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DEVELOPMENTAL AND PHENOLOGICAL RESPONSES OF WHEAT TO SOWING DATES

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This study was conducted to study the developmental and phenological responses of different wheat cultivars planted at varying sowing dates. Five wheat cultivars viz. Sahar-2006 (SH-06), Faisalabad-2008 (FSD-08), Lassani-2008 (LS-08), Abdul Staar-2002 (AS-02) and Triple Dwarf-1 (TD-1) were sown on 25th Oct, 10 and 25th Nov, and 10th and 25th Dec. Minimum days to emergence and tillering were recorded in early planted wheat. In comparison late planted wheat took less time to switch into other phenophases like jointing, booting and grain formation stages due to high temperature during lateral growth stages of late planted wheat. Likely, early planted wheat accumulated less growing degree days (GDD) and photo thermal units (PTU) for emergence but accumulated more GDD and PTU to switch into next phenophases from tillering to grain development. Nonetheless late planted wheat required more helio-thermal units (HTU) only during grain formation stage. However, total growth period of wheat was substantially decreased from 166 days in early planted (25th Oct) to 110 days in late planted (25th Dec) being a photosensitive in nature. Tested wheat cultivars behaved differently and LS-08 and AS-02 had higher grain yield and heat use efficiency (HUE) due to higher tillering capacity and longer growth period, whereas performance of short duration cultivar (TD-1) was poor. In conclusion, wheat cultivars LS-08 and AS-02 planted on 10th Nov produced more grain yield and had higher HUE.
Keywords: Sowing dates, growing degree days, flag leaf growth rate, grain yield, heat use efficiency

INTRODUCTION

Delayed planting is one of the chief yield limiting constraints of wheat in rice-wheat and cotton-wheat cropping systems of South Asia (Fujisaka *et al*., 1994). In Pakistan, optimum time for wheat panting is last week of October to mid of November and delay in planting after mid November suffered about one percent yield tax for every day delay in sowing (Tanveer *et al*., 2009). But late maturing of Basmati varieties of rice and delayed picking of cotton compelled the sowing of wheat up to late December (Nayyar and Iqbal, 2001). In addition, occasional rainfall during land preparation may further delay wheat planting by 2-3 weeks (Aslam *et al*., 1993). Late planted wheat matures a little late in such a way that temperature is high enough to influence the grain filling rate and duration accompanied with yield penalty (Rahman *et al*., 2009). Furthermore, late planted wheat completes its entire life cycle in much shorter time because starch accretion is ended at same specific time without depending on its sowing time due to its photosensitive nature.

Phenology is the study of growth phases during plant life cycle. Knowledge about length of total growing season and relative duration of vital phenophases is important as both are critical determinants of final grain yield of crop under different growing environments (Kantolic and Slafer, 2005). Crop performance is strongly influenced by prevailing weather conditions; and temperature and solar radiation are among the driving forces to modulate assimilates production and development rate of crops (Reynolds *et al*., 2002). Temperature plays a key role in determining the sowing time and consequently the duration of different phenophases to influence crop productivity (Tewari and Singh, 1993). Thus, awareness of correct timing of phenological events and their connection with yield determinants is pre-requisite to boost up wheat productivity under varying environmental conditions (Gbmez-Macpherson and Richards, 1997).

Generally early planted wheat experiences smaller germination phase than late planting but days taken to start anthesis and booting stages notably decreased in late sown wheat due to elevated heat stress later in the season (Nahar *et al*., 2010). Overall impact of delayed planting is also reflected in the form of shortening of plant height, reduction in number of internodes, days to heading, days to maturity and grain filling period and ultimately in the reduction of yield and yield components (Amir and Sinclair, 1991; Miralles *et al*., 2001; Rahman *et al*., 2009). At early phenophases, phenothermal indices decreased and increased in later growth stages in case of late sowing than normal planting wheat (Sikder, 2009). Buildup of GDD and PTU are good estimators to study wheat phenology and can be used as reliable tool to optimize the sowing period for different wheat cultivars (Pal *et al*., 1996; Prabhakar *et al*., 2007). Although accretion of GDD and PTU for each phenophase is somewhat constant but different wheat varieties can modify it noticeably (Phadnawis and Saini, 1992). Likewise, estimation of heat use efficiency (HUE) is also useful for the appraisal of yield potential of wheat in different growing conditions. Addition of NPK fertilizers improves crop yields (Shehu *et al*. 2010).

Wheat required 68 to 90 days for grain formation but late planted wheat manifested severe reduction in number of days to complete grain formation due to short life cycle and high temperature at reproductive stage (Slafer and Whitechurch, 2001; Sial *et al*., 2005). Nonetheless, late planting may not permit to achieve the desired level of vegetative growth of crop; high temperature during its later stages lead to forced maturity and low productivity (Prabhakar *et al*., 2007; Farooq *et al*., 2011). Night temperature over 13°C coupled with day temperature of 33-35 °C in the 2nd fortnight of Oct had adverse effects on tillering and resulted in smaller ears with fewer fertile spikelets (De *et al*., 1983). At higher and lower temperatures, different wheat genotypes observe different time to start emergence, crown root development and stem elongation (Jame and Cutforth, 2004).

With the ongoing global climate change, for the last few years winter comes a bit late in Pakistan and optimum temperature for wheat emergence is available even during the 1st fortnight of Dec. Therefore, this study was designed to study the developmental and phenological responses of different wheat cultivars to sowing dates for optimizing the sowing time to harvest maximum wheat productivity.

MATERIALS AND METHODS

***Site description and experimental details*:** This study was conducted at Research Farm, University College of Agriculture, Bahauddin Zakariya University, Multan (71.43° E, 30.2° N and 122 meters above sea level), Pakistan, during winter 2009-10. The experimental area was quite uniform and sandy clay loam in texture. The experiment was laid out according to randomized complete block design (RCBD) with split plot arrangement having net plot size of 5 m × 1.8 m and replicated three times. Five wheat cultivars viz. Sahar-2006 (SH-06), Faisalabad-2008 (FSD-08), Lassani-2008 (LS-08), Abdul Staar-2002 (AS-02) and Triple Dwarf-1 (TD-1) were sown on 25th Oct, 10 and 25th Nov, and 10th and 25th Dec, respectively. Weather data recorded during whole course of study are given in Table 1.

***Crop husbandry*:** Before seedbed preparation, pre-soaking irrigation of about 10 cm was applied. When soil reached to practicable moisture level, seedbed was crafted by cultivating the field two times with tractor-mounted cultivator followed by planking. All wheat cultivars were sown on well prepared seedbed on aforementioned sowing dates. Sowing was done by hand drill keeping the row to row distance of 22.5 cm and seed rate of 125 kg ha^{-1}. Fertilizers were applied @ 200 and 150 kg ha^{-1} nitrogen and phosphorus, respectively by using urea and triple super phosphate (TSP) as source. Whole phosphorus and half nitrogen were applied at the time of sowing while remaining nitrogen was applied with first irrigation. Irrigations at crown root, booting, flowering and grain formation stages of wheat were applied to save the crop from the damaging effects of moisture stress. All other necessary agronomic practices were adopted to keep crop free from insect, diseases and weeds. Mature crop was harvested during second decade of April, 2010.

***Measurements*:** When the 1st seedling got emerged, it was recorded as days to start emergence. The days on which 50% seedlings switched into tillering, jointing and booting stage were recorded as days to start tillering, jointing and booting stage. Days taken from flowering to grain formation were recorded when more than 50% plants complete their flowering to physiological maturity of crop. Daily growing degree days (GDDs) (°C days) were calculated as under:

$$\text{Daily GDD} = [(T_{max} + T_{min})/2] - T_b$$

Where, T_{max} and T_{min} represent the maximum and minimum temperatures in °C and T_b denotes the base temperature

Table 1. Weather data throughout the study

Month	Mean monthly temperature (°C)	Mean monthly RH (%)	Total rainfall (mm)
Oct-09	25.30	59.60	00.50
Nov-09	19.20	75.10	00.00
Dec-09	15.50	76.80	00.00
Jan-10	12.20	79.00	02.10
Feb-10	15.80	63.00	02.40
Mar-10	23.50	62.00	45.10
Apr-10	30.40	34.00	06.50

Source: Agro-climatic Cell, Central Cotton Research Institute, Multan, Pakistan (minimum temperature at which growth ceases) and 0°C was taken as base temperature for emergence and tillering stage while 5°C was used as base temperature for next phenophases. Accumulated GDDs for different phenophases were calculated by summation of daily GDD of each developmental stage. Accumulated GDDs for each phenophase were multiplied with maximum possible sunshine hours (N) and actual sunshine hours (n) to calculate PTU and HTU.

To estimate the tillering capacity, total number of tillers of random selected five plants was counted from each plot on daily basis up to constant count and then averaged. At maturity, data regarding plant height and grain and straw yield was also computed by using standard procedures. Grain yield was then adjusted to 10% moisture contents and grain yield data was taken from Hussain *et al*. (2012). Heat use efficiency (HUE) was computed by using the below given formulae:

HUE (kg ha^{-1} °C days^{-1})

= Grain yield (kg ha^{-1})/ Accumulated GDDs (°C days)

Statistical analysis: The collected data were statistically analyzed by using Fisher’s analysis of variance technique and LSD test at 5% probability level was used to compare the differences among treatment’s means (Steel *et al*., 1997).

RESULTS

Interaction among different sowing dates and wheat cultivars had significant effect on all phenological events except days taken from sowing to start emergence of wheat (Table 2).

More days to start tillering were observed in late planted (25th Dec) wheat cultivars SH-06, FSD-08, LS-08 and TD-1 while minimum days to start tillering were noted in SH-06, AS-02 and TD-1 planted on 25th Oct and 10th Nov (Table 2).

Table 2. Interactive effect of sowing dates and wheat cultivars on days taken to start different phenophases of wheat

Treatments	Days from sowing to emergence (days)	Days from sowing to tillering (days)	Days from sowing to jointing (days)	Days from sowing to booting (days)	Days from flowering to grain formation (days)	Days from sowing to maturity (days)
D_1V_1	4.67	12.00 ij	45.00 d	68.00 gh	90.33 b	158.33 c
D_1V_2	5.00	14.67 def	44.67 de	81.33 b	94.33 a	175.33 a
D_1V_3	4.67	13.67 fgh	41.33 fg	81.00 b	95.67 a	176.67 a
D_1V_4	4.67	11.67 j	45.00 d	82.33 b	87.00 c	169.33 b
D_1V_5	4.67	12.33 ij	41.33 fg	70.33 fg	80.67 d	151.00 d
D_2V_1	6.33	12.67 hij	52.33 a	76.00 cd	78.67 e	153.67 d
D_2V_2	5.67	14.00 efg	53.00 a	76.33 cd	75.00 f	151.33 d
D_2V_3	6.67	14.67 def	48.00 c	82.33 b	78.00 e	160.33 c
D_2V_4	6.00	11.67 j	50.00 b	87.00 a	81.67 d	168.67 b
D_2V_5	5.33	12.67 hij	43.00 ef	74.00 de	76.00 f	150.00 d
D_3V_1	7.67	14.33 def	39.00 i	76.33 cd	64.00 h	140.33 e
D_3V_2	8.00	13.00 ghi	38.33 i	71.67 ef	68.00 g	139.67 e
D_3V_3	8.00	12.00 ij	41.00 gh	76.67 c	62.67 h	139.34 e
D_3V_4	8.67	14.00 efg	47.00 c	81.00 b	59.00 i	140.00 e
D_3V_5	8.33	16.00 bc	39.33 hi	71.33 f	67.00 g	137.33 e
D_4V_1	9.00	15.00 cde	38.67 i	67.33 hi	57.00 j	124.33 f
D_4V_2	9.33	14.33 def	40.00 ghi	65.33 i	59.00 i	124.33 f
D_4V_3	8.33	13.00 ghi	41.33 fg	71.67 ef	51.00 k	122.67 f
D_4V_4	9.00	12.33 ij	48.00 c	74.00 de	49.67 k	123.67 f
D_4V_5	9.00	15.33 bcd	40.00 ghi	60.33 j	63.67 h	124.00 f
D_5V_1	9.67	18.00 a	36.00 j	59.67 j	50.00 k	109.67 g
D_5V_2	10.00	18.67 a	40.00 ghi	61.00 j	45.67 i	106.67 g
D_5V_3	9.00	18.00 a	38.33 i	70.00 fg	40.00 m	110.00 g
D_5V_4	9.33	16.33 b	44.00 de	71.00 f	40.00 m	111.00 g
D_5V_5	9.33	18.00 a	39.33 hi	59.67 j	51.00 k	110.67 g
D × V	**NS**	**1.07**	**1.96**	**2.36**	**1.83**	**5.14**

Where D_1, D_2, D_3, D_4 and D_5 represent 25 Oct, 10 Nov, 25 Nov, 10 Dec and 25 Dec, respectively; while V_1, V_2, V_3, V_4 and V_5 represent SH-06, FSD-08, LS-08, AS-02 and TD-1, respectively

Means not sharing the same letter within a column differ significantly from each other at 5% probability level

However, wheat cultivars SH-06 and FSD-08 sown on 10th Nov switched later to jointing stage against late planted (25th Dec) SH-06 which started jointing stage earlier (Table 2). Cultivar AS-02 planted on 10th Nov took maximum days to enter into booting stage while SH-06 and FSD-08 planted on 25th Dec and TD-1 planted on 10th and 25th Dec observed lesser days to start booting stage (Table 2). Moreover days taken to complete grain formation were gradually reduced with delay in wheat planting from 25th Oct to 25th Dec; and maximum days to complete grain formation were noted in FSD-08 and LS-08 planted on 25th Oct while LS-08 and AS-02 planted on 25th Dec observed minimum days to complete grain formation (Table 2). Moreover life cycle of wheat gradually decreased with delayed planting and cultivars behaved differently. Cultivars LS-08 and FSD-08 experienced longer life cycle on early planting (25th Oct) against the extreme short life cycle of all tested cultivars upon delayed planting (25th Dec) (Table 2).

Interactive effect of sowing dates and wheat cultivars had significant effect on the accrual of GDD to switch into different phenophases except to start emergence and jointing stage of wheat (Table 3). Wheat cultivar FSD-08 planted on 25th Oct accumulated more GDDs to start tillering while AS-02 planted on 10th and 25th Dec, and LS-08 planted on 25th Nov and 10th Dec accumulated few GDDs to start tillering (Table 3). Cultivars FSD-08, LS-08 and AS-02 accumulated more GDDs to start booting stage whereas SH-06, FSD-08 and TD-1 accumulated fewer GDDs in late planted wheat (25th Dec) (Table 3). Likewise, cultivars FSD-08 and LS-08 planted on 25th Oct and TD-1 planted on 10th Dec

Table 3. Interactive effect of sowing dates and wheat cultivars on growing degree days (GDD) accumulation to start different phenophases of wheat

Treatments	GDD from sowing to emergence (°C days)	GDD from sowing to tillering (°C days)	GDD from sowing to jointing (°C days)	GDD from sowing to booting (°C days)	GDD from flowering to grain formation (°C days)
D_1V_1	88.20	226.56 cd	701.10	820.76 c	1210.50 cd
D_1V_2	94.50	276.91 a	695.91	981.69 a	1264.10 ab
D_1V_3	88.20	258.03 b	643.97	977.67 a	1281.90 a
D_1V_4	88.20	220.27 cde	701.10	993.76 a	1165.80 efg
D_1V_5	88.20	232.85 c	643.97	848.92 b	1080.90 i
D_2V_1	96.58	183.67 fg	564.68	652.08 kl	1194.20 de
D_2V_2	86.42	203.00 e	571.87	654.94 jkl	1138.50 g
D_2V_3	101.67	212.67 de	517.92	706.42 h	1184.00 def
D_2V_4	91.50	169.17 ghi	539.50	746.46 efg	1017.80 j
D_2V_5	81.33	183.67 fg	463.97	634.92 lm	1153.70 fg
D_3V_1	101.35	181.03 g	462.54	768.68 def	1104.00 hi
D_3V_2	105.76	164.19 hij	454.63	721.68 gh	1173.00 ef
D_3V_3	105.76	151.56 ij	486.26	772.03 d	1081.00 i
D_3V_4	114.57	176.82 gh	557.42	815.67 c	1017.80 j
D_3V_5	110.17	202.08 ef	466.49	718.33 h	1155.80 fg
D_4V_1	109.26	179.25 gh	419.15	699.59 hi	1136.60 gh
D_4V_2	113.31	171.28 gh	433.60	678.81 ij	1176.50 def
D_4V_3	101.17	155.35 ij	448.05	744.62 fg	1016.90 j
D_4V_4	109.26	147.38 j	520.32	768.86 de	990.40 j
D_4V_5	109.26	183.23 fg	433.60	626.86 m	1269.50 ab
D_5V_1	105.17	177.48 gh	392.40	566.24 n	1079.00 i
D_5V_2	108.80	184.05 fg	436.00	578.89 n	985.50 j
D_5V_3	97.92	177.48 gh	417.83	664.30 jk	863.20 k
D_5V_4	101.55	161.05 hij	479.60	673.79 jk	863.20 k
D_5V_5	101.55	177.48 gh	428.73	566.24 n	1100.60 i
LSD at 5%	NS	15.10	NS	**23.86**	**30.43**

Where D_1, D_2, D_3, D_4 and D_5 represent 25 Oct, 10 Nov, 25 Nov, 10 Dec and 25 Dec, respectively; while V_1, V_2, V_3, V_4 and V_5 represent SH-06, FSD-08, LS-08, AS-02 and TD-1, respectively.

accumulated more GDDs from flowering to grain formation whereas LS-08 and AS-02 planted on 25th Dec accumulated less GDDs from flowering to grain formation stage (Table 3).

Interaction amid sowing dates and wheat cultivars had significant effect on PTU accumulation to switch into different phenophases except to start tillering (Table 4). All wheat cultivars planted on 25th Nov and 10th Dec observed higher accrual of PTU to start emergence compared with early and late planted crop (Table 4). However early planted SH-06, FSD-08 and AS-02 took more PTU to switch into jointing phase while SH-06 planted on 10th and 25th Dec and FSD-08 and TD-1 planted on 10th Dec took minimum PTU to switch into jointing stage (Table 4). Cultivars FSD-08, LS-08 and AS-02 observed higher accumulation of PTU to switch into booting stage in case of early planted wheat than late planted TD-1, SH-06 and FSD-08 which accumulated lesser PTU to switch into booting phase of wheat (Table 4). Cultivars FSD-08 and LS-08 planted on 25th Dec took more PTU from flowering to grain formation while LS-08 and AS-02 planted on 25th Dec took fewer PTU from flowering to grain formation (Table 4).

Table 4. Interactive effect of sowing dates and wheat cultivars on photo thermal units (PTU) accumulation to start different phenophases of wheat

Treatments	PTU from sowing to emergence (°C days hours)	PTU from sowing to tillering (°C days hours)	PTU from sowing to jointing (°C days hours)	PTU from sowing to booting (°C days hours)	PTU from flowering to grain formation (°C days hours)
D_1V_1	882 def	2220	6661 a	7715 c	12407 cd
D_1V_2	945 bcde	2714	6611 a	9228 a	12957 ab
D_1V_3	882 def	2529	6117 b	9190 a	13140 a
D_1V_4	882 def	2159	6660 a	9341 a	11949 efg
D_1V_5	882 def	2282	6117 b	7980 b	11080 j
D_2V_1	946 bcde	1763	5251 cd	5999 i	12240 de
D_2V_2	847 ef	1949	5318 c	6025 i	11670 gh
D_2V_3	996 abcd	2042	4817 ef	6499 h	12136 def
D_2V_4	897 cdef	1624	5017 de	6867 fg	12707 bc
D_2V_5	797 f	1763	4315 hi	5841 ij	11825 fgh
D_3V_1	973 abcde	1665	4278 hi	7110 de	11537 hi
D_3V_2	1015 abcd	1511	4205 ij	6676 gh	12258 de
D_3V_3	1015 abcd	1394	4498 gh	7141 de	11297 ij
D_3V_4	1100 a	1627	5156 cd	7545 c	10635 k
D_3V_5	1057 ab	1859	4315 hi	6644 gh	12078 def
D_4V_1	1005 abcd	1613	3877 kl	6646 gh	11877 fgh
D_4V_2	1042 abc	1542	4011 jkl	6449 h	12294 de
D_4V_3	931 bcdef	1398	4144 ij	7074 ef	10627 k
D_4V_4	1005 abcd	1326	4813 ef	7304 d	10349 k
D_4V_5	1005 abcd	1649	4011 jkl	5955 i	13266 a
D_5V_1	946 bcde	1668	3826 l	5521 k	11599 ghi
D_5V_2	979 abcde	1730	4251 hij	5644 jk	10594 k
D_5V_3	881 def	1668	4074 ijk	6477 h	9279 l
D_5V_4	914 bcdef	1514	4676 fg	6569 h	9279 l
D_5V_5	914 bcdef	1668	4180 ij	5521 k	11831 fgh
LSD at 5%	140.15	NS	**235.68**	**224.59**	**318.07**

Where D_1, D_2, D_3, D_4 and D_5 represent 25 Oct, 10 Nov, 25 Nov, 10 Dec and 25 Dec, respectively; while V_1, V_2, V_3, V_4 and V_5 represent SH-06, FSD-08, LS-08, AS-02 and TD-1, respectively

Means not sharing the same letter within a column differ significantly from each other at 5% probability level

Interaction amid sowing dates and wheat cultivars had significant effect on HTU accumulation to switch into different phenophases of wheat (Table 5). All the tested cultivars took maximum HTU to start emergence when planted on 25th Oct and 25th Nov while all tested cultivars except AS-02 took minimum HTU to start emergence when planted on 10th Nov (Table 5). Cultivar FSD-08 planted on 25th Oct and 10th Nov, and LS-08 planted on 25th Oct, 10th Nov and 25th Nov buildup higher HTU to switch into tillering phase while all the tested cultivars except AS-02 took lesser HTU to switch into tillering (Table 5). However higher accretion of HTU to switch into jointing and booting stage was computed in early planted wheat (25th Oct) while least accretion was recorded in late planted crop, although the cultivars differ slightly in this regard (Table 5). Moreover, TD-1 planted on 25th Nov recorded higher HTU accumulation from flowering to complete grain formation while TD-1 planted on 25th Oct and LS-08 and AS-02 planted on 25th Dec observed minimum HTU accretion from flowering to grain formation stage (Table 5).

Interaction between sowing dates and wheat cultivars had significant effect on plant height, tillering capacity, grain and straw yield, HUE and TDM accumulation of wheat (Table 6).

Maximum plant height was observed in 10th Nov planted LS-08 while TD-1 planted on 10th and 25th Dec recorded minimum plant height (Table 6). As-02 planted on 10th Nov recorded superior tillering capacity (more number of tillers per plant) while delayed planting (25th Dec) observed drastic reduction in tillering capacity of all tested cultivars

Table 5. Effect of sowing dates on helio thermal units (HTU) accumulation to start different phenophases of divergent wheat cultivars

Treatments	HTU from sowing to emergence (°C days hours)	HTU from sowing to tillering (°C days hours)	HTU from sowing to jointing (°C days hours)	HTU from sowing to booting (°C days hours)	HTU from flowering to grain formation (°C days hours)
D_1V_1	688 abc	1028 efghi	3870 a	4941 c	8994 jk
D_1V_2	737 a	1257 a	3841 a	5910 a	9392 ghi
D_1V_3	688 abc	1171 abc	3555 b	5885 a	9525 fgh
D_1V_4	688 abc	1000 fghij	3870 a	5983 a	8662 l
D_1V_5	688 abc	1057 defgh	3555 b	5110 b	8031 m
D_2V_1	580 defgh	1080 cdef	3523 b	3495 lm	9768 ef
D_2V_2	519 gh	1194 ab	3568 b	3510 lm	9313 hi
D_2V_3	610 cdefg	1251 a	3232 d	3786 ij	9685 efg
D_2V_4	549 fgh	995 ghij	3366 cd	4001 fg	10141 cd
D_2V_5	488 h	1080 def	2895 ef	3403 mn	9437 gh
D_3V_1	639 abcdef	1135 bcd	2868 f	4166 e	9892 de
D_3V_2	667 abcd	1029 efghi	2819 f	3912 ghi	10510 b
D_3V_3	667 abcd	950 ij	3014 e	4184 e	9686 efg
D_3V_4	723 ab	1109 bcde	3456 bc	4421 d	9119 ijk
D_3V_5	695 abc	1267 a	2892 ef	3893 ghi	10356 bc
D_4V_1	607 cdefg	1120 bcde	1982 ij	3701 jk	10161 cd
D_4V_2	630 bcdef	1071 cdefg	2051 hij	3591 kl	10518 b
D_4V_3	562 efgh	971 hij	2119 hi	3939 fgh	9091 ijk
D_4V_4	607 cdefg	921 j	2461 g	4067 ef	8854 kl
D_4V_5	607 cdefg	1145 bcd	2051 hij	3316 no	11349 a
D_5V_1	657 abcde	697 kl	1789 k	3193 o	10132 cd
D_5V_2	680 abc	723 k	1988 ij	3265 no	9254 hij
D_5V_3	612 cdefg	697 kl	1905 jk	3747 j	8105 m
D_5V_4	635 bcdef	633 l	2178 h	3800 hij	8105 m
D_5V_5	635 bcdef	697 kl	1955 j	3193 o	10334 bc
LSD at 5%	94.51	80.94	139.10	134.46	261.51

Where D_1, D_2, D_3, D_4 and D_5 represent 25 Oct, 10 Nov, 25 Nov, 10 Dec and 25 Dec, respectively; while V_1, V_2, V_3, V_4 and V_5 represent SH-06, FSD-08, LS-08, AS-02 and TD-1, respectively

Means not sharing the same letter within a column differ significantly from each other at 5% probability level

Table 6. Interactive effect of sowing dates and wheat cultivars on plant height, tillering capacity, grain and straw yield, heat use efficiency (HUE) and total dry matter accumulation of wheat

Treatments	Plant height (cm)	Tillering capacity	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	HUE (kg ha^{-1} ºC day^{-1})	TDM (g m^{-2})
D_1V_1	104.70 c	4.60 f	13920 ab	6856 b	3.37 c	1924.33 c
D_1V_2	102.50 c	6.33 c	12900 cd	5759 d	2.56 g	1967.18 bc
D_1V_3	110.40 b	6.20 c	12730 d	5937 cd	2.63 fg	1778.31 d
D_1V_4	104.80 c	7.87 b	12210 de	7122 ab	3.29 c	1990.12 bc
D_1V_5	84.10 fgh	6.20 c	10160 gh	4945 e	2.56 g	1799.14 d
D_2V_1	109.30 b	4.13 fghi	11480 ef	6070 c	3.29 c	2291.00 a
D_2V_2	104.00 c	5.27 e	13080 bcd	5804 cd	3.23 c	2034.25 b
D_2V_3	115.90 a	6.07 cd	13840 abc	7270 a	3.84 a	1844.88 cd
D_2V_4	103.70 c	9.13 a	14440 a	7255 a	3.65 b	1990.12 bc
D_2V_5	85.50 efg	4.13 fghi	9399 hi	6011 cd	3.36 c	1799.14 d
D_3V_1	104.70 c	3.13 jk	12590 d	5152 e	2.75 ef	1796.24 d
D_3V_2	102.00 c	4.47 fg	11330 ef	4218 fg	2.23 hi	1791.73 d
D_3V_3	102.30 c	6.00 cd	13090 bcd	5996 cd	3.23 c	1917.88 c
D_3V_4	101.70 c	8.00 b	12930 cd	5152 e	2.81 de	1887.45 cd
D_3V_5	80.80 hi	3.60 ij	6474 k	3952 g	2.11 i	1544.56 e
D_4V_1	91.67 d	3.80 hi	9222 hij	5182 e	2.82 de	1796.24 d
D_4V_2	86.67 efg	4.00 ghi	10840 fg	4218 fg	2.27 h	1791.73 d
D_4V_3	93.93 d	4.00 ghi	10000 gh	5937 cd	3.37 c	1785.27 d
D_4V_4	88.00 e	5.20 e	9689 h	5759 d	3.27 c	1887.45 cd
D_4V_5	78.10 ij	4.33 fgh	8489 ij	2707 i	1.42 k	1478.21 ef
D_5V_1	87.27 ef	2.33 l	9585 h	4485 f	2.72 ef	1552.25 e
D_5V_2	83.33 gh	2.87 kl	9563 h	3581 h	2.29 h	1429.11 fg
D_5V_3	85.20 efg	2.60 kl	9371 hi	4500 f	2.94 d	1721.32 d
D_5V_4	80.93 hi	5.60 de	9334 hi	3552 h	2.31 h	1440.21 f
D_5V_5	75.20 j	2.60 kl	8341 j	2767 i	1.66 j	1338.59 g
LSD at 5%	**3.59**	**0.56**	**979**	**287**	**0.16**	**96.50**

Where D_1, D_2, D_3, D_4 and D_5 represent 25 Oct, 10 Nov, 25 Nov, 10 Dec and 25 Dec, respectively; while V_1, V_2, V_3, V_4 and V_5 represent SH-06, FSD-08, LS-08, AS-02 and TD-1, respectively

Means not sharing the same letter within a column differ significantly from each other at 5% probability level

(Table 6). Wheat planted on 10th Nov outperformed with higher grain yield while delayed planted (25th Dec) observed 58% yield reduction @ 60 kg ha^{-1} day^{-1} for each day delay in planting after 10th Nov (Table 6). Wheat cultivars behaved differently in this regard; and LS-08 and AS-02 outperformed when planted on 10th Nov while TD-1 planted on 10 and 25th Dec performed poorly (Table 6). Significantly higher and lower straw yield of wheat was observed in AS-02 planted on 10th Nov and TD-1 planted on 10 and 25th Dec (Table 6). Superior HUE was noted in LS-08 planted on 10th Nov whereas TD-1 planted on 10th Dec recorded minimum HUE (Table 6). Moreover, maximum TDM was noted in SH-06 planted on 10th Nov while TD-1 and FSD-08 planted on 25th Dec observed minimum TDM accumulation (Table 6).

DISCUSSION

Delayed planting had significant effect on tillering, phenology and productivity of wheat cultivars with overall shortening of growing season leading to reduced grain yield and HUE, although cultivars behaved differently in this regard (Tables 2-6). It is well documented that wheat phenology and productivity is significantly affected by sowing dates (Miralles *et al*., 2001; Haq and Khan, 2002; Sial *et al*., 2005; Rahman *et al*., 2009; Hussain *et al*., 2012). Delay in wheat planting from 25th Oct to 25th Dec gradually increased the time to start emergence due to decline in existing mean temperature (Jame and Cutforth, 2004); as the mean prevailing temperature was 22.3, 21.5, 18, 17 and 15 ºC, on 25th Oct, 10th Nov, 25th Nov, 10th Dec and 25th Dec, respectively. However, wheat planted on 10th Nov switched into tillering earlier due to prevailing low temperature during early Dec; as low temperature causes injury to wheat that enhances tillering, while high temperature favors main stem growth and therefore tillering starts normally late. Therefore, early planted crop enjoyed more time with suitable temperature for tillering and ultimately exhibited high tillering capacity (Shahzad *et al*., 2002; Donaldson *et al*., 2001). The reduction in tillering capacity in late planted crop might be due to unfavorable temperature not suitable for tillering (Aslam *et al*., 2003; Shah *et al*., 2006; Qasim *et al*., 2008). Moreover, high tillering observed in AS-02 followed by LS-08 was associated with their genetic makeup; as wheat cultivars differ in their tillering potential when exposed to same or different climatic conditions (Aslam *et al*., 2003; Shah *et al*., 2006; Qasim *et al*., 2008).

After emergence and tillering, late planted crop took less time to switch into further phenophases due to existing high temperature and longer photoperiod. It might be due the fact that wheat phenological events are very sensitive to temperature and photoperiod, and high temperature and long photoperiod fastened the development process and heading start earlier (Slafer and Rawson, 1995). Moreover days taken from flowering to complete grain formation drastically reduced from 89 (25th Oct) to 45 (25th Dec) mainly due to mean high temperature at reproductive stage in late planted wheat (Slafer and Whitechurch, 2001; Sial *et al*., 2005). Nahar *et al*. (2010) observed that early planted wheat had small germination phase than late planting but days taken to start anthesis and booting stages notably declined in late sown wheat due to elevated heat stress (high temperature) later in the season. Moreover, total life cycle of 25th Dec sown wheat reduced to about 110 days compared with 166 days life cycle of early (25th Oct) planted crop because late planted wheat has to complete its entire life cycle in much shorter time as starch accretion is ended at same specific time without depending on its sowing time due to its photosensitive nature. Wheat cultivars behaved differently owing to their different genetic makeup and high tillering cultivars (AS-02 followed by LS-08) took minimum time to start tillering than low tillering cultivars. Moreover, long durational cultivars (AS-02 and LS-08) took relatively more days to enter into booting stage from jointing and minimum days taken for grain formation (Table 2).

Lesser accrual of GDDs to start emergence in early planted wheat (25th Oct and 10th Nov) was linked with minimum calendar days taken to start emergence (Table 2) due to high temperature (Table 1) than delay planted crop. After that, higher GDDs accrual to switch into next phenophases like tillering, jointing, booting and grain formation in early planted crop was attributed to higher calendar days taken accordingly (Table 2); as late planted crop faced high temperature and long photoperiod to switch into next phenophases and completed life cycle in much shorter time (Table 2). Sikder *et al*. (2009) reported higher accrual of GDDs at all phenophases of early planted wheat than late planted crop. Moreover, lesser PTU recorded in early planting was also related with least GDDs accumulation to start emergence but after that early planted crop experienced higher PTU to switch into next phenophases chiefly due to higher GDDs accretion on respective stages than delay planted crop (Table 3); as PTU is a product of GDDs and possible sunshine hours. Prabhakar *et al*. (2007) reported least accretion of GDDs and PTU coupled with short life cycle in late planted wheat. However up to booting stage HTU accumulation experienced almost same fashion as observed for PTU but wheat planted on 25th Nov and 10th Dec accumulated more HTU from flowering to complete grain formation (Table 3). Although the days taken to complete grain formation was high in early planted crop but short days and foggy weather resulted in extreme short possible sunshine hours (n) leading to reduced HTU; as it started flowering during 2nd fortnight of Jan compared with 25th Nov and 10th Dec planted wheat which switch into flowering phase during last week of Feb to 1st fortnight of March (Table 2). Sikder *et al*. (2009) also reported higher accumulation of HTU only at maturity stage of wheat even having higher GDD at maturity compared with other phenophases in late planted wheat than normal sowing.

Different wheat cultivars had undergone different accretion of GDD, PTU and HTU to switch into different phenophases due to their divergent genetic makeup (Tables 2-5). Several earlier reports available in literature stressed that different wheat cultivars had different requirement of GDD and PTU buildup at different growth stages both under normal and late sowing conditions (Phadnawis and Saini, 1992; Pal *et al*., 1996; Prabhakar *et al*., 2007; Nahar *et al*., 2010).

Reduced total dry matter (TDM) due to shorter life cycle in late planted crop might be the possible reason of decreased plant height as wheat switches from vegetative to reproductive stage at some specific temperature due to its photosensitive nature without accumulating a specific amount of TDM. Cultivars behaved differently in this regard due to different genetic makeup; long durational cultivar (LS-08) observed more plant height than short durational cultivar TD-1 and these results are in line with those of Shahzad *et al*. (2002).

Wheat yield decreased @ 60 kg ha^{-1} day^{-1} for each day delay after 10th Nov and about 58% yield tax was paid in 25th Dec planted crop than wheat planted on 10th Nov (Table 6). Impaired tillering capacity coupled with lesser TDM accumulation and least accumulation of GDD and PTU due to drastic reduction in growth period in late planted wheat were the chief reasons of this yield penalty (Tables 2-6). Although wheat planted on 25th Oct had high tillering capacity and TDM due to longer growth period but it switched into anthesis and grain formation stage during 2nd fortnight of Jan and low existing temperature at that time caused pollen abortion leading to lesser number of grains per spike (data not shown) and thus yielded next to wheat planted on 10th Nov. Likewise, long durational cultivars LS-08 and AS-02 harvested higher grain yield due to their high tillering capacity and more TDM; whereas short durational cultivar TD-1 performed poor due to its low tillering capacity. Nonetheless, higher straw yield and TDM accumulation in early planted wheat (25th Oct and 10th Nov) was also associated with high tillering capacity and getting maximum GDD and PTU owing to longer growing season (Tables 2-6). Donaldson *et al*. (2001) reported that early sowing resulted in higher straw and biological yield due to more number of tillers. Lower straw yield recorded in TD-1 was the direct result of its low tillering potential and dwarf nature (Table 6). Least HUE observed in late planted crop and wheat cultivar TD-1 was primarily associated with drastic reduction in grain yield (Table 6). Minimum HUE in late planted crop highlighted that late planted crop could not efficiently utilized the available sources particularly solar radiation. The mother reason in the wake of this entire story is of varying temperature at different growth stages of wheat. Mainly wheat required 68 to 90 days for grain formation but under late sown conditions these numbers of days were limited up to 56 and 45 days in 10th and 25th Dec planted wheat respectively (Table 2). This reduction in days required for grain formation is due to high temperature at reproductive stage of late planted crop (Slafer and Whitechurch, 2001; Sial *et al*., 2005).

In conclusion, wheat planted on 10th Nov outperformed with higher grain yield primarily due to higher tillering capacity, TDM, and higher accrual of GDD and PTU during grain formation leading to higher HUE. Poor tillering and short growing season caused 58% yield penalty in late planted (25th Dec) wheat than wheat planted on 10th Nov. Long durational cultivars LS-08 and AS-02 harvested more grain yield due to higher tillering capacity and TDM accumulation. Planting of AS-02 and LS-08 on 10th Nov seemed the most productive combination.

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