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Thermal responses on different wheat cultivars under different thermal environments for Chhattisgarh plain

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सार – रायपुर के इंदिरा गाँधी कृषि विश्वविधालय के अनुसंधान फार्म में 2009-2010 के समय रबी की फसल के दौरान "छत्तीसगढ़ के मैदानों में विभिन्न उष्मीय पर्यावरण के अंर्तगत गेंहूँ की पैदावार करने वाले खेती में उष्मीय प्रतिक्रिया" नामक शीर्षक से प्रस्तुत शोध पत्र में जांच की गई है। विभिन्न उष्मीय पर्यावरण में फसल के बोने से लेकर पकने तक विभिन्न किस्मों के लिए बढ़ रही डिग्री दिनों (जी डी डी) के संचयन में काफी भिन्नता है। सुजाता और अमर की किस्मों में 25 नवम्बर (D_1) के अंर्तगत अत्यधिक जी डी डी पाई गई। अधिकांश किस्मों में 5 जनवरी (D_5) को अधिकतम पी टी यू और एच टी यू देखे गए। सी वी जी डब्ल्यू - 273 को छोड़कर अधिकांश किस्मों में 25 नवम्बर, 5 दिसंबर और 15 दिसंबर को फसल बोने के बाद एच यू ई मान पाए गए। सभी किस्मों में 5 जनवरी (D_5) को बोने के बाद निम्नतम एच यू ई को देखा गया। सभी किस्मों में 5 जनवरी को बोने के बाद निम्नतम आर यू आई को देखा गया। अधिकांश किस्मों में 25 (D_1) नवंबर के बाद अधिकतम आई पी ए आर मानों को देखा गया। 5 दिसंबर तथा 15 दिसंबर को बोने के साथ ईयर हैड/ मीटर^2 प्रति अधिकतम संख्या को देखा गया। 15 दिसंबर 25 दिसंबर और 5 जनवरी को देर से फसल की बुआई की अपेक्षा फसल को बोने की पहली और दूसरी तारीख (25 नवंबर और 5 दिसंबर) को दीर्घ ईयर हैड (9.4 सें मी) देखे गए। जी डब्ल्यू-273 (9.4) की किस्म में दीर्घ हैड देखे गए जबकि अमर में छोटे (8.4) देखे गए। बुआई की दूसरी तारीख (5 दिसंबर) को बोई गए फसल में अधिकतम अनाज का उत्पादन 3307 कि. ग्रा./है. हुआ जो कि पहले और विलंब से बोई गई फसलों की तुलना में विशेष रूप से अधिक था। औसतन जी डब्ल्यू - 273 के बाद कंचन की किस्म (3190 कि.गा./ हैक्ट.) में विशेष रूप से अनाज का उत्पादन अधिक हुआ जबकि अमर (2609 कि.गा./ हैक्ट.) और सुजाता (2740 कि.गा./ हैक्ट.) की किस्म एक समान होते हुए भी अनाज का उत्पादन कम हुआ। चार किस्मों में, जी डब्ल्यू 273 सामान्यत: क्षमता वाली किस्म भी जबकि अन्य किस्में उष्मीय दबाव के प्रति संवेदनशील या फसल की बढ़ोतरी में कुल अवधि और अवरूद्ध विकास के लिए यह संभावित कारण हो सकता है।

ABSTRACT. The present investigation entitled "Thermal responses on different wheat cultivars under different thermal environments for Chhattisgarh plain" was carried out during Rabi season of 2009-2010, at the Research Farm of Indira Gandhi Krishi Vishwavidhyalaya, Raipur. Accumulated growing degree days (GDD) for different varieties under different thermal environments varied considerably from sowing to maturity. Higher GDD was observed under 25 November (D_1) in varieties Sujata and Amar. Highest PTU and HTU were observed in 5 January (D_5) in most of the varieties. Highest HUE values were observed under 25 November, 5 December and 15 December sowing in most of the variety except GW-273. Lowest HUE was observed under 5 January sowing (D_5) in the all varieties. Lowest RUE was observed under 5 January sowing (D_5) in the all varieties. Highest IPAR values were observed under 25 November (D_1) sowing in most of the varieties. Higher number of ear heads / m^2 observed with 5 December and 15 December sowing. Longer ear head (9.4 cm) was observed in first and second date of sowing (25 November and 5 December) as compared to delayed sowing of 15 December, 25 December and 5 January. Longer ear head was observed in variety GW-273 (9.4) while minimum (8.4) was observed in Amar. Maximum grain yield 3307 kg/ha was harvested in 2nd (5 December) date of sowing which was significantly higher as compared to before and delayed sowing. On an average significant higher grain yield was obtained in variety Kanchan (3190 kg/ha) followed by GW-273 whereas, the lower grain yield was recorded in variety Amar (2609 kg/ha) and Sujata (2740 kg/ha) being at par to each other. Among the four varieties, GW-273 was found to be moderately susceptible while other varieties are susceptible for thermal stress; this might be probable reason for reduction total duration and stunted crop growth.

Key words – GDD, PTU, HTU, Heat use efficiency (HUE), Radiation use efficiency (RUE), Plant Population, Phenology and grain yield.

1. Introduction

Wheat (*Triticum aestivum* L) is the most widely cultivated food grain crop of the world. It is grown not only in temperate zones but also in tropical and sub tropical zones. In India, wheat is the second important staple food crop, rice being the first. It has wide adaptability and can tolerate severe cold.

The best wheat are produced with cool and moist weather during the major portion of the growing period followed by dry warm weather during grain filling and maturity period. Wheat (*Triticum spp*.) is the major Rabi crop in India and is sensitive to various biotic and abiotic stresses like weather and inter-seasonal climatic variability (in terms of changes in temperature, rainfall, radiation), soil conditions and agricultural inputs like nitrogen, water and pesticides. Three main species commonly grown in the world including India are the common wheat (*Triticum aestivum)* the marconi or durum wheat (*Triticum durum*) and the emmer wheat (*Triticum dicoccum*), out of these species maximum area is under *Triticum aestivum*. In India, more than 80 per cent of the total wheat area is under this species whereas the area under marconi and emmer wheat, the area is only 12 per cent and 1 per cent respectively.

In India, wheat is grown in an area of 281.93 lakh ha. with an average productivity of 2790 kg/ha which contributes about 25 per cent of total food grain production of the country. The productivity of wheat in Chhattisgarh is very low as compared to the national average. In Chhattisgarh wheat crop is grown in 1.63 lakh ha. with an average productivity of 1108 kg/ha. The main reasons for low productivity are shorter winter span and high temperature during the grain filling and maturity stages. Seasonal temperature is important climatic factors which have profound effects on the yield of rabi crops. Changes in seasonal temperature affect the grain yield, mainly through phonological development processes. Winter crops are especially vulnerable to high temperature during reproductive stages and differential response of temperature change (rise) to various crops has been noticed under different production environments. The effect of temperature on the wheat productivity can easily by seen in Central India because of high inter-annual fluctuations in the productivity due to fluctuations in seasonal temperature. The productivity of wheat is largely dependent on the magnitude of temperature change. One °C increase in temperature throughout the growing seasons will have no effect or slight increase on productivity in north India. But, an increase of 2 °C temperature reduced potential grain yield at most of the places (Agrawal and Sinha, 1993).

In Chhattisgarh, wheat is grown mostly under irrigated conditions in rice based cropping system. The sowing of wheat is often delayed due to delay in harvesting of medium and late duration of rice varieties. Late sown wheat crop faces high temperature during grain filling and ripening phases which is one of the major causes of stunted growth and low productivity of wheat in this area. Time of sowing is one of the most important factors which govern the crop Phenological development and total biomass production along with efficient conversion of biomass into economic yield. Delayed sowing of wheat crop is exposed to sub-optimal temperatures at establishment and supra-optimal temperatures at reproductive phases resulting into reduction of not only crop duration but also the yield (Sardana *et al.*, 1999). Temperature, being a key component of climate, determines the seeding time and consequently the rate and duration of growth and productivity of any crop.

The optimum date of sowing is considered equally important which helps in good germination and better growth of crop plants which leads finally to better harvest. Too much delay in sowing resulted in reduction in crop yields. Dwarf wheat being photo-insensitive, suits in early as well as late sowing, thus well fitted in double and multiple cropping patterns. However, too early sowing produces less tillers and too late sown crop produce wrinkled seeds due to higher temperature.

The occurrence of different phenological event during growing season of any crop and the effect of temperature on plant growth can be inferred using accumulated heat units or growing degree days (GDD). The duration of each growth phase is a result of crop response to external environmental factors. The concept of heat units has been applied to correlate the phonological development of different crops to predict grain yield and phonological maturity (Swan *et al*., 1987).

Temperature based agro-meteorological indices such as growing degree days (GDD) and heat use efficiency (HUE) can be quite useful in predicting growth and yield of crops. Growing degree days are based on the concept that real time to attain a phonological stage is linearly related to temperature in the range between base temperature (T_b) and optimum temperature. Heat use efficiency (HUE), *i.e*., efficiency of utilization of heat in terms of dry matter accumulation is an important aspect, which has great practical application. The total heat energy available to any crop is never completely converted to dry matter even under the most favourable agro climatic conditions. Efficiency of conversion of heat energy into biomass depends upon genetic factors, sowing time and crop type (Rao *et al*., 1999).

2. Materials and method

2.1. *Location of Experimental site*

The field experiment was carried out at the Research and Instructional farm of Indira Gandhi Krishi Vishwavidyalaya; Raipur situated in Eastern Central part of Chhattisgarh at latitudes of 21°.16′ N, longitude 81°.36′ E and altitude 289.5 m above mean sea level.

2.2. *Experimental detail*

The experiment consisting of 5 date of sowing and 4 wheat varieties were laid out in a randomized block design with three replications.

Season	:	Rabi
Crop	:	Wheat
Date of Sowing	:	Five
	:	D_1 - 25 November 2009
	:	D_2 - 5 December 2009
	:	D_3 - 15 December 2009
	:	D_4 - 25 December 2009
	:	D_5 - 5 January, 2010
Varieties	:	V_1 – Kanchan
	:	V_2 – GW-273
	:	V_3 – Sujata
	:	V_4 – Amar
Experimental design	:	RBD
Seed rate	:	125 kg/ha
Spacing	:	20 cm row to row
Plot size	:	7 m × 4.4 m (30.8 m^2)
Total number of plots	:	60
Plot to plot distance	:	0.5 m
Fertilizer doses	:	100:60:40 kg/ha N: P_2O_5:K_2O
Irrigation	:	Six (One come up irrigation and five coinciding with critical stages)

2.3. *Growing degree days*

Growing Degree Days (GDD) concept assumes that there is a direct and linear relationship between growth and developments of plants and temperature and the growth is dependent on the total amount of heat to which it is subjected during its life time. The growing degree days was computed by using following formula:

$$GDD = \Sigma\ [(Tx + Tn)/2 - \text{Base temperature}]$$

where,

Tx = Daily maximum temperature

Tn = Daily minimum temperature

The base Temperature is defined as, "The temperature below which no plant physiological activity takes place" which is considered 5.0 for Rabi crops.

2.4. *Photothermal unit (PTU)*

PTU is calculated by multiplying GDD with maximum possible sunshine hours (N).

$$PTU = GDD \times N$$

where,

N = maximum possible sunshine hour.

2.5. *Heliothermal unit (HTU)*

HTU is calculated by multiplying GDD with actual sunshine hours (n) (Rajput, 1980).

$$HTU = GDD \times n$$

where,

n = actual sunshine hour.

2.6. *Heat use efficiency (HUE)*

Heat Use Efficiency (HUE) for total dry matter was obtained as under:

$$\text{HUE (g/m}^2\text{ /° day)} = \frac{\text{Biomass}\left(g/m^3 \right)}{\text{GDD}(\text{°days})}$$

2.7. *Radiation use efficiency (RUE)*

$$\text{RUE (gMJ}^{-1}) = \text{Biomass } (g/m^{-2}) \text{ / IPAR (M J}^{-2})$$

where,

IPAR is cumulative intercepted photo synthetically active radiation.

TABLE 1

Accumulated growing degree days (GDD) at different growth stages of wheat varieties under different thermal environments

Sowing dates	Emergence	C.R.I.	Tillering	Ear emergence	50% Flow.	Milking	Dough	Maturity
				Kanchan				
D_1-25 Nov	69.5	345.9	511.2	752.0	973.6	1341.4	1567.7	1791.6
D_2-05 Dec	84.3	341.9	497.6	748.7	1008.8	1335.1	1604.5	1897.7
D_3-15 Dec	94.5	293.0	465.2	661.6	974.6	1302.0	1601.1	1728.2
D_4-25 Dec	86.6	281.3	434.2	676.0	1000.3	1290.0	1611.5	1802.3
D_5-05 Jan	94.9	258.2	414.6	731.4	1068.7	1345.3	1667.7	1802.4
				GW-273				
D_1-25 Nov	69.5	345.9	511.2	738.3	989.4	1341.4	1567.7	1747.0
D_2-05 Dec	84.3	341.9	486.1	720.0	973.4	1335.1	1604.5	1770.6
D_3-15 Dec	94.5	293.0	465.2	677.4	1010.9	1302.0	1601.1	1728.2
D_4-25 Dec	86.6	281.3	434.2	676.0	1020.6	1290.0	1611.5	1802.3
D_5-05 Jan	94.9	258.2	414.6	731.4	1045.3	1345.3	1695.2	1858.2
				Sujata				
D_1-25 Nov	69.5	345.9	527.9	918.4	1062.4	1439.0	1705.3	1986.8
D_2-05 Dec	84.3	341.9	497.6	920.0	1144.2	1471.5	1649.2	1926.0
D_3-15 Dec	79.0	293.0	477.9	896.6	1127.0	1415.1	1674.8	1867.0
D_4-25 Dec	86.6	281.3	447.7	924.3	1086.8	1334.7	1722.0	1856.8
D_5-05 Jan	79.8	258.2	430.3	976.1	1155.4	1395.2	1774.9	1942.8
				Amar				
D_1-25 Nov	69.5	345.9	543.5	932.3	1062.4	1439.0	1705.3	1986.8
D_2-05 Dec	84.3	341.9	511.1	920.0	1162.2	1471.5	1649.2	1926.0
D_3-15 Dec	79.0	293.0	477.9	918.5	1127.0	1415.1	1674.8	1867.0
D_4-25 Dec	86.6	295.1	461.4	962.4	1110.7	1334.7	1722.0	1856.8
D_5-05 Jan	79.8	270.9	442.1	998.4	1177.8	1395.2	1774.9	1942.8

The photo synthetic active radiation can be calculated by using the following formula:

$$PAR = Rs \times 0.5$$

where,

Rs = incoming solar radiation

The incoming solar radiation can be calculated by the formula:

$$Rs = Rs_0 (a + b \times n/N)$$

where,

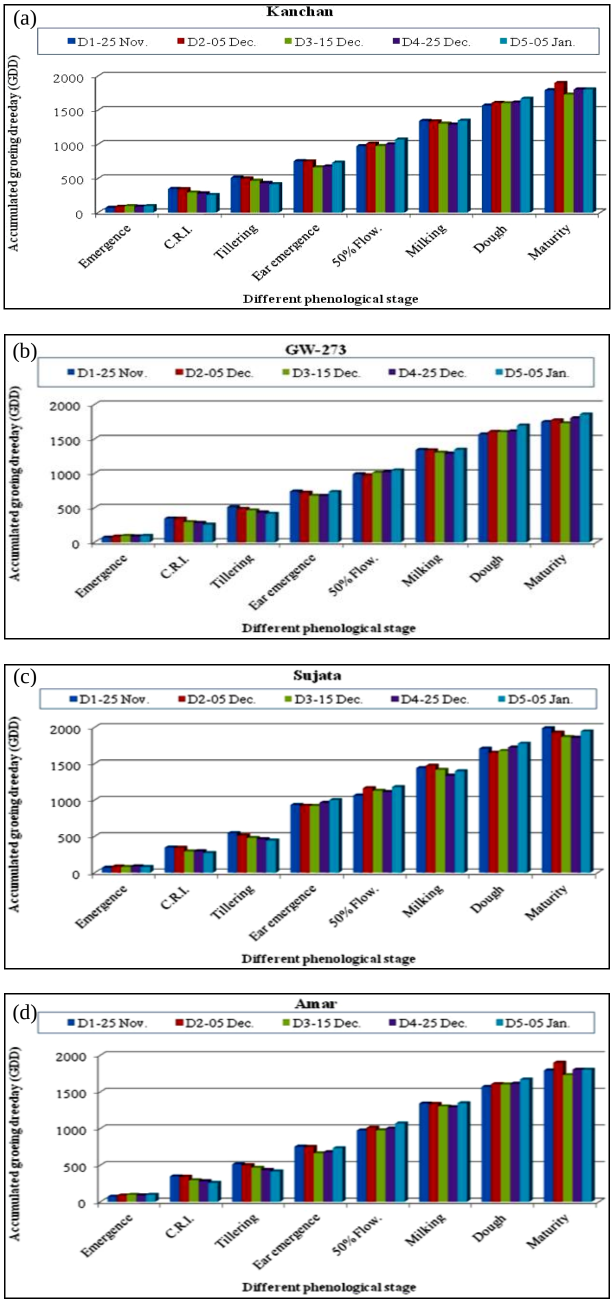
Rs_0 = Extra terrestrial radiation

n / N = Per cent sunshine hours

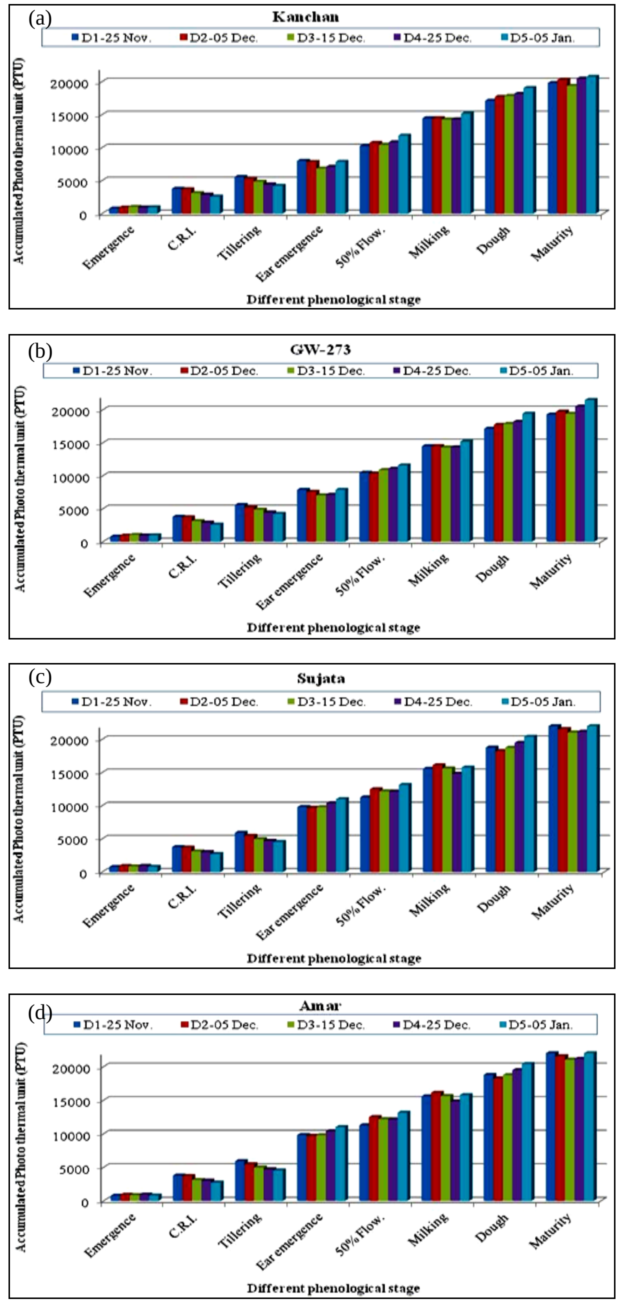
a = 0.2, b = 0.4

3. Results and discussion

In Chhattisgarh wheat is mostly grown under irrigated condition in command area and in tube well irrigated areas. The productivity of this crop is low as compared to national average, because of delayed sowing in rice based cropping system, shorter winter span and higher temperature during grain filling and maturity stages. With this background



Figs. 1(a-d). Accumulated growing degree days (GDD) at different growth stages of wheat varieties under different thermal environments



Figs. 2 (a-d). Accumulated photothermal units (PTU) at different growth stages of wheat varieties under different thermal environments

the present experiment was conducted during winter season of 2009-10 to identify suitable high yielding varieties of wheat for late sown conditions under rice based cropping system which can tolerate the high temperatures during reproductive and grain filling stages.

3.1. *Heat units*

3.1.1. *Growing degree day (GDD)*

Heat unit requirement or GDD has been used for characterizing the thermal response in wheat crop (Rajput *et al.*, 1987) and other crops. Bright sunshine hours,

TABLE 2

Accumulated Photothermal Units (PTU) at different growth stages of wheat varieties under different thermal environments

Sowing dates	Emergence	C.R.I.	Tillering	Ear emergence	50% Flow.	Milking	Dough	Maturity
				Kanchan				
D_1-25 Nov	773.7	3769.8	5561.7	8005.7	10251.0	14466.0	17118.5	19805.9
D_2-05 Dec	913.3	3705.7	5316.7	7837.3	10721.9	14472.3	17705.1	20276.1
D_3-15 Dec	1023.8	3126.9	4855.8	6848.1	10435.1	14271.1	17860.3	19385.5
D_4-25 Dec	938.2	2893.5	4428.1	7103.0	10819.5	14295.9	18153.9	20475.8
D_5-05 Jan	952.8	2591.8	4228.7	7859.2	11834.9	15154.1	19055.2	20755.1
				GW-273				
D_1-25 Nov	773.7	3769.8	5561.7	7867.7	10431.5	14466.0	17118.5	19270.1
D_2-05 Dec	913.3	3705.7	5200.8	7549.6	10316.2	14472.3	17705.1	19698.3
D_3-15 Dec	1023.8	3126.9	4855.8	7028.6	10851.1	14271.1	17860.3	19385.5
D_4-25 Dec	938.2	2893.5	4428.1	7103.0	11063.1	14295.9	18153.9	20475.8
D_5-05 Jan	952.8	2591.8	4228.7	7859.2	11553.5	15154.1	19401.6	21458.7
				Sujata				
D_1-25 Nov	773.7	3769.8	5742.7	9675.9	11268.7	15584.5	18770.3	22147.7
D_2-05 Dec	913.3	3705.7	5316.7	9703.7	12273.0	16109.1	18240.9	21563.1
D_3-15 Dec	856.4	3126.9	4982.8	9541.2	12181.6	15628.3	18744.7	21051.1
D_4-25 Dec	938.2	2893.5	4563.6	9948.0	11857.5	14831.7	19479.9	21163.6
D_5-05 Jan	800.7	2591.8	4409.2	10723.7	12875.3	15752.9	20408.1	22527.0
				Amar				
D_1-25 Nov	773.7	3769.8	5912.4	9815.9	11268.7	15584.5	18770.3	22147.7
D_2-05 Dec	913.3	3705.7	5451.8	9703.7	12479.3	16109.1	18240.9	21563.1
D_3-15 Dec	856.4	3126.9	4982.8	9792.2	12181.6	15628.3	18744.7	21051.1
D_4-25 Dec	938.2	3031.5	4701.7	10384.6	12144.3	14831.7	19479.9	21163.6
D_5-05 Jan	800.7	2719.8	4543.8	10990.7	13144.1	15752.9	20408.1	22527.0

maximum and minimum temperature during the growth period were recorded from meteorological observatory of the University Growing degree days (GDD) were computed by taking a base temperature 5 °C (Nuttonson, 1955).

It was evident from the Table 1 that accumulated growing degree days (GDD) for different genotypes under different thermal environments varied considerably from sowing to maturity. Different wheat varieties responded differently in terms of accumulated GDD at the time of maturity. Higher GDD was observed under 25 November sowing (D_1) in varieties Sujata and Amar.

In case of Kanchan higher GDD was noticed under 5 December sowing followed by 25 December and 5 January sowing. Lower GDD was noticed under 15 December sowing. But, in case of GW-273 higher GDD was noticed under 5 January sowing and lowest was noticed under 25 November sowing. In general the GDD values decreased when the sowing was delayed except under 5 January sowing, this may due to early maturity of crops under delayed sown condition because of higher temperature [Figs. 1(a-d)].

In case of variety Sujata and Amar, the GDD value was highest in 25 November followed by 5 January, 5 December, 15 December and 25 December at maturity period. Decreased heat unit requirement with delay in sowing were also reported by Rajput *et al.*, 1987 and Agrawal *et al.*, 1999.

TABLE 3

Accumulated Heliothermal Units (HTU) at different growth stages of wheat varieties under different thermal environments

Sowing dates	Emergence	C.R.I.	Tillering	Ear emergence	50% Flow.	Milking	Dough	Maturity
				Kanchan				
D_1-25 Nov	610.4	2667.9	3872.2	5253.5	7375.5	10464.6	12506.3	14464.3
D_2-05 Dec	626.5	2457.6	3601.1	5310.8	7391.6	10415.4	12834.0	14861.5
D_3-15 Dec	567.7	2057.6	3008.4	4806.1	7321.9	10519.0	13140.6	14369.1
D_4-25 Dec	552.0	1800.1	3071.8	4984.3	7973.4	10595.0	13609.7	15306.3
D_5-05 Jan	715.1	1733.7	3123.5	5693.8	9030.9	11427.3	14352.1	15693.6
				GW-273				
D_1-25 Nov	610.4	2667.9	3872.2	5245.3	7375.5	10276.4	12506.3	14040.3
D_2-05 Dec	626.5	2457.6	3500.6	5050.6	7168.6	10415.4	12834.0	14382.5
D_3-15 Dec	567.7	2057.6	3008.4	4927.4	7645.2	10519.0	13140.6	14369.1
D_4-25 Dec	552.0	1800.1	3071.8	4984.3	8176.4	10595.0	13609.7	15306.3
D_5-05 Jan	715.1	1733.7	3123.5	5693.8	8787.1	11427.3	14626.6	16203.3
				Sujata				
D_1-25 Nov	610.4	2667.9	3994.1	6782.7	7891.2	11228.8	13848.4	16323.3
D_2-05 Dec	626.5	2457.6	3601.1	6684.9	8563.8	11760.9	13258.1	15848.7
D_3-15 Dec	431.8	2057.6	3117.2	6696.2	8780.7	11550.4	13875.2	15523.7
D_4-25 Dec	552.0	1800.1	3202.7	7182.6	8831.7	11019.1	14526.6	15851.3
D_5-05 Jan	645.4	1733.7	3230.6	8106.9	9640.8	11923.8	15424.1	16991.1
				Amar				
D_1-25 Nov	610.4	2667.9	3997.2	6883.2	7891.2	11228.8	13848.4	16323.3
D_2-05 Dec	626.5	2457.6	3708.7	6684.9	8713.2	11760.9	13258.1	15848.7
D_3-15 Dec	431.8	2057.6	3117.2	6893.3	8780.7	11550.4	13875.2	15523.7
D_4-25 Dec	552.0	1808.3	3337.5	7580.7	9061.1	11019.1	14526.6	15851.3
D_5-05 Jan	645.4	1857.4	3234.1	8327.2	9831.2	11923.8	15424.1	16991.1

3.1.2. *Photo thermal unit (PTU)*

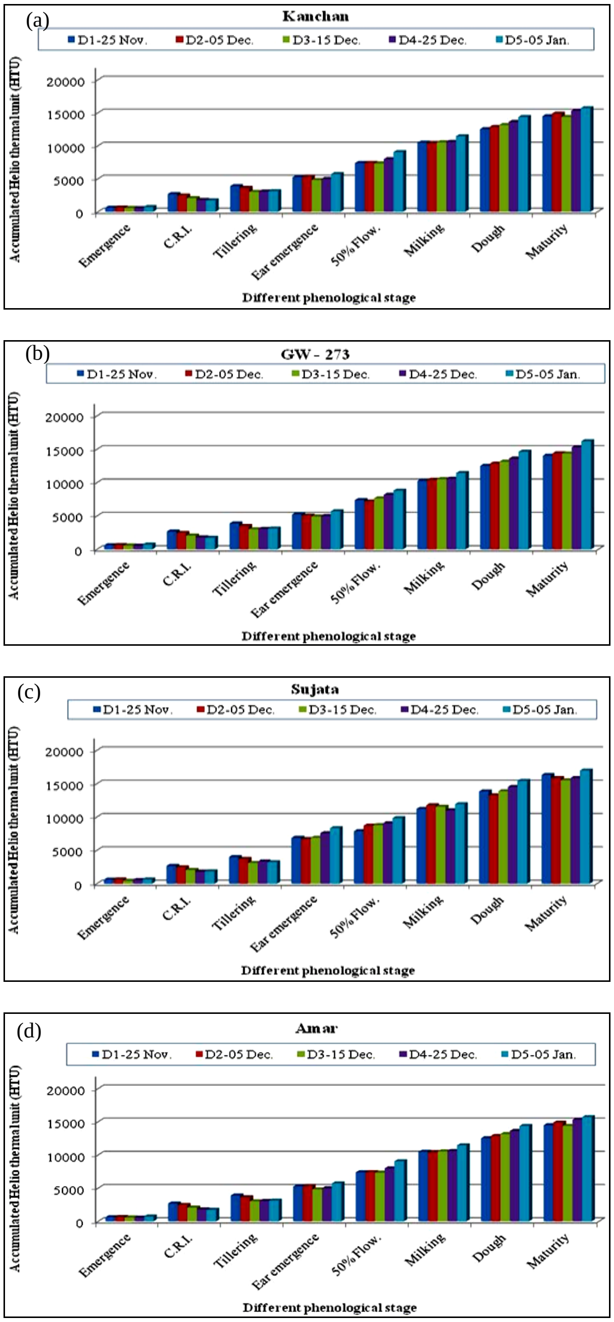
Different wheat varieties responded differently in terms of accumulated PTU at the time of maturity. Highest PTU was observed under 5 January sowing (D_5) in the all varieties.

Photothermal unit (PTU) for different genotypes under different thermal environment varied considerably at maturity (Table 2). In case of variety Sujata and Amar the highest PTU was observed under 5 January followed by 25 November, 5 December, 25 December and 15 December. In case of GW-273 maximum PTU was observed in 5 January followed by 25 December, 5 December, 15 December and 25 November. The highest PTU value was observed in case of Kanchan under sow date of 5 January which is followed by 25 December, 5 December, 25 November and 15 December. Highest PTU was observed under 5 January sowing (D_5) in the all varieties [Figs. 2 (a-d)].

3.1.3. *Helio thermal unit (HTU)*

Different wheat varieties responded differently in terms of accumulated HTU at the time of maturity. Highest HTU was observed under 5 January sowing (D_5) in the all varieties.

Heliotermal unit (HTU) for different genotypes under different thermal environment varied considerably under maturity period (Table 3). In case of Kanchan the highest HTU was observed under 5 January followed by



Figs. 3(a-d). Accumulated heliothermal units (HTU) at different growth stages of wheat varieties under different thermal environments

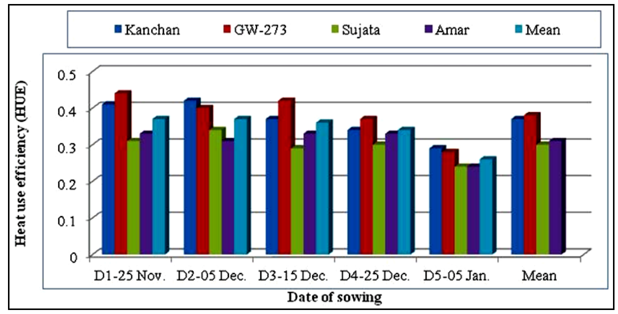


Fig. 4. Heat use efficiency (HUE) of wheat varieties under different thermal environments

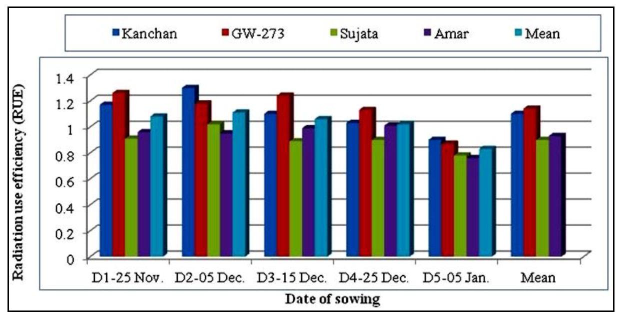


Fig. 5. Radiation use efficiency (RUE) of wheat varieties under different thermal environments

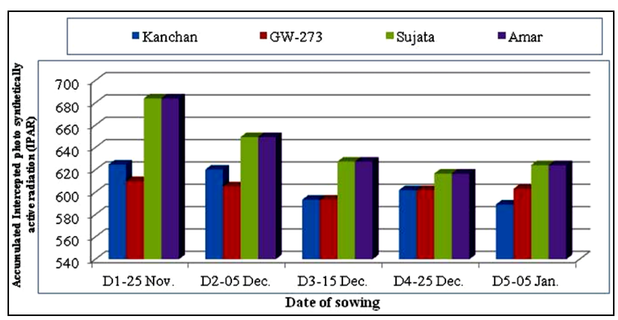


Fig. 6. Accumulated intercepted photo synthetically active radiation (IPAR) of wheat varieties under different thermal environments

25 December, 5 December, 25 November and 15 December. In case of GW-273 maximum HTU was observed in 5 January followed by 25 December, 5 December, 15 December and 25 November. In variety Sujata the highest HTU was observed in 5 January followed by 25 November, 25 December, 5 December and 15 December. But in case of Amar highest HTU value was recorded on 5 January followed by 25 November, 25 December, 5 December and 15 December. Highest HTU was observed under 5 January sowing (D_5) in the all varieties [Figs. 3(a-d)].

The growing degree day GDD for entire crop growing period decreased with subsequent delay in sowing, where as HTU, PTU were decreased up to late sowing date (D_3) but increased under very late sowing date (D_4) condition. These results are in general agreement with the findings of Sandhu *et al.* (1999).

TABLE 4

Heat use efficiency (HUE) of wheat varieties under different thermal environments

Varieties	Heat use efficiency (gm/m^2 deg day/m^2)					
	D_1-25 Nov	D_2-05 Dec	D_3-15 Dec	D_4-25 Dec	D_5-05 Jan	Mean
Kanchan	0.41	0.42	0.37	0.34	0.29	0.37
GW-273	0.44	0.40	0.42	0.37	0.28	0.38
Sujata	0.31	0.34	0.29	0.30	0.24	0.30
Amar	0.33	0.31	0.33	0.33	0.24	0.31
Mean	0.37	0.37	0.36	0.34	0.26	

TABLE 5

Radiation Use Efficiency (RUE) of wheat varieties under different thermal environments

Varieties	Radiation Use Efficiency (g MJ^{-1})					
	D_1-25 Nov	D_2-05 Dec	D_3-15 Dec	D_4-25 Dec	D_5-05 Jan	Mean
Kanchan	1.17	1.30	1.10	1.03	0.90	1.10
GW-273	1.26	1.18	1.24	1.13	0.87	1.14
Sujata	0.91	1.02	0.89	0.90	0.78	0.90
Amar	0.96	0.95	0.99	1.01	0.76	0.93
Mean	1.08	1.11	1.06	1.02	0.83	

TABLE 6

Accumulated Intercepted photo synthetically active radiation (IPAR) of wheat varieties under different thermal environments

Varieties	Intercepted photo synthetically active radiation (MJ m^{-1})				
	D_1-25 Nov	D_2-05 Dec	D_3-15 Dec	D_4-25 Dec	D_5-05 Jan
Kanchan	624.74	620.33	593.29	601.87	588.94
GW-273	609.97	605.12	593.29	601.87	602.96
Sujata	683.94	649.36	627.42	616.65	624.19
Amar	683.94	649.36	627.42	616.65	624.19

The occurrence of different Phenological events during growing season of any crop and the effect of temperature on plant growth can be inferred using accumulated heat units or growing degree days (GDD). The duration of each growth phase is a result of crop response to external environmental factors. The concept of heat units has been applied to correlate the Phenological development of different crops to predict grain yield and physiological maturity (Swan *et al*., 1987).

3.1.4. *Heat use efficiency (HUE)*

Heat use efficiency (HUE) for different genotypes under different thermal environments varied considerably (Table 4). Higher HUE values were observed under 25 November and 5 December sowing closely followed by 15 December sowing (0.36) and 25 December sowing (0.34). Lowest HUE was observed under 5 January sowing.

In case of Kanchan maximum HUE was observed in 5 December sowing followed by 25 November, 15 December, 25 December and 5 January. In case of GW-273 maximum HUE was observed in 25 November followed by 15 December, 5 December, 25 December and 5 January. In variety Sujata the highest HUE was observed in 5 December followed by 25 November, 25 December, 15 December and 5 January. But in case of

TABLE 7

Effect of different thermal environments on phenology of wheat varieties

Sowing dates	Crop growth stages							
	Emergence	C.R.I.	Tillering	Ear emergence	50% Flow	milking	Dough	maturity
				Kanchan				
D_1-25 Nov	5	22	34	51	68	89	100	110
D_2-05 Dec	5	22	34	52	69	86	98	107(3)
D_3-15 Dec	6	21	33	48	66	82	95	100(10)
D_4-25 Dec	6	20	32	48	65	78	91	98(12)
D_5-05 Jan	7	19	30	48	64	76	88	93(17)
				GW-273				
D_1-25 Nov	5	22	34	50	69	89	100	108
D_2-05 Dec	5	22	33	50	67	86	98	105(3)
D_3-15 Dec	6	21	33	49	68	82	95	100(8)
D_4-25 Dec	6	20	32	48	66	78	91	98(10)
D_5-05 Jan	7	19	30	48	63	76	89	95(13)
				Sujata				
D_1-25 Nov	5	22	35	64	74	94	106	118
D_2-05 Dec	5	22	34	64	76	92	100	111(7)
D_3-15 Dec	5	21	34	62	74	87	98	105(13)
D_4-25 Dec	6	20	33	61	69	80	95	100(18)
D_5-05 Jan	6	19	31	60	68	78	92	98(20)
				Amar				
D_1-25 Nov	5	22	36	65	74	94	106	118
D_2-05 Dec	5	22	35	64	77	92	100	111(7)
D_3-15 Dec	5	21	34	63	74	87	98	105(13)
D_4-25 Dec	6	21	34	63	70	80	95	100(18)
D_5-05 Jan	6	20	32	61	69	78	92	98(20)

Amar the HUE values were similar in 25 November, 15 December, 25 December, sowing followed by 5 December and 5 January. Lowest HUE was observed under 5 January sowing (D_5) in the all varieties. On the mean basis higher HUE was observed with variety GW-273 followed by Kanchan. Variety Amar and Sujata were found with lower HUE because of late duration variety (Fig. 4).

Kumari *et al*. (2009) reported that the date of sowing the timely (20 November) sown wheat crop exhibited maximum HUE of 2.23 kg grain ha^{-1} deg $days^{-1}$. Timely sowing (20 November) of wheat crop, in this (Ranchi) region, seems to be essential for harnessing the good impact of the prevailing weather conditions.

3.1.5. *Radiation use efficiency (RUE)*

Radiation Use Efficiency (RUE) for different genotypes under different thermal environments varied considerably (Table 5). On the mean basis higher RUE value was observed under 5 December sowing followed by 25 November, 15 December, 25 December and 5 January sowing. Among the varieties GW-273 showed better in terms of RUE followed by Kanchan, Amar and Sujata.

In case of GW-273 maximum RUE was observed in 25 November followed by 15 December, 5 December, 25 December and 5 January. In variety Sujata the highest RUE was observed in 5 December followed by 25

TABLE 8

Plant population of wheat varieties as influenced by different thermal environments

Varieties	Plant population/m^2					
	D_1	D_2	D_3	D_4	D_5	Mean
Kanchan	216	226	246	211	210	222
GW-273	210	248	215	195	191	212
Sujata	200	250	238	225	215	226
Amar	215	243	240	211	203	222
Mean	210	242	235	211	205	
	SEm+/-	CD (P = 0.05)	CV (%)			
D	3.5	9.9	5.4			
V	3.1	8.9				
D × V	7.0	19.9				

TABLE 9

Plant height (c.m.) per plant of wheat varieties at 10 days intervals under different thermal environments

Sowing dates	Days after sowing							
	30	40	50	60	70	80	90	Maturity
Kanchan								
D_1-25 Nov	35.6	47.2	64.6	77.7	79.5	82.1	83.0	84.7
D_2-05 Dec	34.3	41.6	55.8	71.3	73.3	78.0	78.2	80.3
D_3-15 Dec	34.0	39.4	52.1	66.2	73.4	77.7	79.6	80.0
D_4-25 Dec	31.6	40.8	50.6	69.1	69.8	75.0	75.4	77.1
D_5-05 Jan	24.8	38.7	46.0	57.0	67.6	68.0	69.6	74.1
GW-273								
D_1-25 Nov	37.4	44.2	61.3	74.3	76.7	78.0	82.8	84.6
D_2-05 Dec	31.4	49.8	64.1	75.7	78.2	80.6	83.3	85.8
D_3-15 Dec	31.0	40.4	53.2	68.7	72.4	76.7	80.2	82.6
D_4-25 Dec	30.3	38.4	51.5	68.0	70.9	75.1	78.7	81.9
D_5-05 Jan	28.2	37.1	46.4	58.7	67.2	72.4	78.5	80.5
Sujata								
D_1-25 Nov	30.4	52.8	60.1	78.0	90.7	94.0	95.5	98.7
D_2-05 Dec	37.2	54.2	66.7	81.3	93.4	101.4	103.0	105.0
D_3-15 Dec	30.4	42.0	56.7	75.8	80.6	91.6	94.5	96.4
D_4-25 Dec	30.0	40.3	48.9	55.8	75.5	88.7	90.4	93.5
D_5-05 Jan	28.7	35.8	37.8	51.0	66.1	86.9	88.4	91.2
Amar								
D_1-25 Nov	34.6	44.4	62.7	76.5	87.9	94.4	96.6	98.1
D_2-05 Dec	31.9	51.6	61.9	76.7	94.3	97.4	99.1	101.0
D_3-15 Dec	31.6	41.2	52.9	68.2	81.5	91.9	94.3	96.3
D_4-25 Dec	30.0	40.5	51.4	59.7	78.4	88.4	92.0	94.4
D_5-05 Jan	28.3	33.9	37.4	51.6	63.8	86.3	89.7	92.3

November, 25 December, 15 December and 5 January. But in case of Amar highest RUE value was recorded on 25 December followed by 15 December, 25 November, 5 December and 5 January. Lowest RUE was observed under 5 January sowing (D_5) in the all varieties (Fig. 5).

The mean HUE in kg ha^{-1} deg day^{-1} varied from 2.21 for normal date (1^{st} week of December) of sowing to 1.27 for vary late sowing (1^{st} week of January) Patra and Sahu (2007). Similar findings were also reported by Rao *et al.* (1999). The results revealed that under normal sowing condition the crop accumulated higher amount of heat unit than late sown condition. The RUE and HUE were also higher for earlier sowings than later sowings.

3.1.6. *Intercepted photo synthetically active radiation (IPAR)*

Intercepted photo synthetically active radiation (IPAR) for different genotypes under different thermal environments varied considerably from sowing to maturity (Table 6). Highest IPAR values were observed under 25 November (D_1) sowing in most of the all varieties.

Intercepted photo synthetically active radiation (IPAR) for different genotypes under different thermal environments varied considerably under maturity period (Table 6). In case of Kanchan the highest IPAR was observed under 25 November followed by 5 December, 25 December, 15 December and 5 January. In case of GW-273 maximum IPAR was observed in 25 November followed by 5 December, 25 December, 15 December and 5 January. In variety Sujata the highest IPAR was observed in 25 November followed by 5 December, 15 December, 5 January and 25 December. But in case of Amar highest IPAR value was recorded on 25 November followed by 5 December, 15 December, 5 January and 25 December. Lowest IPAR was observed under 5 January sowing (D_5) in the varieties Kanchan and GW-273 (Fig. 6).

3.1.7. *Phenological studies*

The days taken from sowing to emergence, CRI, tillering, ear head emergence, 50% flowering, milking, dough and maturity of wheat varieties under different thermal environments are given in Table 7.

The result reveals that days taken for emergence increased gradually from 5 days to 7 days when the sowing was delayed from 25 November to 5 January at 10 days interval. However, in general 5 to 6 days is required for emergence. Delayed sown crop took more number of days for emergence due to low temperature at the time of sowing on 25 December and 5 January. The mean temperature was below 20.0°C at the time of sowing on 25 November, 25 December and 5 January whereas the mean temperature was above 20.0°C on 5 and 15 December sowing.

Different varieties did not showed remarkable variation in days taken for emergence under different respective thermal environments. The occurrence of phenological events in wheat crop was affected due to different thermal environments (Table 7) the duration for emergence was delayed by 2 days in different varieties when sowing was delayed from 25 November to 5 January. The Phenological events such as CRI, tillering, ear emergence 50 per cent flowering, milking, dough and maturity decreased appreciably with delay in sowing. However days for these phenological events varied from variety to variety due to their response to different environments.

It can be seen that the highest effect of thermal stress on phonological stages was observed in cv. Sujata and Amar followed by Kanchan. The least effect of thermal stress was observed in case of GW-273 (13 days). The variety GW-273 was not affected much due to thermal stress and the duration decreased only by 10 and 13 days respectively under 25 December and 5 January sowing.

The least difference in days taken for sowing to maturity was only 13 days in GW-273, while the decrease in duration from sowing to maturity was maximum of 20 days in case of Sujata and Amar Similarly duration of other phenological events decreased to a considerable extent in delayed sowing of 5 January as compare to sowing on 25 November.

In central India, the winter span is shorter as compared to North India. The mean temperature was 26.6 °C at maturity under early sowing of 25 November. Whereas, it was 29.5 °C in late sown crop of 5 January. Adverse effect of higher temperature on wheat crop had also been reported by Agrawal *et al.* (1999). It has been well documented that thermal stress is immediately expressed by any plant through phenological stages.

The results of phenology of wheat crop under five dates of sowing showed that the duration of different phenological events started decreasing right from CRI and continued in all the stages as the sowing was delayed after 25 November. The decrease in duration at these stages varied differently for different varieties.

TABLE 10

Number of ear heads/m^2 of wheat varieties under different thermal environments

	Date of Sowing					
Varieties	D_1	D_2	D_3	D_4	D_5	Mean
Kanchan	355	346	354	319	246	324
GW-273	295	332	332	284	244	297
Sujata	347	344	353	296	232	314
Amar	357	388	359	320	214	328
Mean	339	353	350	305	234	
	SEm +/-	CD (P = 0.05)	CV (%)			
D	4.6	13.0	5.0			
V	4.1	11.7				
D × V	9.1	26.1				

TABLE 11

Length of ear heads (cm) of wheat varieties under different thermal environments

	Date of Sowing					
Varieties	D_1	D_2	D_3	D_4	D_5	Mean
Kanchan	8.9	9.6	8.9	8.7	8.4	8.9
GW-273	9.6	10.1	9.7	8.9	8.7	9.4
Sujata	10.0	9.2	8.5	9.2	8.1	9.0
Amar	9.4	8.7	8.5	8.4	7.4	8.4
Mean	9.4	9.4	8.9	8.8	8.1	
	SEm +/-	CD (P = 0.05)	CV (%)			
D	0.09	0.27	3.63			
V	0.08	0.24				
D × V	0.19	0.54				

3.1.8. *Plant population*

The data summarising the plant population per unit area under different thermal environments and varieties are shown in Table 8. It can be seen from the table that mean plant population was significantly higher with variety Sujata which was at par with Kanchan and Amar. Lowest plant population (212) was observed with variety GW-273, which may be due to higher seed index of this variety.

The data showing plant population per m^2 area under different dates of sowing revealed that plant population influenced significantly due to different thermal environments. Significantly higher plant population was recorded with the crop sown on 5 and 15 December because of favourable temperatures during this period. The mean temperature during 5 and 15 December was near 20 °C whereas during earlier or late sowing it was below 20 °C.

3.1.9. *Plant height*

The plant height is the best measures and index of the total performance and response of the crop to the weather condition. Response of wheat varieties on different thermal environment are given in Table 9.

The plant height of the different varieties at 10 days intervals from 30 DAS to maturity are sown in Table 9.

TABLE 12

Grain yield (kg/ha) of wheat varieties under different thermal environments

	Date of Sowing					
Varieties	D_1	D_2	D_3	D_4	D_5	Mean
Kanchan	3571	3844	3705	2815	2017	3190
GW-273	3221	3226	3149	2961	2527	3017
Sujata	2949	3216	2913	2712	1909	2740
Amar	2825	2943	2856	2599	1823	2609
Mean	3142	3307	3156	2772	2069	
	SEm +/-	CD (P=0.05)	CV (%)			
D	51.4	147	6.1			
V	46.0	132				
DXV	102.9	295				

It can be seen that the initial plant height up to 30 DAS was higher in GW-273 (37.4 cm) followed by Kanchan (35.6 cm). It was observed that the plant height increased rapidly from 40 DAS to 60 DAS that is till the crop entered reproductive stage. There after the increase in height was marginal. At maturity Sujata attained maximum height of 105.0 cm followed by Amar (101.0 cm) when the crop was sown on 5 December. GW-273 attained the highest height of (85.8 cm) under 5 December followed by Kanchan (84.7 cm) in case of 25 November sowing.

Regarding the thermal effect on plant height Sujata expressed the highest effect as the height reduced from 105.0 cm to 91.2 cm under D_2 to D_5, the same trend was followed by Amar (101.0 cm to 92.3 cm). GW-273 variety was least affected due to thermal stress where the decrease in height was from 85.8 cm to 80.5 cm, *i.e.*, 5.3 cm only.

It was observed that the plant height increased with advancement in crop growth and reached to maximum at maturity. The increase in plant height took place slowly up to 40 days after sowing. Maximum rate of increase in plant height was observed between 40 to 60 days after sowing when the crop was in ear emergence stage. In general, higher Plant height was observed in varieties Sujata and Amar and lower plant height was recorded in varieties Kanchan and GW-273.

3.1.10. *Number of ear heads / m^2*

The data showing the influence of sowing dates on number of ear heads / m^2 of different wheat varieties are shown in Table 10. It was observed from the table that there was significant influence of sowing dates and on an average maximum no. of ear heads / m^2 was observed in variety Amar (328) followed by Knchan (324) and Sujata (314) whereas, Minimum no. of ear heads /m^2 was recorded in variety GW-273 (297). Higher no. of ear heads/m^2 (353) was observed 5 December sowing as compared to 25 November, 25 December and 5 January sowing (339, 305 and 234, respectively) but significantly at par with that with 15 December sowing (350). Ear heads/m^2 decreased slowly up to 25 December and after it decreased sharply when sowing was done on 5 January (D_5).

Under 25 November, 5 December, 15 December and 25 December sowing variety Amar, Kanchan and Sujata performed well and produced comparatively higher ear heads/m^2 as compared to GW-273 while under 5 January sowing it also produced good numbers of tillers and found next to Kanchan.

Higher number of ear heads / m^2 observed with 5 December and 15 December sowing may be due to favourable temperature conditions during tillering stage, *i.e.*, maximum was below 28 °C, minimum was below 12 °C and mean temperature was below 20 °C. Average maximum number of effective tillers/m^2 was observed in first date of sowing (20 November) as compared to delayed sowing (5, 20 December and 4 January).

3.1.11. *Length of ear heads (cm)*

The data showing the influence of sowing dates on length of ear heads of different wheat varieties are shown in Table 11. Significantly higher length of ear heads was observed in earlier sowing of 25 November and 5 December (9.4 cm each) which decreased as the sowing was delayed from 5 December to 15, 25 December and 5 January. It was observed from the table that on an average the highest length of ear heads was observed in varieties GW-273 (9.4) which was significant superior over other varieties whereas the lowest length of ear head was observed in variety Amar (8.4). Wheat variety Kanchan and Sujata were found at par to each other with respect to length of ear heads.

Length of ear heads of different wheat varieties was influenced due to temperature and shifting thermal environment. Longer ear head (9.4 cm) was observed in first and second date of sowing (25 November and 5 December) as compared to delayed sowing of 15 December, 25 December and 5 January. Longer ear head was observed in variety GW-273 (9.4) while minimum (8.4) was observed in Amar. Longer ear heads was observed in variety GW-273 (9.4) while minimum (8.4 cm) was observed in Amar. This may be due to different genetic constituents of these wheat varieties.

3.1.12. *Grain yield (kg/ha)*

The data pertaining to influence of different thermal environments on grain yield of different wheat varieties are given in Table 12. It was observed from the table that maximum grain yield 3307 kg/ha was harvested in 2^{nd} date of sowing which was significantly higher as compared to before and delayed sowing. Sowing of wheat on 25 November and 15 December being at par to each other produced significant higher grain yield as compared to 25 December and 5 January sowing which were differed significant among them significant lowest grain yield was recorded with sowing of wheat on 5 January. On an average significant higher grain yield was obtained in variety Kanchan (3190 kg/ha) followed by GW-273 whereas, the lower grain yield was recorded in variety Amar (2609 kg/ha) and Sujata (2740 kg/ha) being at par to each other. Interaction effect of sowing dates and varieties was found significant and it was found that under 25 November, 5 and 15 December sowing variety Kanchan produced comparatively higher yield, but under delayed sown condition GW-273 produced higher yield.

4. Conclusions

It was found that the first date of sowing (25 November) took more number of days from sowing to maturity as compared to delayed sowings. Maximum duration to attained maturity was found in wheat cultivar Sujata (118 days) and Amar (118 day) followed by Kanchan (110 days), GW-273 (108 days). In general the duration of all varieties shortened due to delayed sowing. Delayed sown crop took more number of days for emergence due to low temperature at the time of sowing on 25 December and 5 January.

It can be seen that the highest effect of thermal stress on phonological stages was observed in cv. Sujata and Amar followed by Kanchan. The least effect of thermal stress was observed in case of GW-273 (13 days). The variety GW-273 was not affected much due to thermal stress and the duration decreased only by 10 and 13 days respectively under 25 December and 5 January sowing. Significantly higher plant population was recorded with the crop sown on 5 and 15 December because of favourable temperatures during this period.

The increase in plant height took place slowly up to 40 days after sowing. Maximum rate of increase in plant height was observed between 40 to 60 days after sowing when the crop was in ear emergence stage. In general, higher plant height was observed in varieties Sujata and Amar and lower plant height was recorded in varieties Kanchan and GW-273.

Higher number of ear head /m^2 (353) was observed 5 December sowing as compared to 25 November, 25 December and 5 January sowing but significantly at par with that with 15 December sowing (350). Ear heads/m^2 decreased slowly up to 25 December and after it decreased sharply when sowing was done on 5 January (D_5).

Length of ear of different wheat varieties was influenced due to temperature and shifting thermal environment. Longer ear head (9.4 cm) was observed in first and second date of sowing (25 November and 5 December) as compared to delayed sowing of 15 December, 25 December and 5 January. Longer ear head was observed in variety GW-273 (9.4) while minimum (8.4) was observed in Amar. Number of grain/ear head with 5 December sowing was found next that of 25 November sowing but significant superior over 15 and 25 December sowing. Significantly lower number of grains/ear head was observed with 5 January sowing. Among different variety GW-273 produced significantly higher number of grains/ear head closely followed by Kanchan being at par to each other (50 and 48, respectively) Sujata and Amar produced lower number of grains/ear head and were found statistically similar to each other.

The accumulated growing degree days (GDD) for different genotypes under different thermal environments varied considerably during different growth stages. Different wheat varieties responded differently in terms of accumulated GDD at the time of maturity. Higher GDD was observed under 25 November sowing (D_1) in varieties Sujata and Amar. Highest PTU and HTU was observed under 5 January sowing (D_5) in the all varieties. Highest HUE values were observed under 25 November, 5 December and 15 December sowing in most of the variety. Lowest HUE was observed under 5 January sowing (D_5) in the all varieties. Radiation Use Efficiency (RUE) for different genotypes under different thermal environments varied considerably. Lowest RUE was observed under 5 January sowing (D_5) in the all varieties. Highest IPAR values were observed under 25 November (D_1) sowing in most of the all varieties.

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