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Genotypic Variations in Wheat for Phenology and Accumulative Heat Unit under Different Sowing Times

Abdul Sattar[1], Muhammad Mahmood Iqbal[2], Ahsan Areeb[1], Zeeshan Ahmed[3], Muhammad Irfan[1], Rana Nauman Shabbir[3], Ghulam Aishia[4] and Saddam Hussain[4,5]*

[1] Department of Agronomy, University of Agriculture, Faisalabad-38040, Pakistan
[2] Ayyub Agriculture Research Institute Jhang Road, Faisalabad-38040, Pakistan
[3] Department of Crop Physiology, University of Agriculture, Faisalabad-38040, Pakistan
[4] College of Plant Science and Technology, Huazhong Agricultural University, Wuhan, Hubei 430070, China
[5] College of Resources and Environment, Huazhong Agricultural University, Wuhan, Hubei 430070, China

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Abstract: Delay in wheat is perhaps the one of the major factors responsible for low crop yield mainly due to the sub-optimal temperature during the different phenological stages. A field study was carried out to investigate the phenological performance of five newly developed wheat cultivars (Lasani-2008, Faisalabad-2008, Shafaq-2006, Sahar-2006 and Inqlab-91) under early (10-November) and the late sown (10-December) conditions during 2011-12 growing season. The experiment was laid out in randomized complete block design under factorial arrangement of treatments replicated four times. Results indicated that delay in sowing of wheat was detrimental for its growth. Early sown wheat got more number of days to attain different phenological stages, higher heat unit and heat use efficiency as compared to the late sowing. In case of late sowing, the cultivars phased a significant level of high temperature stress that affected the required days to crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity of all cultivars as compared with early sown crop. When wheat was sown late in season, the heat use efficiency was reduced in the range of 21-35% across different cultivars compared with early sown crop. Variations were also apparent among cultivars regarding their response to sowing dates. The cultivar Faisalabad-2008 ontogenically being more plastic, performed well in late sown conditions, nonetheless, cultivar Iqlab-91 remained superior to rest of cultivars, when planted early in season. These results are of practical concern for wheat growers in Pakistan and may be fruitful in future for crop modelling in wheat.

***Corresponding author:** Saddam Hussain
Tel.:+86 13 5458 74 386; **Fax:** +86 27 8728 8380. **Email:** shussain@webmail.hzau.edu.cn

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1. Introduction

Sowing cereal crops at an appropriate time is one way of realizing higher economic yields as it allows the crop to fully express their yield potential. Seasonal changes in temperature, precipitation and growth periods have potential impacts on the phasic development as well as productivity of crops (Hussain et al., 2014). In the era of climate change, considerable improvement in cereal production is inevitable to feed the ever increasing and burgeoning population and to maintain global food security (Deryng et al., 2014). Yield decline of cereal crops including rice, wheat, corn with rising temperatures is shocking, as yield augmentations predicted by increasing CO_2 are either not realized or are negated by rising temperatures (Prasad et al., 2006; Rehmani et el., 2014). Global production of wheat is predicted to decrease by 6% for each °C of further increase in temperature and become more variable over space and time (Asseng et al., 2014). Adverse effects of high temperature on crop yields results from the negative impact on development of morphological units that contribute to harvest index and such responses vary with the duration, timing, and sternness of the high temperature stress (Asseng et al., 2014).

Like other crops, wheat requires particular environmental conditions for better emergence and vigorous growth. A volumetric data is available on the effect of planting time on wheat with a general consensus that planting too early or beyond optimum time reduce wheat yield enormously. Delayed planting of wheat seems inevitable both in rice-wheat and cotton-wheat cropping systems, and has been identified as a major bottleneck in wheat production in these systems in the Indo-Gangetic plains (Hussain et al., 2015).

Phenological development is the most important attribute involved in adaptation of various crops to their growing environments. Phenology is known as an ordered sequence of different processes punctuated by discrete events such as sowing, emergence, booting, heading, anthesis, and maturity. It has been assumed that the plant, or part of the plant, possesses developmental clock that proceed at given rate for each of the above phases, dependent on temperature (Thornley and Johnson, 1990). Wheat is adopted in a wide range of environmental conditions but it can grow well and can achieve full genetic potential under optimum environmental conditions (Asseng et al., 2014). Wheat growth and phenology are adversely affected due to sub-optimal temperature during all growth stages. Porter and Gawith (1999) observed that wheat require 17-23°C temperature over the course of entire growing season with a minimum temperature of 0°C and a maximum of 32°C beyond which growth is seized. However, wheat is less sensitive to temperature during its vegetative phase than the reproductive phase (Entz and Fowler, 1988).

Temperature beyond optimum reduces the length of crop growing season, so less radiations are intercepted resulting in less photo-assimilation and ultimately lowered grain yield (Lawlor and Mitchell, 2000; Fahad et al., 2014). Wang et al., (2008) stated that the growth period of wheat from seedling emergence to stem elongation was reduced by 4.3 day, while it was prolonged by 3.3 day from stem elongation to booting stage for every 1.8°C of increase in minimum temperature during the growth period. Photoperiod also determine the solar radiation interception period and it's direct relation with temperature play a key role in driving developmental processes, general responses of leaf initiation and appearance rates and leaf number (Slafer et al., 1994; Brooking et al., 1995). All these components are critical determinants of grain yield (Kantolic and Slafer, 2005). Phenological phases of a crop may respond to the changes in both minimum and maximum temperatures (Zhou et al., 2007). Change in temperature ranges may pose direct impact on crop phenological seasonality in many ecological regions of the world (Chmielewski and Rotzer, 2002).

Understanding the relationship between temperature and phenological developmental process of crop plant is critical for determination of production areas for introducing new species (Ye et al., 2002; Zhang et al., 2003). Parmesan and Yohe (2003) observed that changing environment expected to lead changes in life cycle events. Ample environmental factor relates with the genetics to influence the phenological and phyllochron development but no single environmental factor completely predicts development, nonetheless temperature and occasionally photoperiod are obviously the most critical factors (Masle et al., 1989).

Each developmental stage of wheat has its own total heat requirement. Development can be estimated by accumulating degree days between the high and low temperature thresholds throughout the season. It is tough to predict plant growth based on the calendar time because temperature may vary greatly from year to year. Instead, growing degree days based on actual temperatures are a simple and accurate way to predict the time spam of plant growth stage. In coming decades, high temperature governed by global warming could be a great challenge for global food security as it has been predicted to pose a catastrophic loss of wheat productivity. Therefore, present study was carried out to determine the genotypic variations in phenology and accumulated heat units in wheat and to identify the well adapted cultivar under late sowing high temperature stress conditions

2. Material and Methods

2.1 Site description

Present study was conducted at Agronomic Research Area, University of Agriculture, Faisalabad (31.25° N, 73.09° E, and 184 m above sea level) during 2011-12. The soil of the experimental site was a sandy clay loam with proportion of sand, silt and clay as 54.95, 20.15 and 24.90%. Soil pH and EC was 7.3 and 0.97 dSm-1, respectively. The organic matter, total nitrogen, available phosphorus and potassium were 0.84%, 0.069%, 16.2 mg kg-1 and 174 mg kg-1, respectively. The bulk density and cation exchange capacity was 1.34 g CC-1 and 4.35 cmolc kg^{-1}.

2.2 Experimentation

Treatments comprised of five genotypes (Faisalabad-2008, Inqlab-91, Lasani-2008, Sahar-2006 and Shafaq-2006) and two sowing dates viz. 10-November (early) and 10-December (late) in 2011-12 growing season. Experiment was laid out in Randomized Complete Block Design with factorial arrangements replicated four times. The net plot size was 7.5 m × 5.0 m. Seedbed was prepared by cultivating the soil with a tractor-mounted disk plough and then cultivating twice with a cultivator followed by planking. All cultivars were sown with a single row hand drill using seed rate of 125 kg ha-1 in 22.5 cm apart rows.

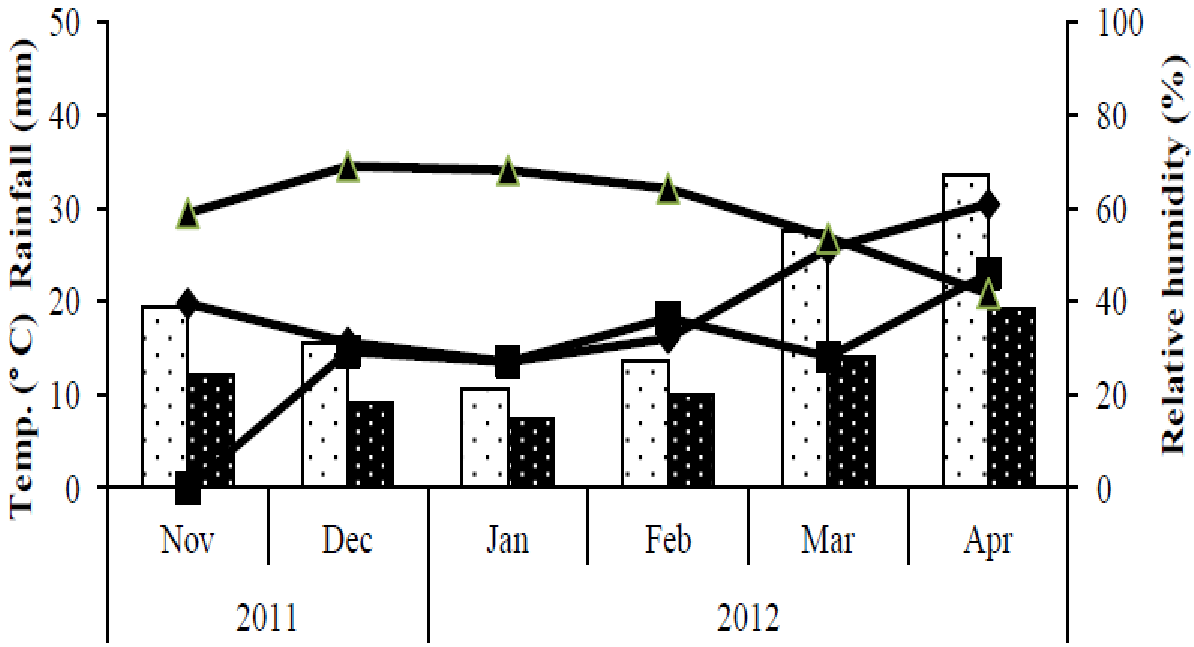

Figure 1: Summary of the metrological data during the crop season (2011-2012).

A standard fertilizer dose of 120:60 kg N: P ha-1 was applied in the form of urea and diammonium phosphate (DAP). The whole of the phosphorus and 1/3rd of the N was applied as a starter basal dose while residual N was equally split at tillering and booting. The first irrigation was applied 15 days after crop emergence, and subsequent irrigations were applied at tillering, jointing, booting, anthesis and grain filling. In all, six irrigations were applied to mature a crop besides soaking irrigation. No serious incidence of insect or disease was observed and no pesticide or fungicide was applied to either plants. Crop was manually harvested at physiological maturity on 15th of April.

Number of days required for different phenological stages (crown root initiation, tillering, boot, heading, anthesis, grain filling and maturity) were recorded when 50% or all plants in that particular plot reached the specified growth stage in the treatments. The growing degree days were calculated by using the following formula.

$$GDD = \left[\frac{T_{MAX} - T_{MIN}}{2} \right] - T_{BASE}$$

Where T_{MAX} is the daily maximum air temperature, T_{MIN} is the daily minimum air temperature, and T_{BASE} is the temperature below which the process of interest does not progress.

Heat use efficiency (HUE) for grain yield was obtained by the following formula;

$$HUE = \frac{Grain\ yield\ (kg/ha)}{Accumulated\ heat\ units\ (°C/day)}$$

2.3 Statistical Analysis

Data collected on all parameters were analyzed statistically by using Fisher's analysis of variance technique and least significantly difference (LSD) test at 5% probability level was applied to compare the treatments' means (Steel et al., 1997).

3. Results

Results indicated significant differences among wheat cultivar in attaining days for different phenological stages when sown under early and late season (Table 1). Under early sown conditions (10-Nov), Inqlab-91 took the maximum days to attain the crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity which was statistical at par with Faisalabad-2008, Sahar-2006 and Lasani-2008. Nevertheless, under normal sowing condition, Shafaq-2006 took minimum days to attain all the phenological stages. Late sowing of wheat significantly decreased the number of days for attaining phenological phases of development in all wheat cultivars. The cultivar Faisalabad-2008 took maximum days for attaining the crown root stage, tillering, booting, heading, anthesis, grain filling and maturity which was closely followed by the Inqlab-91, when planted under late sown conditions. Whereas, minimum days for attaining all phenological stages of development was recorded by Sahar-2006 which was statistically at par with Lasani-2008, followed by the Shafaq-2006.

Significant influence of sowing dates and cultivars on accumulated heat unit (growing degree days; GDD) at all the phenological stages of development was observed (Table 2). Minimum GDD was observed at crown root initiation, but at later stages (tillering, booting, heading, anthesis, grain filling and maturity) GDD were increased all the phenological stages of wheat development. Finally, maximum GDD were recorded at maturity. Among different cultivars, maximum GDD was recorded in cultivar Inqlab-91 at all the phenological stages (crown root initiation, tillering, booting, heading, anthesis, grain filling and maturity) that was statistically at par with Faisalabad-2008 followed by the cultivar Sahar-2006 when planted early in season (10-Nov). Under late sowing high temperature stress, growing degree days of all cultivars were reduced at all phenological stages of development. Results showed that Faislabad-2008 required highest GDD for all phenological stages, when planted under late sowing high temperature (10-Dec) conditions and closely followed by the cultivar Inqlab-91. While minimum GDD were observed in cultivar Sahar-2006 followed by the Lasani-2008 when sown late in season (10-Dec).

In case of heat use efficiency (HUE), it was observed that all the cultivars used the heat more efficiently when planted early (10-Nov) in season (Table 3). Under late sowing high temperature, Lasani-2008 and Faisalabad-2008 used maximum heat. However, minimum HUE under late sowing was observed in Inqlab-91 and Sahar-2006. Under late sowing high temperature conditions, significantly reductions in HUE were observed for all cultivars but at different magnitude, when compared with normal sowing (10-Nov). Maximum reduction was recorded in Inqlab-91 and Sahar-2006, when planted at 10-Dec.

4. Discussion

High temperature stress is a major cause of yield loss and in the near future, the number of heat events is projected to increase (Rehmani et al., 2014). Quantifying the future impact of high temperature stress on wheat production and developing appropriate adaptation and mitigation strategies are inevitable for developing food security policies worldwide (Liu et al., 2014). In present study, high temperature near maturity might have induced modifications in plants, which is apparent from the change in existing physiological processes or from the altering pattern of development.

Table 1. Phenology (days after sowing) of five wheat cultivars as affected by sowing dates

Cultivars	Crown root initiation		Tillering stage		Booting stage		Heading Stage	
	10-Nov	10-Dec	10-Nov	10-Dec	10-Nov	10-Dec	10-Nov	10-Dec
Lasani-2008	17.0 ef	21.0 ab	23.0 bc	20.0 e	64.0 abc	51.7 f	68.0 ab	55.7 e
Faisalabad-2008	19.0 cd	21.3 ab	23.6 abc	20.6 de	66.3 a	56.6 d	69.0 a	60.7 c
Shafaq-2006	16.6 ef	20.0 bc	22.0 bc	18.0 f	61.6 c	52.7 ef	65.7 b	56.6 de
Sahar-2006	16.0 f	21.0 ab	24.6 ab	19.0 ef	63.3 bc	51.4 f	67.4 ab	55.3 e
Inqlab-91	18.0 de	22.3 a	25.0 a	20.3 de	65.4 ab	55.0 de	69.3 a	59. cd
Mean	17.3 B	21.1 A	23.6 A	19.6 B	64.1 A	53.4 B	67.2 A	57.4 B

Cultivars	Anthesis stage		Grain filling stage		Maturity stage	
	10-Nov	10-Dec	10-Nov	10-Dec	10-Nov	10-Dec
Lasani-2008	79.7 ab	66.4 e	114.7 b	95.0 e	125.7 b	103.7 ef
Faisalabad-2008	76.4 c	71.0 d	109.6 c	100.3 d	122.4 c	108.4 d
Shafaq-2006	77.4 bc	67.0 e	111.3 c	95.7 e	124.0 bc	104.6 ef
Sahar-2006	79.0 abc	65. 4 e	115.3 ab	95.4 e	126.0 ab	102.3 f
Inqlab-91	81.6 a	70.0 d	118.0 a	99.3 d	128.7 a	106.3 de
Mean	78.8 A	68.0 B	113.8 A	97.1 B	125.3 A	105.0 B

Mean values sharing the different letters in a trait differ significantly at $P \geq 0.05$.

Table 2: Growing degree days (GDD) of five wheat cultivars as affected by late sowing high temperature

Cultivars	Crown Root Initiation		Tillering stage		Booting stage		Heading Stage	
	10-Nov	10-Dec	10-Nov	10-Dec	10-Nov	10-Dec	10-Nov	10-Dec
Lasani-2008	230.92 de	280.58 ab	304.58 ab	267.92 de	681.39 ab	585.81 e	710.81 ab	622.39 e
Faisalabad-2008	255.83 bcd	287.58 a	310.08 ab	275.92 cd	698.31 a	630.56 c	695.81 b	661.97 c
Shafaq-2006	226.58 de	280.53 ab	292.92 bc	243.25 f	667.97 b	597.39 de	693.06 b	630.89 de
Sahar-2006	218.67 e	272.25 abc	319.33 a	255.83 ef	677.64 ab	581.64 e	705.64 ab	619.39 e
Inqlab-91	243.25 dce	297.25 a	322.50 a	272.08 de	690.39 a	616.72 cd	722.28 a	650.64 cd
Mean	235.05 B	283.65 A	309.88 A	263.00 B	683.14 A	602.42 B	705.52 A	637.06 B

Cultivars	Anthesis stage		Grain filling stage		Maturity stage	
	10-Nov	10-Dec	10-Nov	10-Dec	10-Nov	10-Dec
Lasani-2008	812.90 ab	698.64 e	1184.82 b	969.74 e	1343.11 b	1056.21 e
Faisalabad-2008	784.65 c	738.43 d	1121.23 c	1022.62 d	1292.42 c	1106.10 d
Shafaq-2006	791.99 bc	702.81 e	1141.41 c	976.17 e	1318.73 bc	1066.32 de
Sahar-2006	805.99 bc	693.14 e	1192.91 b	973.00 e	1346.97 ab	1042.72 e
Inqlab-91	834.57 a	729.37 d	1229.46 a	1013.34 d	1385.42 a	1083.31 de
Mean	806.02 A	712.48 B	1173.92 A	991.13 B	1337.43 A	1070.91 B

Mean values sharing the different letters in a trait differ significantly at $P \geq 0.05$.

Table 3: Heat use efficiency (HUE) of five wheat cultivars as affected by late sowing high temperature

Cultivars	Heat use efficiency		Reduction (%) under late sowing
	10-Nov	10-Dec	
Lasani-2008	4.45 a	3.53 b	20.67
Faisalabad-2008	4.34 a	3.34 bc	23.04
Shafaq-2006	4.07 a	3.14 bcd	22.85
Sahar-2006	4.31 a	2.95 cd	31.55
Inqlab-91	4.26 a	2.76 d	35.21
Mean	4.28 A	3.13 B	26.86

Mean values sharing the different letters in a trait differ significantly at $P \geq 0.05$.

These responses may differ from one phenological stage to another. Vulnerability of species and cultivars to high temperatures may vary with the stage of plant development, but all vegetative and reproductive stages are affected by high temperature stress to some extent (Wahid et al., 2007).

During the early growth, well developed root system is extremely important for the growth and development of wheat (McMaster et al., 2003). Our result showed that under late sowing, crown root initiation took more time as compared with that in early sown crop. Numerous studies have shown that environmental factors like temperature affect crown roots growth (Chmielewski and Rotzer, 2002; Wang et al., 2008). Crown roots are more sensitive to the range of temperature occurring during the early growth. The response of crown root development differs greatly among the species. Under late sown condition, cultivar Faisalabad-2008 took maximum days for initiation crown roots as compared with rest of wheat cultivars. It tends to have an optimum temperature for initiation which also various greatly among the species. Crown root initiation depends on mobilization of seed reserve. The 25°C temperature may increase enzymes activity for the mobilization of seed reserve and thus enhanced crown roots imitation.

Shehzad et al. (2002) reported that yield components were assumed to develop sequentially, and earlier-forming components like tiller formation influence those developing in later stages and thus final yield. Late maturing cultivars with long grain filling period were assumed to influence only kernel weight, because spike number per plant and kernel number per spike were determined before the initiation of grain filling. Reproductive phases of wheat crop like booting, heading and anthesis are more sensitive to high temperature (Foolad, 2005). Both male and female gametophytes are sensitive to high temperature and the response varies with genotypes; however, ovules are generally less heat sensitive than pollen (Peet and Willits, 1998).

In present study, all the cultivars phased their booting stage between 61 to 66 days in early sowing. But under late sowing, wheat crop reached early to its booting stage due to high temperature stress. The timing of heading and maturity are among the major traits that are related to the adaptation of wheat cultivars under prevalent field conditions in particular areas. Under normal sowing conditions, early heading and late maturity, permits a long grain-filling period and improves grain filling because the contribution of post-anthesis assimilates is important to grain yields in wheat (Sanchez et al., 2002; Khan et al., 2007). Heat units as GDD were higher for early sowing than the late sowing conditions. 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 unfavorable high temperature during the growing period. So, the heat units decreased for different phenological stages with late sowing.

Comparative cultivar obtained higher GDD than those of lower ones for their longer phenological stages. Previous studies also reported that requirement of heat units decreased for different phenological stages with delay in sowing (Sandhu et al., 1999, Paul and Sarker, 2000). In the present study, all the cultivars used heat more efficiently under early sowing than those of late growing condition. Similar results were reported by Paul and Sarker (2000) and Haque (2000). They reported that the timely sown crop furnish higher grain yield by using accumulated heat units more efficiently. Favorable temperature ranges in timely sown crop resulted in efficient heat accumulation and increased physiological activities that resulted in higher grain yield (Singh et al., 2008). Under late sowing high temperature conditions, the wheat crop completes its life cycle much faster than under normal temperature conditions. All crop stages receive short duration, consequently, there are fewer days to accumulate assimilate during life cycle and production of biomass is reduced. It ultimately affects grain filling and finally lower crop yield.

5. Conclusion

Conclusively, of the factors included in this study, cultivar and sowing times were dominant in determining wheat phenology as well as accumulated heat units, suggesting that cultivar selection and timely sowing of wheat are effective strategies to attain full genetic potential of cultivar.

Our study also confirmed the adverse effects of late sowing in terms of wheat phenology and accumulated heat unit. Contradictions were apparent among cultivars, and Faisalabad-2008 ontogenically being more flexible performed well in late sown conditions, nevertheless, Iqlab-91 was at the top when planted at recommended time. These results are of practical concern for wheat growers in Pakistan and may be helpful in future for crop modelling and assessing future wheat production under changing climatic conditions.

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Competing Interests

There is no competing interest regarding the publication of this paper.

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