-13), respectively. Phenology was significantly influenced by the interaction effect of sowing times and genotypes for both the years. But the number of days for different phenological stages differed from genotype to genotype. Under normal growing condition, BAW-1143 required the highest number of days for booting, heading, anthesis and physiological maturity in both years. This was followed by BARI Gom-25, BARI Gom-26 and Prodip. But Pavon-76 required the lowest number of days for different phenological stages. In this growing condition, BAW-1143 required 60 days for booting, 65 days for heading, 69 days for anthesis, 105 days for physiological maturity in the first year (2011-12) and in the second year the corresponding values were 63, 68, 72, and 109 and days, respectively. Whereas, for Pavon-76, these growth durations were 52, 59, 63 and 97 days in the first year (2011-12) and in the second year the corresponding values were 57, 62, 67 and 98 days respectively.

Under late and very late growing conditions, all the genotypes significantly decreased the requirement of days to attaining different phenological stages of growth. At late growing condition again, the HT genotype BAW-1143 more days, as for attaining booting (58 days), heading (63 days), anthesis (67days) and physiological maturity (100 days) in the first year and in the second year, the corresponding values were 61, 66, 70 and 104 days, respectively and these were closely followed by other HT genotypes BARI Gom-25, BARI Gom-26 and Prodip. Whereas, HS genotype Pavon-76 required the lowest number of days to attaining all the phenological stages of growth. In this condition, the growth duration for Pavon-76 was 50 days for booting, 57 days for heading, 61 days for anthesis and 92 days for physiological in the first year and in the second year, the corresponding values were 55, 60, 64 and 93 days, respectively. At the very late growing condition, the HT genotype BAW-1143 more days, as to attain for Booting (47 days), heading (54 days) , anthesis(56 days) and physiological maturity (87 days) in the first year and in the second year, the corresponding values were 59, 64, 68 and 99 days respectively which were closely followed by other HT genotypes BARI Gom-25, BARI Gom-26 and Prodip. The HS genotype Pavon-76 required the lowest number of days for all the phenological stages which was followed by other MHT genotypes BAW-1146, BAW-1147, BAW-1148. In this heat stress condition, the growth duration for Pavon-76 were 47 days for booting, 54 days for heading, 56 days for anthesis and 85 days for physiological maturity in the first year and in the second year, the corresponding values were 50, 55, 59 and 89 days, respectively.

Table 01: Days to phonological stages after sowing of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	Booting			Heading			Anthesis			Physiological maturity		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S1	S_2	S_3
Prodip	59ab	57cd	54fg	63c	61de	58g	67bc	65de	63f	104ab	99abcd	90de
BARI Gom-25	58bc	56de	53gh	64b	62cd	59f	68ab	66cd	63f	103ab	98abcd	92cde
BARI Gom-26	59ab	57cd	53gh	64b	62cd	58g	68ab	66cd	64ef	104ab	99abcd	93cde
BAW-1143	60a	58bc	55ef	65a	63c	60e	69a	67bc	65de	105a	100abc	95bcd
BAW-1146	56de	54fg	51 ij	63c	62cd	61de	68ab	66cd	64ef	103ab	98abcd	92cde
BAW-1147	56de	54fg	51 ij	63c	62cd	61de	67bc	65de	63f	103ab	98abcd	91cde
BAW-1148	56de	54fg	51 ij	63c	62cd	61de	67bc	65de	63f	103ab	98abcd	91cde
Pavon-76	52hi	50j	47k	59f	57h	54i	63f	61g	56h	97abcd	92cde	85e
CV (%)		2.28			4.01			3.02			2.91	

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

Legend: S_1 = Normal growing condition, S_2 = Late growing condition, S_3 = Very late growing condition

Table 02: Days to phonological stages after sowing of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	Booting			Heading			Anthesis			Physiological maturity		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Prodip	61bc	59de	56gh	66c	64e	60i	70c	68e	64i	105cd	100fg	95k
BARI Gom-25	62ab	60cd	57fg	67b	65d	62g	71b	69d	66g	106bc	101ef	96jk
BARI Gom-26	62ab	60cd	57fg	67b	65d	62g	71b	69d	66g	107b	102e	97ij
BAW-1143	63a	61bc	59de	68a	66c	64e	72a	70c	68e	109a	104d	99gh
BAW-1146	61bc	59de	56gh	66c	64e	61h	71b	68e	65h	105cd	101ef	93l
BAW-1147	61bc	59de	56gh	66c	64e	61h	71b	68e	64i	104d	100fg	92l
BAW-1148	60cd	58ef	55h	65d	63f	60i	70c	67f	64i	102e	98hi	92l
Pavon-76	57fg	55h	50i	62g	60i	58h	67f	64i	60j	98hi	93l	89m
CV (%)		3.05			2.87			3.56			2.43	

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

Legend: S_1 = Normal growing condition, S_2 = Late growing condition, S_3 = Very late growing condition

The shortening in the crop growth period under late and very late sown condition was due to sudden drop in temperature during early vegetative phase and sharp rise in temperature during reproductive phase, so plants did not have enough assimilates to translocation to sinks. Similar results were found by Sikder *et al.,* (2012), Rajput *et al.,* (1987), Saini *et al.,* (1986) and Saifuzzaman *et al.,* (1996), Nahar *et al.,* .2010. Hossain *et al.,* (2011, 2012) and Hakim *et al.,* (2012) also found that duration of maturity of spring wheat genotypes reduced by high temperature stress in northern Bangladesh. In the present study, late sowing caused unfavorable high temperature at reproductive phase and low temperature at the early vegetative phase resulting in reduced number of days for attaining different phenological stages.

Vegetative phase verses mean temperature

The relationship between vegetative phase and mean temperature is presented in figures 01 and 02. It was observed that vegetative phase of wheat has a negative relationship with mean temperature during that period. An increase in mean temperature by 1ºC resulted in reduction of vegetative period by about 3 days. The regression equation ($Y = -2.751\ X + 106.7$, $R^2 = 0.609$) predicts the vegetative phase of the experiment in the year of 2011-12. In 2012-13 an increase in mean temperature by 1ºC resulted in reduction of vegetative period by about 2 days. The regression equation ($Y = -1.634\ X + 91.47$, $R^2 = 0.899$) predicts the vegetative phase of the experiment in the year of 2012-2013. Hay (1986) also found that the duration of the phase was linearly and negatively associated with the delaying sowing date. This result is in agreement with Amrawat *et al.,* (2013). Changes in the duration of vegetative period associated with temperature are largely responsible for changes in crop duration from sowing to harvest. During vegetative period of growth, mainly photosynthetic system develops, that is, the leaf and agriculture is a system of exploiting photosynthesis. Yield of agricultural plants ultimately depends on the size and efficiency of this photosynthesis system because it serves as the primary source of all energy for mankind.

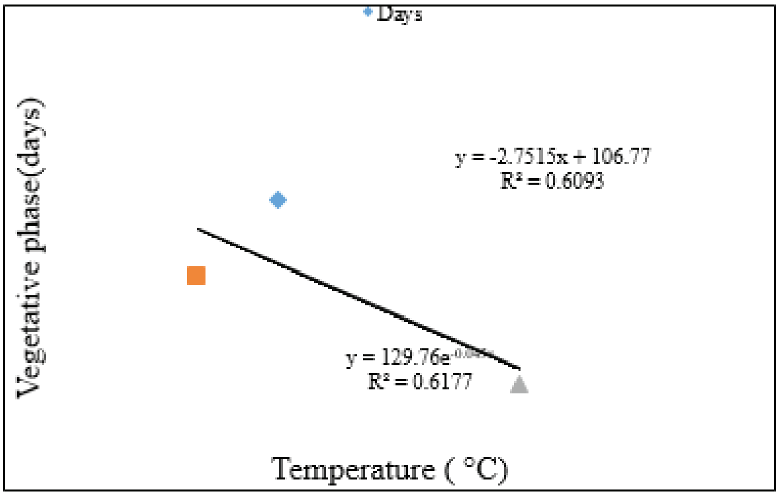

Figure 01: Vegetative phase of wheat as influenced by mean temperature in the year2011-12.

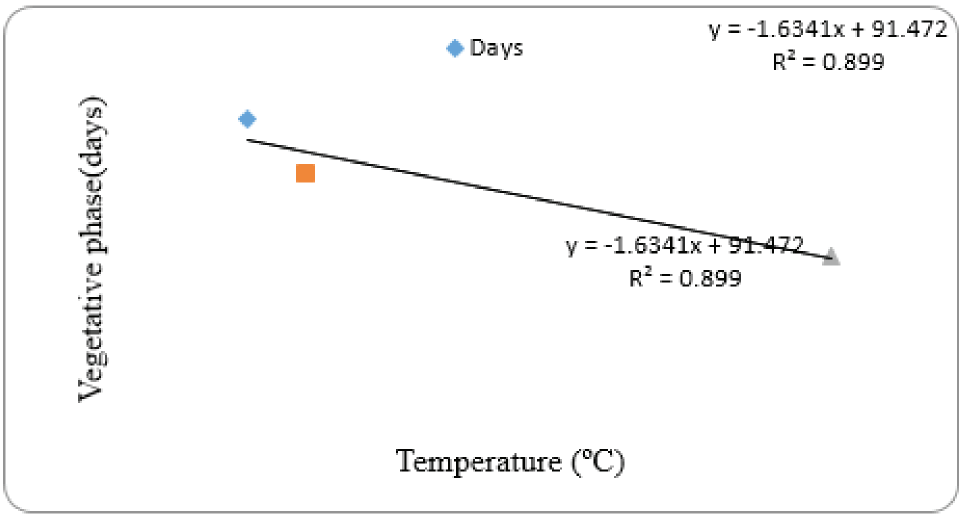

Figure 02: Vegetative phase of wheat as influenced by mean temperature in the year 2012-13.

Reproductive phase verses mean temperature

The relationship between reproductive phase and mean temperature is presented in Figure 03 for 2011-12 and Figure 04 for 2012-13 which show that reproductive phase of wheat, has a negative relationship with mean temperature during that period. An increase in mean temperature by 1ºC resulted in reduction of reproductive period by about 2 days. The regression equation (Y= -1.411 X +63.14, R^2 =0.947) predicts the reproductive phase of the experiment for the year of 2011-12. In 2012-13 an increase in mean temperature by 1ºC resulted in reduction of the vegetative period by about 1 day. The regression equation (Y= -0.990 X +60.92, R^2 = 0.941) predicts the reproductive phase of the experiment in the year of 2012-2013. Hay (1986) also found that the duration of the phase was linearly and negatively associated with the delaying of sowing date. Wiegand and Cuellar (1981) stated that each 1.0º C increase in mean daily air temperature during the grain filling period of wheat resulted in decrease of 3.1 days in grain filling duration. Increasing temperature during grain tended to stop grain growth prematurely and to hasten physiological maturity. A similar result was found by Amrawat *et al.,* (2013).

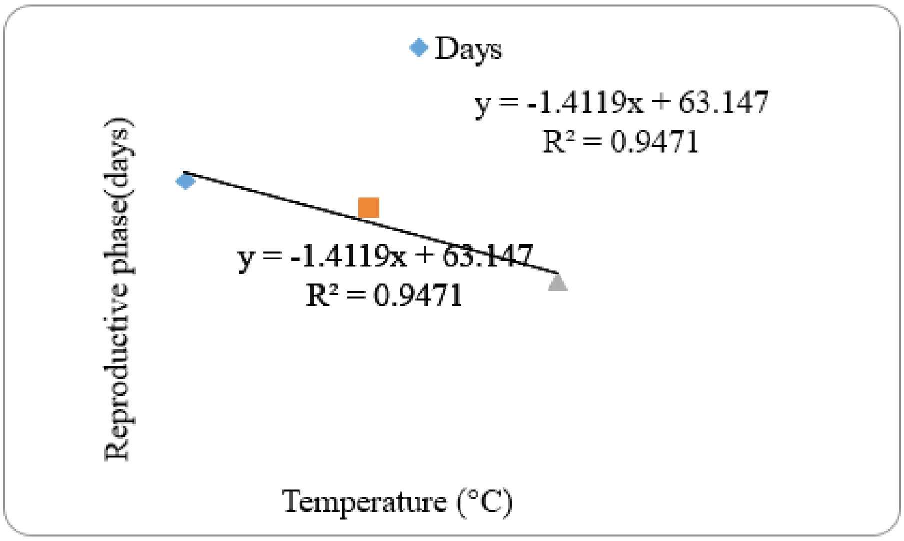

Figure 03: Reproductive phase of wheat as influenced by mean temperature for the year 2011-12.

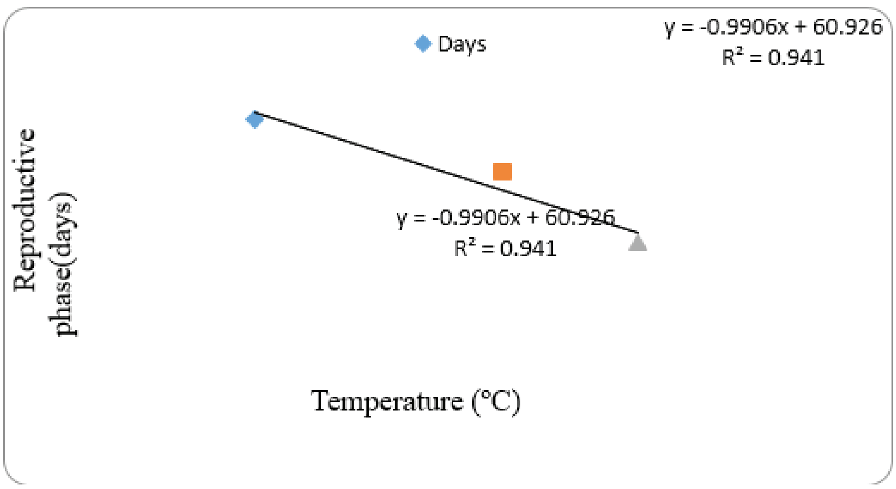

Figure 04: Reproductive phase of wheat as influenced by mean temperature for the year 2012-13.

Growing degree days (GDD)

Growing degree days (GDD) from sowing to different phenological stages of eight wheat genotypes are shown in Table 03 (for the year 2011-12) and Table 04 (for the year 2012-13). The interaction effect of growing conditions and genotypes on heat unit (GDD) was significant at all the phenological stages in both the years. The lowest heat unit (GDD) requirement was observed in booting stage, whereas in the successive phenological stages like, heading, anthesis, grain filling and maturity stages there were an increasing trend of heat unit (GDD) requirement for all the genotypes in each sowing of every year. Under normal growing condition of both years, BAW-1143 needed the highest heat unit at all the phenological stages, whereas Pavon-76 required the lowest heat unit (GDD) for attaining different phenological stages. In this normal growing condition, the GDD values in BAW-1143 were 974 for booting, 1056.50 for heading, 1121.1 for anthesis and 1839.55 for grain filling in the first year and in the second year the corresponding values were 1077.1, 987.1, 1058.25, 1138, and 1177.55 respectively. Whereas, the lowest values of GDD were attained by Pavon-76 were 852.3 for booting, 950.21for heading, 1023.10 for anthesis and 1650.89 for grain filling and in the first year and in the second year the corresponding values were 873.40, 946.30,1003.35 and1565.65 respectively. Under late and very late growing heat stress condition, all the genotypes had a reduced heat unit (GDD) requirement to attaining different phenological stages of growth. In late sowing condition again, the HT genotype BAW-1143 showed the highest heat unit (GDD) to attaining all the growth stage which was followed by other HT genotypes Prodip, BARI Gom-25 and BARI Gom-26. Whereas, HS genotype Pavon-76 had the lowest heat unit requirement for attaining different phenological stages which was followed by other MHT genotypes BAW-1146, BAW-1147 and BAW-1148. In this heat stress condition, the attainment of GDD values in BAW-1143 were 906.9 for booting, 100.70 for heading, 1080.30 for anthesis and 1675 for grain filling in the first year and in the second year the corresponding values were 966.00 for booting, 1120.21 for heading , 1126.05 for anthesis and 1877.30 for grain filling in the first year and in the second year, respectively . In this late growing heat stress condition all the genotypes had a reduced heat unit (GDD) requirement for attaining different phenological stages of growth.

Table 03: Growing Degree Days (GDD) at different phenological stages of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	Booting			Heading			Anthesis			Physiological maturity		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Prodip	958.20b	890.45f	919.40d	1023.10d	960.70g	1006.00e	1089.35de	1041.80gh	1120.30c	1817.75e	1797.45g	1783.2h
BARI Gom-25	943.2c	875.45g	916.45d	1040.20c	982.00f	1028.50d	1104.85cd	1061.05fg	1120.30c	1794.75g	1772.85i	1832.8d
BARI Gom-26	958.20b	890.45f	916.45d	1040.20c	982.00f	1006.00e	1104.85cd	1061.05fg	1143.30b	1817.75e	1797.45g	1855.4b
BAW-1143	974.00a	906.90e	941.65c	1056.50b	1000.70e	1051.30b	1121.10c	1080.30ef	1165.10a	1839.55c	1675j	1899.75a
BAW-1146	914.45d	842.70j	858.05h	1023.01d	982.00f	1074.00a	1104.85cd	1061.05fg	1143.30b	1794.75g	1772.85i	1832.8d
BAW-1147	914.45d	842.70j	858.05h	1023.10d	982.00f	1074.00a	1089.35de	1041.80gh	1120.30c	1794.75g	1772.85i	1808.2f
BAW-1148	914.45d	842.70j	858.05h	1023.10d	982.00f	1074.00a	1089.35de	1041.80gh	1120.30c	1794.75g	1772.85i	1808.2f
Pavon-76	852.30i	772.30k	771.55k	950.21h	890.45j	919.40i	1023.10h	960.70i	964.15i	1650.89k	1623.15m	1647.05l
CV (%)		2.79			7.35			6.85			3.38	

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

Table 04: Growing Degree Days (GDD) at different phenological stages of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	Booting			Heading			Anthesis			Physiological maturity		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Prodip	958.45g	925.55i	1003.4c	1003.35h	950.78l	1098.30c	1077.00jk	1060.15l	1196.45c	1728.35hj	1826.00dh	1984.35ac
BARI Gom-25	971.20f	946.00h	1003.4c	1021.10g	980.56j	1147.90b	1096.35i	1081.05j	1245.35b	1777.55fi	1877.30cg	2028.35ab
BARI Gom-26	971.20f	946.00h	1026.2b	1021.10g	1000.34h	1147.9b	1117.10g	1102.95h	1245.35b	1802.15eh	1903.15bf	2040.10a
BAW-1143	987.10d	966.00f	1074.1a	1058.25e	1020.21g	1196.45a	1138.00e	1126.05f	1296.05a	1777.55fi	1877.30cg	2028.35ab
BAW-1146	958.45g	925.55i	1003.4c	987.00i	934.23n	1098.30c	1138.00e	1040.40m	1196.45a	1728.35hj	1826.00dh	1943.95ad
BAW-1147	958.45g	925.55i	1003.4c	987.00i	924.34o	1074.10d	1058.25l	1021.15n	1172.00d	1704.05j	1800.80eh	1917.85ae
BAW-1148	946.40h	906.00j	981.3e	958.35k	925.55o	1049.80f	1021.10n	1002.05o	1172.00d	1657.65ik	1751.95gj	1865.95cg
Pavon-76	873.40k	787.65m	865.81l	946.30m	906.00p	981.30j	1003.35o	985.80p	1074.10k	1565.65k	1632.15jk	1800.15eh
CV (%)		3.36			3.37			3.36			4.05	

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

Legend: S_1 = Normal growing condition, S_2 = Late growing condition, S_3 = Very late growing condition

In late and very late sowing condition again the HT genotype BAW-1143 showed the highest heat unit (GDD) to attaining all the growth stages which were followed by other HT genotypes Prodip, BARI Gom-25 and BARI Gom-26. Whereas, HS genotype Pavon-76 had the lowest heat unit requirement for attaining different phenological stages which was followed by other HS genotype BAW-1146, BAW-1147, and BAW-1148 was similar because it matured in the shortest period.

In the very late growing heat stress condition, the requirements of heat unit (GDD) in BAW-1143 were 771.55 for booting, 1051.30 for heading, 1165.1 for anthesis and 1899.75 for grain filling in the first year and in the second year the corresponding values were 1074.1, 1196.45, 1296.05and 2028.35 respectively. Whereas, the lowest values of GDD which were attained by Pavon-76 were 771.55 for booting, 919.40 for heading, 964.15 for anthesis and 1647.05 for grain filling in the first year and in the second year the corresponding values were 865.81, 981.30, 1074.10 and 1800.15, respectively.

The heat unit or GDD was proposed to explain the relationship between growth duration and temperature. The requirement of heat units (GDD) was higher for normal growing condition than the late and very late growing condition. The early sown wheat has availed the longest period for completion of phenological stages and thus attained maximum values for GDD and it appeared to be reduced with subsequent delayed sowing. GDD decreased for different phenological stages with late and very late sowing. It was due to prevailing low temperature during reproductive phases of development in late-sown crop. These results were similar to those of Khichar and Niwas (2007). So, the requirement of heat units decreased for different phenological stages with late sowing.

Heat tolerant genotypes obtained higher GDD than heat sensitive ones for their longer phenological stages. The results were similar to those of Pal *et al.,* (1996) who reported that

GDD requirements were dependent on genetic constitution. Sandhu *et al.*(1999)), Rajput *et al.,* (1987), Paul and Sarker (2000) and Tripathi *et al.,* (2007) also reported that the requirement of heat units decreased for different phenological stages with delay in sowing. Panday *et al.,* (2010) also reported lower consumption of heat units under delayed sowing.

Pheno-thermal index (PTI)

Pheno-thermal indices (PTI) under different growing condition of eight wheat genotypes are presented in Table 05 for the first year and Table 06 for the second year.

It was observed that PTI was the highest during grain filling, whereas during tillering to booting stage, it was the lowest in both years. The duration of different phenophase of vegetative growth was lower in the very late sown crop as compared to the timely sown crop, and then growth duration increased with plant age. From the overall results it was found that BAW-1143 had the highest (17.64 and 21.29 for first and second year respectively) and Pavon-76 showed the lowest (16.74 and 20.48 for first and second year respectively) PTI at grain filling to maturity stage of late growing condition.

As a result, at the later stage (heading to physiological maturity) the value of PTI was closer among sowing time. Thus the trend of duration and GDD supported the value of PTI under all dates of sowing (Rajput *et al.,* 1987). The phenothermal indices decreased during vegetative stages but increased during reproductive phenophase with delay in sowing.

Heat use efficiency (HUE)

The interaction of sowing times and genotypes significantly influenced the heat use efficiency (HUE) in both years (Table 07 for 2011-12 and Table 08 for 2012-13). In both years, all the genotypes used heat more efficiently at normal growing condition compared to late and very late growing condition. Under normal growing condition, HT genotype BAW-1143 had the significantly highest HUE (2.22 and 2.37 for first and second year, respectively) and was followed by other three HT genotypes Prodip, BARI Gom-25 and BARI Gom-26. Whereas, HS genotype Pavon-76 had the lowest HUE (1.71 and 2.16 for first and second year, respectively).

Table 05: Phenothermal index (PTI) at different phenological stages of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	Booting			Heading			Anthesis			Physiological maturity		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Prodip	17.79ab	14.84c	14.97c	16.24bcde	15.75de	17.34abc	16.26b	16.03b	17.78a	17.48bc	18.16b	19.81a
BARI Gom-25	17.79ab	14.84c	14.97c	16.25bcde	15.84de	17.43ab	16.25b	16.08b	17.78a	17.42bc	18.09b	19.92a
BARI Gom-26	17.79ab	14.84c	14.97c	16.25bcde	15.84de	17.34abc	16.25b	16.08b	17.86a	17.48bc	18.16b	19.95a
BAW-1143	17.52ab	14.84c	14.93c	16.25bcde	15.88de	17.52a	16.25b	16.12b	17.92a	17.52bc	16.75c	20.00a
BAW-1146	17.94ab	14.78c	14.97c	16.24bcde	15.84de	17.61a	16.25b	16.08b	17.86a	17.42bc	18.09b	19.92a
BAW-1147	17.94ab	14.78c	14.97c	16.24bcde	15.84de	17.61a	16.26b	16.03b	17.78a	17.42bc	18.09b	19.87a
BAW-1148	17.94ab	14.78c	14.97c	16.24bcde	15.84de	17.61a	16.26b	16.03b	17.78a	17.42bc	18.09b	19.87a
Pavon-76	15.29c	14.71c	15.00c	16.11cde	15.62e	17.03abcd	16.24b	15.75b	17.22a	17.02bc	17.64bc	19.38a
CV (%)		4.43			3.78			4.21			4.54	

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

Legend: S_1 = Normal growing condition, S_2 = Late growing condition, S_3 = Very late growing condition

Table 06: Phenothermal index (PTI) at different phenological stages of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	Booting			Heading			Anthesis			Physiological maturity		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Prodip	15.71ab	15.69ab	15.82ab	15.68ab	15.34ab	15.26ab	15.84ab	15.34ab	15.24ab	17.28b	17.12b	17.11b
BARI Gom-25	15.66ab	15.77ab	15.80ab	15.71ab	15.56ab	15.07ab	15.89ab	15.67ab	15.01ab	17.43b	16.99b	16.98b
BARI Gom-26	15.66ab	15.77ab	15.80ab	15.71ab	15.63ab	15.07ab	15.96ab	15.81ab	15.01ab	17.50b	16.89b	16.85b
BAW-1143	15.67ab	15.84ab	16.11a	15.79ab	15.70ab	15.43ab	16.03a	15.67ab	14.86ab	17.43b	16.99b	16.98b
BAW-1146	15.71ab	15.69ab	15.82ab	15.67ab	15.32ab	15.26ab	16.03a	16.01a	15.24ab	17.28b	17.12b	17.09b
BAW-1147	15.71ab	15.69ab	15.82ab	15.67ab	15.41ab	15.27ab	15.79ab	15.69ab	15.24ab	17.21b	17.12b	17.14b
BAW-1148	15.77ab	15.62ab	15.01b	15.71ab	15.69ab	15.48ab	15.71ab	15.67ab	15.24ab	17.09b	17.16b	17.11b
Pavon-76	15.88ab	15.15b	15.54ab	15.77ab	15.62ab	15.46ab	15.68ab	15.49ab	15.43ab	17.02b	16.95b	20.69a
CV (%)		5.89			6.21			5.23			4.56	

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

Legend: S_1 = Normal growing condition, S_2 = Late growing condition, S_3 = Very late growing condition

At the late and very late growing condition, all the genotypes significantly reduced their HUE at various magnitude compared to the normal growing condition. These reductions for HT genotypes viz. BAW-1143, Prodip, BARI Gom-25 and BARI Gom-26 were lower (41.00% to 53.60% and 44% to 49% for first and second year, respectively) compared to HS genotypes Pavon-76 (63.74% and 72.69% for first and second year, respectively). However, in heat stress condition again, the HT genotype BAW-1143 attained the highest HUE (1.31 and 1.36 for first and second year, respectively), whereas HS genotype Pavon-76 showed the lowest heat use efficiency (0.62 and 0.59 for first and second year, respectively).

Table 07: Heat use efficiency (HUE) on grain yield basis at different phenological stages of eight wheat genotypes under normal, late and very late growing conditions in 2011-12

Genotypes	Heat use efficiency (HUE) (kg /ha / ºC day)			Reduction (%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	2.17ab	1.82cd	1.02f	53.00
BARI Gom-25	2.19a	1.87c	1.05f	52.05
BARI Gom-26	2.22a	1.86c	1.03f	53.60
BAW-1143	2.22a	1.84c	1.31e	41.00
BAW-1146	2.12ab	1.80cd	0.99f	53.30
BAW-1147	2.10ab	1.78cd	0.97f	53.81
BAW-1148	2.05b	1.76cd	0.94f	54.15
Pavon-76	1.71d	1.41fe	0.62g	63.74
CV(%)		4.52		

In a column, mean followed by the same letter(s) did not differ significantly at 5 % level by DMRT

Table 08: Heat use efficiency (HUE) on grain yield basis at different phenological stages of eight wheat genotypes under normal, late and very late growing conditions in 2012-13

Genotypes	Heat use efficiency (HUE) (kg /ha / ºC day)			Reduction (%) at very late growing condition compared to normal
	Normal growing condition	Late growing condition	Very late growing condition	
Prodip	2.43a	1.66c	1.24d	48.97
BARI Gom-25	2.38a	1.72c	1.29d	45.80
BARI Gom-26	2.39a	1.74c	1.31d	45.19
BAW-1143	2.43a	1.77c	1.36d	44.03
BAW-1146	2.37a	1.62c	0.99e	58.23
BAW-1147	2.33ab	1.65c	0.95e	59.23
BAW-1148	2.32ab	1.61c	0.90e	61.21
Pavon-76	2.16b	1.34d	0.59f	72.69
CV (%)		5.34		

In a column, mean followed by the same letter(s) did not differ significantly at 5 % level by DMRT

The higher heat-use efficiency in timely sown wheat genotypes might be due to higher production of crop biomass per heat unit absorbed. The lower HUE in delayed sowing can be expected due to accumulation of comparable GDD to that of early sowing at later crop growth stages. Higher heat-use efficiency at earlier sowings can be ascribed to proportionate increase in dry matter/each heat unit absorbed. The lower heat-use efficiency in delayed sowing can be expected due to accumulation of comparable growing degree days to that of early sowing at later crop growth stages. The results are in close agreement with those of Panday *et al.*(2010). A similar result was also reported by Sikder (2009) and Paul and Sarker (2000). The normal growing plants produced higher grain yield by using accumulated heat units efficiently. Throughout the normal growing condition, heat was accumulated more efficiently and increased physiological activities that confirmed higher grain yield. The timely sown crop used heat more efficiently than the late sown crop.

CONCLUSION

This study demonstrates that heat stress induced severe negative effects on phenology, GDD, PTI and GUE of wheat genotypes. Under normal growing condition in both years, BAW-1143 needed the highest days at all the phenological stages, the highest heat unit (GDD, PTI and HUE whereas Pavon-76 required the lowest days for attaining different phenological stages. Under late and very late growing conditions, all the genotypes significantly decreased the requirement of days for attaining different phenological stages of growth. At late and very late growing conditions, the HT genotype BAW-1143 needed the highest number of days and closely followed by other HT genotypes BARI Gom-25, BARI Gom-26 and Prodip. Whereas, HS genotype Pavon-76 required the lowest number of days for attaining all the phenological stages, GDD, PTI and HUE of growth which was followed by other MHT genotype.

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