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Phenology, heat unit requirement and yield of wheat (*Triticum aestivum*) varieties under different crop-growing environment

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ABSTRACT

An experiment was conducted during 4 consecutive winter (*rabi*) season of 2003 to 2007 to study the phenology, growing degree days and its subsequent effect on grain yield of wheat (*Triticum aestivum* L.emend. Fiori and Paol) varieties grown under varying environmental conditions. The crop sown on 23 November took maximum calendar days and growing degree days for tiller initiation, boot stage, ear emergence, milk stage, dough stage and maturity which got reduced significantly with subsequent delay in sowing time and recorded lowest value on 4 January-sown crop. Highest heat-use efficiency and grain were also obtained when sowing was done on 23 November, both heat-use efficiency and grain yield decreased significantly on delayed sowing. The reduction in grain yield was recorded to the tune of 7.45, 30.91 and 55% when sowing was delayed on 7 December, 21 December and 4 January, respectively as compared to 23 November-sown crop. Per unit increase in growing degree days over 1477.7°C increased grain yield to the tune of 11.1, 7.2, 5.6 and 5.8 kg/ha/day of wheat varieties 'K 9107', 'PBW 343', 'HP 1744' and 'NW 1014', respectively. Among the tested varieties, timely-sown wheat varieties took highest calendar days, growing degree days for these phenophases and recorded highest heat-use efficiency and grain yield than late-sown wheat varieties. The significant reduction in grain yield of timely-sown wheat varieties 'K 9107' and 'PBW 343' was recorded when sowing was delayed beyond 23 November, while significant reduction in late-sown varieties, 'HP 1744' and 'NW 1014' was noticed beyond 7 December. The reduction in grain yield of timely-sown varieties was more pronounced beyond 21 December.

Key words: Accumulated growing degree days, Calendar days, Grain yield, Heat-use efficiency, Phenophases, Wheat varieties

Crop production depends on the agro-climatic requirements of a particular crop. Many factors influencing the rate of plant growth and development, including light (quality, quantity and photoperiod), water, nutrient availability, salinity and CO_2. However, temperature is always cited as the most important environmental factor that affects plant development, growth and yield. All biological process respond to temperature and all responses can be summarized in terms of 3 cardinal temperatures; a base or minimum, an optimum and a maximum. However, the nature of the response to temperature between these cardinal points, which is important for calculating the phenology, adaptation and yield of crop. Changes in ambient temperature from optimum temperature range during plant growth period adversely affects the phasic duration and dry matter accumulation of a crop by influencing the physiological process. The agro-meteorological application of temperature effect on plant growth and phenological development is the heat unit concept which is based on idea that plants have definite temperature requirement before they attain certain phenological stage (Chakravorty and Shastry 1983). Phenological development is usually analyzed in terms of progress towards stages such as germination, seedling emergence, initiation of floral primordial, flowering and physiological maturity. Progress is estimated by integrating a developmental rate over the interval from one stage to next. The rate is usually a function of temperature and photoperiod. Besides, heat-use efficiency, ie efficiency of utilization of heat in terms of dry matter production is another important aspect which has practical utility. Even under best agro-climatic conditions, the total heat energy available during crop season is never utilized fully to dry matter production. Efficiency of heat energy conversion for dry matter production depends on genetic factors, crop and growing environment. The variety-specific differences in growth stages are accommodated by variety-specific genetic co-efficient but also very sensitive to temperature. In general, the wheat grain filling rate decreases as the mean temperature falls below 25°C (Nain *et al.* 2003).

Under north Indian condition, the maturity of wheat is

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hastened due to gradual rise in ambient temperature under delayed planting. Hence, it becomes imperative to have knowledge of exact duration of phenological stages in a particular crop-growing environment and their impact on dry matter accumulation and yield of the crop. Therefore, an experiment was planned to determine the phenology and heat unit requirement of promising wheat varieties under different crop-growing environment of north Bihar.

MATERIALS AND METHODS

The field experiment was conducted during 2003–07 at research farm of Rajendra Agricultural University, Pusa, Samastipur (25° 98′ N, 85° 76′ E and an altitude of 51.3 MSL). The soil was clay loam in texture having *p*H 8.1. The treatment comprised 4 planting dates, viz 23 November, 7 December, 21 December and 4 January under timely, late and very late-sown condition and 4 wheat varieties, 2 of timely, ie 'K 9107', 'PBW 343' and 2 of late sown, ie 'HP 1744', 'NW 1014' conditions. The treatment was laid out in randomized block design with 3 replications. The crop was sown in row 20 cm apart in east-west direction. The wheat crop was grown as per recommended agronomic package of practices.The daily maximum and minimum temperature were recorded from Agro-Meteorological Observatory situated in Crop Research Program Centre of ICAR Unit. Growing Degree Days (GDD) were computed by simple arithmetic accumulation of daily mean temperature above the base temperature value 5°C considered for wheat crop (Nuttonson 1955). The accumulated GDD for each phenophases were obtained by:

$$\text{Accumulated GDD} = \sum_{I}^{n} [\text{T maximum} + \text{T minimum}] - \text{Tb}$$

where,
T_{max}, daily maximum temperature (°C),
T_{min}, daily minimum temperature (°C), Tb, base temperature (°C),
I-start of phenophase or date of sowing
N-end of phenophase or date of harvest
Heat-use efficiency was defined in terms of dry matter accumulation as ratio of amount of biomass produced above the ground and accumulated heat units as:

$$\text{HUE} = \frac{\text{Dry matter accumulation (g/m}^2\text{)}}{\text{Accumulated GDD (degree – days)}}$$

Five plants from each plot was randomly selected for periodic observation of different phenological stages. The date of attainment of a particular stage was considered when more than 3 plants in each plot attained that stage. Seed yield was recorded/plot after harvesting from which yield/ha was calculated. Linear regression was developed between grain yield with different sowing dates. Weather parameters during crop growing period is presented in Table 1.

Table 1 Details of weather parameters during the crop growth period (2003–07)

Months	Temperature (°C)								Relative humidity (%)								Rainfall (mm)			
	2003–04		2004–05		2005–06		2006–07		2003–04		2004–05		2005–06		2006–07		2003–04	2004–05	2005–06	2006–07
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	7 am	2 pm	7 am	2 pm	7 am	2 pm	7 am	2 pm				
Nonember	15.8	28.8	10.3	28.4	12.8	28.3	14.8	27.1	95.8	68.1	98.5	64.5	98.4	48.4	94.8	51.8				4.8
December	9.7	29.1	7.1	23.6	8.7	25.0	9.8	24.6	92.06	57.3	99.0	67.8	95.1	49.9	93.6	54.9	70.0			
January	8.8	18.5	7.8	21.7	7.4	21.8	7.2	21.3	97.8	76.7	98.4	61.2	96.5	58.4	92.3	60.6	14.09	8.6		
February	11.3	24.7	12.3	25.3	13.3	28.2	11.6	24.0	99.6	58.8	95.3	55.3	96.2	55.1	93.3	63.5		16.7		26.0
March	17.0	31.9	17.3	31.6	14.6	31.1	14.0	27.8	93.2	49.8	86.5	46.5	82.2	33.8	87.0	47.9		14.8		21.6
April	21.0	32.7	20.3	36.2	20.2	31.7	21.5	35.2	96.0	76.0	81.4	38.7	76.2	39.7	85.7	46.3	44.0		9.2	53.0

Table 2 Effect of crop growing environment on different phenophase and heat-unit requirement of wheat varieties (mean of 2003–07)

Treatment	Seedling emergence		Tiller initiation		Node stage		Boot stage		Emergence of earhead		Milk stage		Dough stage		Maturity		Heat-use efficiency (g/m²/degree days)
	DAS	HU	DAS	HU	DAS	HU	DAS	HU	DAS	HU	DAS	HU	DAS	HU	DAS	HU	
Date of sowing																	
23 November	5.67	78.21	25.90	314.19	38.25	484.00	60.37	683.88	77.43	881.87	85.77	1001.92	106.70	1378.70	126.5	1708.20	0.454
07 December	6.67	89.93	27.00	309.26	37.80	426.90	59.33	643.69	73.47	832.37	80.77	958.13	97.80	1277.10	115.47	1635.52	0.441
21 December	7.83	81.77	28.27	269.37	36.65	382.25	56.60	602.40	68.03	795.99	75.47	915.91	90.80	1238.90	105.97	1545.19	0.351
04 January	8.27	74.83	29.03	283.47	34.45	367.00	49.43	564.51	62.70	797.84	69.30	929.05	80.90	1170.60	95.50	1477.68	0.242
CD (*P*=0.05)	0.67	3.93	0.57	5.96	0.70	9.90	0.57	16.49	0.76	12.15	0.93	13.76	1.30	36.00	1.00	22.62	0.008
Varieties																	
'K 9107'	7.00	80.71	28.07	306.73	37.10	417.40	55.80	617.78	71.60	843.42	79.53	985.53	97.00	1316.90	112.67	1641.90	0.378
'PBW 343'	7.17	81.46	28.13	307.12	37.45	420.65	60.63	678.31	75.00	895.40	82.10	1020.88	96.60	1308.00	112.07	1625.59	0.389
'HP 1744'	7.20	80.87	27.07	295.44	36.35	410.60	54.97	603.61	67.10	775.56	73.77	885.12	90.60	1228.20	108.23	1546.43	0.362
'NW 1014'	7.03	80.90	26.97	295.50	36.30	411.90	54.50	594.76	67.90	787.69	75.73	913.48	91.90	1242.10	108.50	1553.21	0.376
CD (*P*=0.05)	NS	NS	0.57	5.96	0.70	9.90	0.57	16.49	0.76	12.15	0.93	13.76	1.30	36.00	1.00	22.62	0.008

DAS, Days after sowing; HU, heat unit accumulation

RESULTS AND DISCUSSION

Phenology of crop and accumulated growing degree days

The phenological stages were significantly influenced by sowing dates when measured in terms of calendar days (Table 2). Crop sown earliar on 23 November except for seedling emergence and tiller initiation took maximum days for node initiation, boot stage, ear emergence, milk stage, dough stage and maturity which decreased significantly under delayed sowing except node initiation with 7 December sown crop. The period required for node initiation at 23 November and 7 December sown crop was at par. However, the crop sown very late on 4 January required lowest duration for these phenophases which were significantly lower than the crop sown late on 21 December except seedling emergence. The shortened 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 late developmental phases, anthesis and maturity. Dhiman *et al*. (1985) opined alike. These phenophases also differ significantly among timely and late sown wheat varieties. Timely-sown wheat varieties required significantly higher number of days for these phenophases than late-sown wheat varieties. Except milk-stage among late-sown varieties and boot stage, ear emergence and milk-stage among timely sown varieties, the number of days required for other phenophases did not differ significantly among timely and late-sown group of varieties.

The accumulated growing degree days from sowing to maturity ranged from 74.83 to 1708.2° days at different sowing dates (Table 2). Among sowing dates, earliar sowing on 23 November accumulated highest growing degree days at all the phenophases except seedling emergence and it decreased significantly under delayed sowing except tiller initiation with 7 December sown crop. The significant reduction in growing degree days at tiller initiation was recorded when crop was sown beyond 7 December. The crop sown very late on 4 January accumulated very low growing degree days 74.83–1 477.68° days from sowing to maturity which was significantly lower than the crop sown late on 7 December (81.77–1 545.19° days) from sowing to maturity. Lesser heat unit consumed by the crop under late and very late-sown conditions were due to sub-optimal thermal regime at vegetative phase of the crop in the month of January which hastened at reproductive phase and maturity consequently, the crop growth period was shortened by 21–31 days under late and very late sown condition respectively, depending on genotypes. (Dhaliwal *et al*. 2007) also reported lower consumption of heat unit under delayed sowing. Accumulation of growing degree days also varied significantly among timely and late-sown varieties. Timely-sown variety, 'PBW 343' consumed highest heat unit at all the phenophases but was found at par with 'K 9107' except boot, ear emergence and milk stages and both recorded significantly higher heat unit than the late sown varieties, 'HP 1744' and 'NW 1014'. The accumulation of growing degree days did not vary significantly among late sown wheat varieties except milk stage. Early development of phenological stages might be reason for less consumption of heat unit in late sown wheat varieties.

Heat use efficiency

Sowing dates had marked influence on heat-use efficiency (Table 2). Earlier sowing of crop on 23 November recorded highest heat-use efficiency and it decreased significantly with subsequent delay in sowing time. The lowest heat-use efficiency was associated with the crop sown very late on 4 January. 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, since both maximum and minimum temperature remained higher during the late vegetative and reproductive phases causing enormous detrimental effect on dry matter accumulation. Of the varieties tested, 'PB W343' recorded highest heat-use efficiency which was significantly higher than timely sown wheat variety, 'K 9107' and late-sown varieties, 'HP 1744' and 'NW 1014'. Among the late-sown varieties, 'NW 1014' recorded significantly higher heat-use efficiency than 'HP 1744'. The higher heat-use efficiency in timely-sown wheat varieties might be due to higher production of crop biomass per heat unit absorbed. Similar result was also reported by Tripathi *et al*. (2004).

Growth and yield attributes

The crop sown on 23 November attained maximum plant height and recorded significantly higher value of yield indices, ie effective tillers/m², leaf area index, ear length, grains/ear and test weight than late (21 December) and very late (4 January)-sown crop but was found at par with 7 December sown crop. Plant height differ significantly among wheat varieties. Wheat variety, 'K 9107' recorded maximum plant height while the lowest height was associated with 'PBW 343'. Timely-sown variety 'K 9107' and 'PBW 343' recorded higher number of effective tillers/m^2, leaf area index, ear length and test weight than late-sown varieties, 'HP 1744' and 'NW 1014'. The yield attributing parameters did not differ among timely and late-sown group of varieties. These findings also confirmed the results of Kumar (2006).

Grain yield

Sowing dates had marked influence on grain and straw yields (Table 3). The crop sown on 23 November recorded maximum grain yield and it decreased significantly with subsequent delay in sowing time. The reduction in grain yield was recorded to the tune of 7.45%, 30.91% and 55.00% when sowing was delayed on 7 December, 21 December and 4 January, respectively as compared to the crop sown on 23 November. Per unit increase in growing degree day over 1477.7 °C increased grain yield to the tune of 11.1, 7.2, 5.6 and 5.8 kg/ha/day of wheat varieties, 'K 9107', 'PBW 343', 'HP 1744' and 'NW 1014', respectively (Fig 1). Similar trend

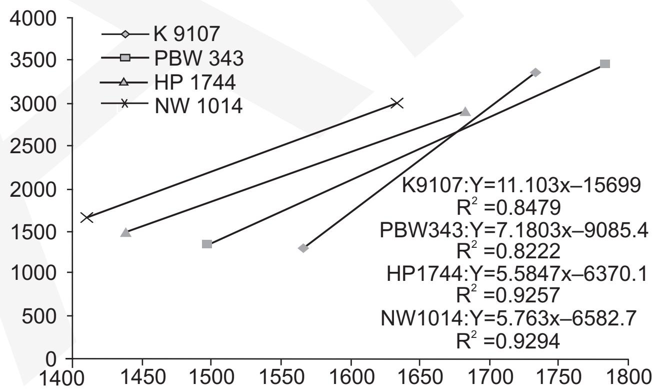

Fig 1 Effect of growing degree days on the grain yield of wheat varieties

Table 3 Effect of crop growing environment on growth, yield attributes and grain yield of wheat varieties (mean of 2003–07)

Treatment	Plant height at harvest (cm)	Effective tillers/m²	Leaf area index (60 DAS)	Length of earhead (cm)	Grains/ ear	1000-grain wt (g)	Grain yield (tonnes/ha)	Straw yield (tonnes/ha)	Harvest index (%)
Date of sowing									
23 November	92.32	351.65	2.86	9.90	45.40	37.83	3.2	4.6	41.03
7 December	88.82	336.65	2.81	9.65	43.14	36.14	2.9	4.3	40.84
21 December	83.38	301.65	2.74	9.20	38.81	33.05	2.2	3.2	40.54
04 January	80.35	234.30	2.67	8.91	34.38	30.86	1.4	2.1	37.05
CD (P=0.05)	4.15	18.35	0.08	0.47	33.01	1.63	0.1	0.2	0.25
Varieties									
'K 9107'	94.99	319.70	2.81	10.04	41.08	35.61	2.5	3.7	40.70
'PBW 343'	77.73	326.65	2.80	9.55	41.28	34.97	2.6	3.7	40.75
'HP 1744'	80.10	300.25	2.72	8.90	39.22	33.44	2.3	3.3	40.41
'NW 1014'	89.39	312.65	2.75	9.18	40.15	33.86	2.4	3.5	40.59
CD (P=0.05)	4.15	18.35	0.08	0.47	NS	1.63	0.2	0.5	0.25

was also observed in straw yield. The higher value of yield-attributing parameters in case of early sowing over delayed ones could be attributed to availability of optimum environment for growth and development of crop which might enhanced accumulation of photosynthates from source to sink. Contrary, on other hand detrimental effect of heat at later stage of crop development and anthesis in delayed sowing had adverse effect on grain yield. Wardlaw and Wringley (1994) reported 3–4% decrease in grain yield for each 1°C rise in ambient temperature above 15°C during grain filling. Among the varieties, timely-sown variety, 'PBW 343' recorded highest grain and straw yields but was at par with 'K 9107' and both produced significantly higher grain and straw yields than late-sown varieties, 'HP 1744' and 'NW 1014'. Similarly, the grain and straw yields recorded in late-sown varieties did not differ significantly. The higher grain yield in timely-sown varieties was due to better expression of yield attributing characters which led towards an increase in grain yield. Tyagi *et al*. (2004) also opined alike.

Interaction between sowing dates and variety on grain yield was significant (Table 4). The significant reduction in grain yield of timely-sown varieties ('K 9107' and 'PBW 343') was recorded when sowing was delayed beyond 23 November. However, in late-sown varieties ('HP 1744' and 'NW 1014') the significant reduction was noticed when sowing was delayed beyond 7 December. The reduction in grain yield of timely-sown varieties was more pronounced when sowing was done beyond 21 December, while it was comparable in late-sown varieties.

Total dry matter production

Total dry matter production of wheat varieties at harvest showed positive linear relationship with growing degree days. Per unit increase in growing degree days over 1477.7 °C increased dry matter production to the tune of 2.7, 1.6, 1.3 and 1.3 g/m^2 of wheat varieties, 'K 9107', 'PBW 343', 'HP 1744' and 'NW 1014', respectively (Fig 2).

Harvest index in 23 November and 7 December sown crop was at par and decreased significantly with further delay in sowing time. Among varieties, 'PB W343' recorded maximum value but was at par with 'K 9107' and 'NW 1014' and significantly higher than 'HP 1744'.

Table 4 Interaction effect of sowing dates and wheat varieties on grain yield (tonnes/ha) (Mean of 2003–07)

Varieties	Date of Sowing			
	23 Nov	7 Dec	21 Dec	4 Jan
'K 9107'	3.4	3.1	2.4	1.3
'PBW 343'	3.5	3.2	2.4	1.3
'HP 1744'	2.9	2.7	2.0	1.5
'NW 1014'	3.0	2.8	2.0	1.6

CD (*P*=0.05) 0.3

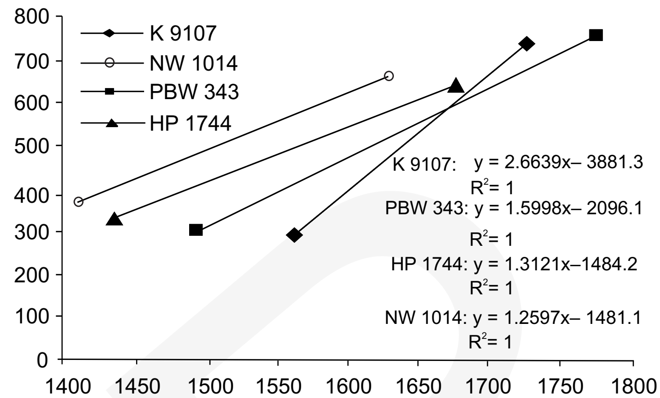

Fig 2 Effect of growing degree days on dry matter production of wheat varieties

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