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IB Pandey
Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

RS Singh
Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Sunil Kumar
Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Dharminder
Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Amrendra Kumar
Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Rajendra Prasad
Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Corresponding Author:
IB Pandey
Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Phenology, thermal requirement and productivity of wheat cultivars under varied crop growing environment of North Bihar

IB Pandey, RS Singh, Sunil Kumar, Dharminder, Amrendra Kumar and Rajendra Prasad

Abstract
An experiment was planned and carried out for three consecutive *rabi* seasons of 2012 to 2014 to study the phenology, thermal requirement and productivity of wheat (*Triticum aestivum* L. emend. Fiori and Pao l) cultivars under varied crop growing environmental condition of Bihar. The crop seeded on 15 November took maximum calendar days and accumulated more heat unit for boot, ear head emergence, milk, dough and maturity stages which deceased with subsequent delay in seeding time and recorded minimum value on 25 December seeded crop, while 25 December seeded crop took maximum calendar days for tiller initiation. Crop seeded on 25 November recorded maximum heat use efficiency which reduced significantly when seeding was done earlier on 15 November and delayed beyond 5 December. Similarly, 25 November seeded crop also recorded highest grain and straw yields and harvest index which decreased significantly under delayed seeding beyond 5 December. The decrease in grain yield was registered to the tune of 4.65, 23.26 and 30.23% under delayed seeding on 5, 15 and 25 December respectively and 6.98% on advanced seeding on 15 November. Delay in seeding from 15 November to 25 December reduced requirement of thermal period upto 4 days, 14 days, and 15 days between ear emergence to milk stage, ear emergence to dough stage and ear emergence to maturity respectively. Among the tested varieties, RW 3711 required minimum calendar days in the study year and build up lower heat unit for these phenophases than HD 2824 and HD 2733. This variety also recorded significantly lower grain yield, harvest index and heat- use efficiency than HD 2733 and HD 2824. Calendar days, accumulated heat unit, grain yield and heat-use efficiency did not varied significantly among HD 2824 and HD 2733. Hence, wheat varieties, HD 2733 and HD 2824 were found ideal for agro-ecological condition of Bihar.

Keywords: Calendar days, GDD, crop growing environment, grain yield, harvest index, heat-use efficiency, phenological stages

Introduction
The phenological stages of wheat and conversion efficiency principally govern by sowing time. The timely sown crop has longer growth duration which consequently provides an opportunity to accumulate higher crop biomass as compared to late sown crop. Under delayed sowing, the wheat crop is exhibited to sub-optimal temperature at grain formation stages, which leads to induced maturity which end as reduction of grain yield (Ram *et al*. 2012) [4] Optimum seeding time is an important parameter which has an impact on growth and yield attributing parameters of wheat compare to other cultivation practices. Temperature is important weather parameters which sway the growth and phenophases of wheat. Every plant requires definite temperature before shifting into other phenological stage. Deviation in ambient temperature from optimum temperature range during plant growth (vegetative as well as reproductive) period negatively affects the phasic duration and dry matter production of the crop by influencing the physiological activities *viz* growth, metabolism, reproduction, defense of the plant. Phenological development is usually expressed in terms of progress towards phenological stages such as germination, seedling emergence, initiation of floral primordia, ear head emergence and physiological maturity. Progress is worked out by integration of developmental stages over the time from one stage to next. The developmental rate is a function of temperature and photoperiod (light and time). Besides, heat-use-efficiency, i.e., efficiency of utilization of solar heat concerning dry matter production. Even under most advantageous climatic conditions, the total solar energy available during crop season is not completely utilized by the crop to produce dry matter production.

Efficiency of heat energy conversion for dry matter production also varied by crop ambient environment as well as by genetic factors. The variety-specific variables in growth stages are accommodated by variety specific genetic co-efficient but also very sensitive to temperature. In north Indian condition, the maturity of wheat crop is accelerated, and crop is forced to mature early due to gradual increase in ambient temperature under delayed sowing condition. Hence, it becomes imperative to have knowledge of proper duration of phenological stages under crop growing environment and their effect on dry matter accumulation and crop yield. Therefore, a trial was designed and conducted to find out the phenology and thermal requirement of newly release prominent wheat varieties under crop-growing environment of north Bihar.

Materials and Methods

The present investigation was laid out during *rabies* as on of 2012-13 to 2014-15 at experimental farm of Rajendra Agricultural University (RAU), Pusa, Samastipur, Bihar. Geographically the centre is located at $25^0 98'$ north latitude and $85^0 76'$ east longitude at a height of 51.3 m above MSL. The soil was calcareous in nature and clay loam in texture having pH value of 8.1. The experiment was carried out in RBD and replicated thrice. The treatment consisted of 5 seeding dates viz, 15 November, Nov. 25, Dec. 5, Dec.15 and Dec.25under timely and late sown condition and 3 wheat cultivars, i.e., RW-3711, HD-824 and HD-2733. The sowing was done in row 20 cm apart and standard agronomic practices were adopted for raising the crop. Maximum and minimum ambient temperature during the crop growing period of wheat was obtained from meteorological observatory of the university. The phenophases were recorded by regular field inspection method. Growing Degree Days (GDD) was calculated by simple arithmetic accumulation of daily mean temperature above the base temperature value of 5 °C considered for wheat (Nuttonson 1955) [2]. The accumulated GDD for each phenological stages was obtained by:

$$\text{GDD} = \sum_{i}^{n} \frac{[T\,max.+T\,min.]}{2} - \text{Tb}$$

Tmax. = daily maximum temperature (°C)
Tmin. = daily minimum temperature (°C)
Tb = base temperature (°C)
I = start of phenophase
N = end of phenophase

Heat- use efficiency was described in terms of dry matter accumulation as ratio of amount of biomass synthesized above the ground and accumulated heat units as:

$$\text{HUE} = \frac{\text{Dry matter production}}{\text{Accumulated GDD (degree-days)}}$$

For periodical observation of different phenological stages, five (5) crop plants from each plot was randomly selected and tagged. The date of attainment of a particular phenological stage was considered when more than three plants in each plot attained the respective stage. Grain and straw yields were recorded per plot after harvesting from which yield per ha were worked out. Data obtained for different parameters were tested using analysis of variance (ANOVA) of randomized block design (Factorial). Comparison of treatment means was done by least significant difference at probability level of 0.05.

Results and Discussion

Phenology of crop and accumulated growing degree days

Seeding times had significant influence on phenological stages of crop (Table 2). The crop grow non Nov. 15 took highest period for commencement of boot, ear head emergence, milk and dough stages which reduced significantly under late seeding. However, crop seeded late on 25 December required lowest period for initiation of these phenophases was crop. While for seedling emergence and tiller initiation late seeded crop on 25 December required maximum period which decreased with subsequent advancement of seeding time. This might be due to abrupt drop of ambient temperature during the period. The shortened in the phenophase period from boot stage onwards under late seeded condition was due to hasty increase in ambient temperature during late developmental stages, anthesis and maturity. Similar result was also obtained by Gupta et al. 2017. The phenophases also varied significantly among the wheat varieties. Wheat variety, RW 3711 required significantly lesser period for initiation of boot, ear head emergence, and milk stages than HD-2824 and HD-2733. However, the period required for these phenophases among HD-2824 and HD-2733 did not vary significantly. The period required for later phenophases viz, dough and maturity did not vary significantly among the varieties. Sudden rise in ambient temperature during this period forced the crop to mature pre-maturely.

The growing degree days towards seeding to maturity of the crop varied from 69.2 to 1863.7^0 days at different seeding dates (Table 2). Amid the seeding dates, except seedling emergence, earliest seeding on Nov.15 accumulated significantly maximum degree days at all the phenological stages which decreased significantly under delayed seeding except boot and milk stages among 15 and 25 December seeding. At these stages significant reduction in growing degree days were recorded up to 15 December seeding further delayed in seeding time fail to produce significant reduction in growing degree days. The crop seeded delayed on 25 December accumulated lesser degree days (69.2 to 1493.5 days) for attainment of different phenophases. Lesser consumption of heat unit under delayed seeding was might be owing to below optimal-thermal regime at early growth stages of wheat crop in the month of December and January which raised abruptly at latter growth stages and maturity ultimately the crop growth period was reduced by 28 days in delayed sowing on 25 December depending on varieties. Wahid et al., 2017 [7] and Ram et al., 2017 [5] also recorded higher accumulation of growing degree days under early seeding compared to delayed seeding. Accumulation of growing degree days also varied significantly among the varieties. Among the wheat varieties, HD-2824 accumulated higher heat unit which was similar to HD-2733 at boot, ear head emergence and milk stages. However, it was significantly higher at dough stage and maturity. While wheat variety, RW-3711 consumed significantly lower heat unit for attainment of these phenophases than HD-2824 and HD-2733. Early initiation of phenological stages could be reason for lesser utilization of heat unit by the variety RW 3711.

Heat-use efficiency

Crop seeded on 25 November registered highest heat-use efficiency and was found similar to crop seeded on 5 December and decreased significantly with subsequent delayed in seeding time as well as advancement of seeding time (Table 2). Higher heat-use efficiency on 25 November sown crop may be due to proportionate increase in plant dry matter per unit of absorbed heat unit. However, lower heat-use efficiency under late seeding might be likely to accumulation of comparable growing degree days to that of early seeding at later growth stages, since both higher and lower temperature was remained higher at late vegetative and reproductive phases causing enormous detrimental impact on dry matter production. Similarly, less proportional enhancement in dry matter accumulation per each heat unit absorbed due to reduction in tiller production/ unit area might be reason for lower heat-use efficiency on earliest seeded crop on 15 November. Decrease in heat-use efficiency in delayed seeding was also reported by Tripathi *et al* 2004 [6]. Among the tested varieties, HD 2733 and HD 2824 recorded similar and significantly higher heat-use efficiency than RW 3711. The higher heat-use efficiency in these varieties may be due to more crop biomass accumulation per heat unit absorbed.

Plant height and yield indices

Crop seeded on 15 November attained maximum plant height which decreased significantly when seeding was delayed beyond 5 December. Similarly, earlier seeded crop on 15 November also recorded longer ear head, grains/ ear head and test weight which reduced with subsequent delay in sowing time, but significant reduction recorded when seeding was delayed beyond 25 November except 1000- grain weigh. However, 1000- grain weight reduced significantly after 15 November seeding. While crop seeded on Nov. 25 recorded significantly higher tillers/m row length than earlier seeded crop on 15 November and later after 5 December. Plant height did not vary significantly among the wheat varieties. However, wheat variety, HD 2733 recorded maximum number tillers which was alike to HD 2824, and both recorded significantly a greater number of tillers than RW 3711, while the ear length was significantly longer in these varieties than RW 3711 than HD2733 and HD 2824. Grains/ ear head and test weight did not differ significantly among wheat varieties.

Grain yield

Seeding time markedly influenced the grain and straw yield (Table 2). Crop seeded on Nov.25 produced higher grain and straw yields which declined with late as well as advancement of seeding time, but significant reduction was recorded when seeding was delayed beyond 5 December. The decline in grain yield was observed to the tune of 4.65, 23.26 and 30.23% when seeding was delayed on 5 December, 15 December and 25 December respectively, while it reduced 6.98% on advanced seeding on 15 November as compared to 25 November seeded crop. Enhancement in tiller production on Nov.25 and Dec. 5 seeded crop and higher value of other yield indices on earliest seeded crop on 15 November over late sown may be ascribed to availability of optimum environmental condition for growth and development of crop which might enhance accumulation of photosynthate from source to sink. On other hand cold stress during early phenophases and harmful effect of temperature at later crop growth stages of crop and anthesis in late seeding had adverse impact on grain and straw yields. Pandey *et al* 2010 [3] also recorded 7.45 to 55.00% reduction in grain yield on delayed sowing on Dec.7 and Jan.4respectively as compared to Nov. 23 sown crop. Among the varieties, HD 2733 recorded maximum grain and straw yields which was found at par with HD 2824 and significantly higher over RW 3711. The higher grain yield of HD 2733 might be reason for better expression of tillers which led toward an enhancement in grain production.

Crop seeded on 25 November also recorded higher harvest index which decreased significantly beyond 5 December seeded crop and advancement of seeding date on 15 November. Among the varieties, HD 2733 and HD 2824 recorded similar and significantly higher harvest index than RW 3711.

Thermal period between phenophases

The period required between ear head emergence to milk, dough and maturity stages decreased with subsequent delay in seeding time (Table 4). Delay in seeding time from Nov.15 to Dec. 25 caused reduction in thermal period up to 4 days, 14 days, and 15 days between ear emergence to milk stage, ear emergence to dough stage and ear emergence to maturity respectively. These reductions in thermal period might be due to increase in ambient temperature beside other environmental factor that encouraged early initiation and completion of phenophases.

Table 1: Details of weather parameters during crop growth period (Pooled mean of 2012-13 to 2014-15)

Months	Temperature (°C)						Relative humidity (%)						Rainfall (mm)			Sunshine duration (days)			Wind velocity (km/hour)		
	2012-13		2013-14		2014-15		2012-13		2013-14		2014-15		2012-13	2013-14	2014-15	2012-13	2013-14	2014-15	2012-13	2013-14	2014-15
	Max.	Min.	Max.	Min.	Max.	Min.	7 am	2 pm	7 am	2 pm	7 am	2 pm									
November	28.7	14.0	27.8	14.0	28.7	13.9	90	49	90	46	87	41	-	-	-	6.1	5.3	5.4	2.3	1.9	1.8
December	20.8	9.7	23.5	10.5	19.9	10.6	93	67	91	55	92	70	-	-	-	1.7	2.5	1.7	2.8	2.1	3.0
January	19.2	7.3	19.4	9.5	19.4	9.6	92	65	90	68	89	68	12.2	9.5	8.4	3.7	2.1	2.6	3.2	3.4	3.6
February	24.8	11.5	22.3	10.7	24.6	12.1	93	60	90	60	90	56	30.6	32.4	1.2	6.8	5.0	4.2	3.6	3.9	3.8
March	30.8	16.0	29.9	15.3	29.6	15.5	88	50	83	41	84	48	-	10.6	32.6	8.1	8.2	7.2	3.8	4.2	4.4
April	35.3	20.6	37.1	19.5	33.2	19.9	78	43	69	28	82	43	13.2	-	33.2	8.3	9.3	7.2	6.0	5.1	5.8

Table 2: Effect of crop growing environment on phenology and heat unit requiredment of wheat varieties (Pooled mean of 2012-13 to 2014-15)

Treatment	Seedling emergence		Tiller initiation		Boot stage		Ear emergence		Milk stage		Dough stage		Maturity		Heat-use efficiency
	DAS	HU	DAS	HU	DAS	HU	DAS	HU	DAS	HU	DAS	HU	DAS	HU	(g/m²/degree day)
Sowing dates															
15 Nov.	5.1	74.3	27.8	405.3	78.3	870.4	88.0	973.8	95.6	1130.6	127.4	1659.6	136.6	1863.7	0.521
25 Nov.	5.6	75.2	27.8	371.1	71.9	759.1	84.8	911.5	93.0	1094.7	119.8	1561.2	130.4	1751.6	0.589
5 Dec.	6.1	76.3	28.2	338.3	67.9	672.1	80.4	869.4	89.0	1048.4	112.2	1505.7	122.6	1683.5	0.587
15 Dec.	6.8	71.1	29.8	312.4	66.1	633.9	77.2	834.3	86.0	986.5	106.0	1398.5	115.8	1594.3	0.527
25 Dec.	7.8	69.2	30.5	288.7	61.8	619.9	73.7	809.4	82.7	979.3	100.0	1359.4	108.5	1493.5	0.521
CD (P=0.05)	0.7	4.1	1.9	10.4	2.5	26.8	1.6	20.7	2.0	19.9	3.5	19.3	2.4	22.7	.0006
Varieties															
RW 3711	6.3	75.4	29.0	349.7	66.6	715.9	78.7	853.3	87.9	1040.6	112.0	1489.5	121.5	1666.8	0.530
HD 2824	6.1	71.7	28.8	348.8	70.9	757.0	82.0	890.4	90.1	1069.9	113.2	1529.6	123.7	1795.3	0.557
HD 2733	6.1	72.5	28.8	349.4	70.1	721.3	81.7	888.3	89.8	1062.3	114.0	1505.6	123.1	1695.3	0.561
CD (P=0.05)	NS	NS	NS	NS	1.9	20.8	1.2	16.2	1.2	15.67	NS	14.7	NS	19.9	.004

DAS, Days after sowing, HU, Heat unit accumulation.

Table 3: Effect of crop growing environment on growth, yield attributes and grain yield of wheat varieties (Pooled mean of 2012-13 to 2014-15)

Treatment	Plant height (cm)	Tillers/m. row length	Length of ear-head (cm)	Grains /earhead	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t /ha)	Hardest index (%)
Sowing dates								
15 Nov.	86.2	85.2	10.8	48.6	41.5	4.0	5.7	41.24
25 Nov.	85.3	98.4	10.3	47.8	38.7	4.3	6.0	41.75
5 Dec.	83.6	95.7	9.7	44.2	37.2	4.1	5.8	41.41
15 Dec.	79.1	89.4	9.4	39.8	35.6	3.4	5.0	41.38
25 Dec.	76.5	82.7	8.8	37.3	30.2	3.0	4.5	4.00
CD (P=0.05)	3.2	8.4	0.6	3.6	2.6	0.3	0.5	0.36
Varieties								
RW 3711	83.1	83.0	10.5	44.2	36.7	3.5	5.2	40.67
HD 2824	82.6	90.7	9.3	43.7	36.1	3.8	5.5	41.31
HD 2733	80.6	97.2	9.7	42.6	36.4	3.9	5.6	41.49
CD (P=0.05)	NS	6.7	0.5	NS	NS	0.2	0.3	0.25

Table 4: Temperature and thermal period requirement for different phenophases of wheat (Pooled mean of 2012-13 to 2014-15).

Sowing dates	Temperature (°C)		
	Ear emergence to milk stage	Ear head emergence to dough stage	Ear head emergence to maturity
15 Nov.	18.5 (10)	23.4 (40)	23.4 (49)
25 Nov.	19.8 (09)	23.5 (36)	23.0 (47)
5 Dec.	21.0 (09)	23.8 (32)	24.3 (43)
15 Dec.	22.5 (08)	26.1 (29)	25.8 (38)
25 Dec.	24.3 (06)	26.7 (26)	26.4 (34)

Figure in parentheses indicate thermal period in days.

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