

Phenological and yield responses of wheat to sowing dates and varieties in Punjab: An agro-climatic index approach

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ABSTRACT

The present study was conducted to evaluate indices that offer critical insights into crop phenology and yield responses of wheat varieties under varying sowing dates during *rabi* season of 2023-24. The experiment was carried out at Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, Punjab. The split-plot experiment consisted of three wheat varieties ('PBW 826', 'PBW 766' and Unnat 'PBW 550') in main plots and three sowing dates (6th November (D₁), 24th November (D₂) and 12th December (D₃) in sub plots. The findings indicated that wheat sown on 6th November exhibited the maximum accumulation of growing degree days (GDD) (1,773.72 °C day) and hygrothermal units (HGTU) (117,039.50 °C day %). Conversely, crop sown on 12th December recorded the lowest accumulation of GDD and HGTU, while early-sown crop exhibited reduced solar thermal degree days (STDD) accumulation. Among sowing dates, wheat sown on 6th November resulted in higher grain yield. Moreover, wheat sown on 12th December acquired the highest accumulated solar thermal degree days (49,241.20 °C day MJ/m²) among other dates to reach physiological maturity. Indices like STDD, HGTU and GDD are highly useful in optimizing sowing time and hence to enhance crop productivity under changing climatic scenario.

Key words: Hygro-thermal units, Solar radiation, Solar thermal degree days, Wheat

Crop phenology is a key bio-indicator of weather, the rising temperatures due to climate change are advancing developmental events of the crop. Sowing time strongly influences crop exposure to temperature regimes, thereby affecting physiological processes, phenology and yield (Dhillon *et al.*, 2017). As a critical non-monetary input, optimal sowing time ensures better use of favorable conditions. Sowing time affects the crop's ability to accumulate the heat units like growing degree days (GDD). Studies on heat units like GDD are essential for assessing phenology of a crop. The weather parameters like temperature, solar radiation and humidity notably impact wheat productivity (Sivakumar, 2023).

To better understand crop weather interactions, apart from GDD other indices such as solar thermal degree days

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(STDD) and hygrothermal units (HGTU) have been developed and used effectively (Kingra & Kaur, 2012; Bora *et al.*, 2024). The present study was conducted with an objective to understand the effect of sowing dates and wheat varieties on crop phenology, agroclimatic indices and grain yield.

The field experiment was conducted at Punjab Agricultural University (PAU), Ludhiana during *rabi* 2023. The split plot experiment consisted of three wheat varieties {'PBW 826' (V₁), 'PBW 766' (V₂) and Unnat 'PBW 550' (V₃)} in main plots and three sowing dates {6th November (D₁), 24th November (D₂) and 12th December (D₃)} in sub plots, replicated thrice. Meteorological data (temperature, humidity, and sunshine hours) were recorded from the Agrometeorological observatory of PAU. Thereafter, agrometeorological indices, i.e. *Growing Degree Days* ($GDD = (T_{max} + T_{min}) / 2 - T_{base}$), *Solar thermal degree days* ($STDD = GDD \times \text{Short wave solar radiation (Rs.)}$) and *Hygrothermal unit* ($HGTU = GDD \times \text{Average relative humidity (RH}_{mean})$) were calculated to quantify the impact of weather on crop phenology. The daily solar radiation was computed from the Angstrom formula (Allen, 2006).

Crop Phenology: The sowing dates illustrated the impact of varying thermal time accumulation and photoperiod

regimes. The delayed occurrence of early developmental stages with later sowing suggested that initial growth may be constrained by suboptimal temperatures and/or reduced light intensity. However, the subsequent accelerated progression to soft dough and maturity in delayed sowings indicates the crops ability to hasten the crop developmental stages to catch-up the delay (Nahar *et al.*, 2010). This could be due to increased temperatures during reproductive development, triggering faster physiological process or a strong vernalization requirement being met earlier, shifting the plant into reproductive phase more rapidly once warmer conditions prevail (Chakrabarti *et al.*, 2021). The statistically significant differences in days taken to complete various stages, except CRI, confirm the phenological shifts and statistically robust responses to planting time and weather variation (Table 1).

Whereas, different varieties demonstrated the inherent genotypic variation in developmental plasticity. Variety Unnat 'PBW 550' consistently exhibits the shortest duration to all the developmental stages, categorizing it as an early-maturing genotype. Conversely, 'PBW 766' required the longest duration, indicative of a late-maturing type, with 'PBW 826' being intermediate. These differences are genetically programmed and reflect variations in sensitivity to environmental cues (e.g., vernalization requirement,

photoperiod sensitivity) and intrinsic growth rates. The statistically significant difference in days taken to complete various phenological stages, except CRI, underscores that these genotypic differences are true biological variations rather than random fluctuations. The statistically non-significant variation in days taken for CRI stage across sowing dates and varieties suggests that this very early developmental stage might be less sensitive to the experimental variations.

Heat unit requirements: Growing degree day: Accumulated growing degree days (AGDD) varied significantly across sowing dates, with the highest AGDD (1773.7 °C day) recorded under early sowing (6th Nov), followed by 24th Nov (1691.9 °C day) and 12th Dec (1652.6 °C day) for maturity. Among varieties, 'PBW 766' recorded the highest AGDD (1898.6 °C day) for reaching maturity (Table 1). Delayed sowing reduced AGDD due to early maturity induced by terminal heat stress, while early sowing enhanced GDD accumulation, positively influencing crop growth and development (Brar *et al.*, 2022).

Solar thermal degree day: Wheat sown on 12th December recorded the highest ASTDD (49,241.2 °C day MJ/m²), followed by 24th November (46,867.0 °C day MJ/m²) and 6th November (46,046.5 °C day MJ/m²). Among varieties, 'PBW 766' showed the highest ASTDD (54,477.1 °C day

Table 1. Number of days taken to achieve maturity under different sowing dates and varieties

Treatment	Number of days				
	CRI	Tillering	Ear Emergence	Soft Dough	Maturity
<i>Sowing dates</i>					
6 th November	20	49	96	119	154
24 th November	22	53	99	115	146
12 th December	24	58	101	109	136
CD (P=0.05)	NS	6.46	3.76	4.51	3.09
SEm±	0.85	1.60	0.93	1.11	0.76
<i>Varieties</i>					
'PBW-826'	22	53	99	114	144
'PBW 766'	24	58	104	120	154
Unnat 'PBW 550'	20	49	93	108	138
CD (P=0.05)	NS	5.93	6.49	7.26	5.91
SEm±	1.65	1.90	2.08	2.33	1.89
Accumulated growing degree days (°C day)					
<i>Sowing dates</i>					
6 th November	298.20	608.16	912.97	1,175.46	1,773.72
24 th November	255.14	464.06	873.19	1,089.44	1,691.91
12 th December	196.31	402.51	935.21	1,082.83	1,652.61
CD (P=0.05)	31.2	48.2	NA	NA	61.1
SEm±	7.7	11.9	19.4	22.8	15.1
<i>Varieties</i>					
'PBW 826'	249.86	490.62	906.41	1,113.02	1,676.73
'PBW 766'	268.24	524.79	970.47	1,204.87	1,898.63
Unnat 'PBW 550'	231.56	459.32	844.49	1,029.84	1,542.87
CD (P=0.05)	NS	49.4	87.5	111.1	127.1
SEm±	17.2	15.8	28.1	35.6	40.8

MJ/m²) (Table 2). Despite early maturity, higher solar irradiance in late sowing led to greater ASTDD. These findings highlight the significant impact of sowing time on thermal energy accumulation and its effect on crop growth and yield potential (Bora *et al.*, 2024).

Hygrothermal unit: Wheat sown in the 6th November recorded the highest AHGTU (117,039.5 °C day%), followed by the 24th November (108,492.9 °C day%) and 12th December (100,941.9 °C day%) (Table 2). Among varieties, 'PBW 766' showed the highest AHGTU (117,908.0 °C day%) reflecting greater exposure to favorable thermal and humidity conditions. The elevated AHGTU in early sowing is linked to prolonged optimal weather, supporting better crop growth and development.

Wheat yield: Wheat sown in the 6th November recorded the highest yield (5,670.0/kg/ha), 9.48% and 22.12% higher than that of the 24th November and 12th December sowings, respectively. Among varieties, 'PBW 826' produced the highest yield (5,299.2/kg/ha). Shivani *et al.* (2003) and Kaur *et al.* (2025) also reported reduction in yield with delay in sowing time of wheat.

The study underscores the importance of sowing time in wheat, a thermo-sensitive long-day crop. Sowing on 6th

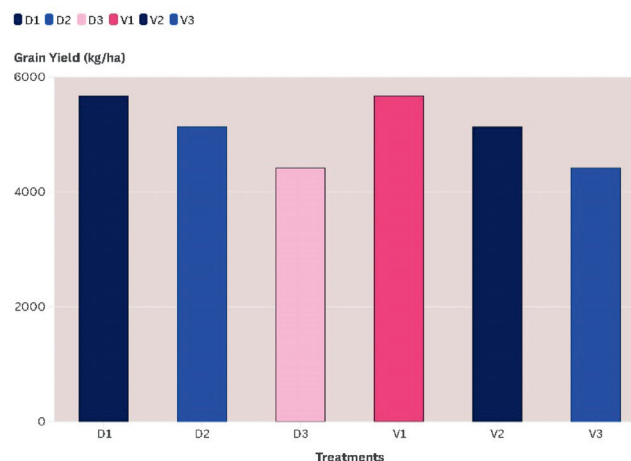


Fig. 1. Grain yield of wheat as influenced by different sowing dates and varieties during *rabi* 2023–24

November resulted in the highest yield. Among varieties 'PBW 826' had maximum grain yield and heat use efficiency. Agro-meteorological indices like GDD, HGTU, and STDD serve as effective tools for optimizing sowing time and improving productivity across varying climatic conditions.

Table 2. Accumulated solar thermal degree days (°C day MJ/m²) and Accumulated Hygrothermal unit (°C day %) at different stages of wheat under different treatments

Treatment	Accumulated solar thermal degree days (°C day MJ/m ²)				
	CRI	Tillering	Ear Emergence	Soft Dough	Maturity
<i>Sowing dates</i>					
6 th November	6,454.7	12,530.6	19,079.1	26,199.0	46,046.5
24 th November	5,044.3	9,117.9	19,338.4	25,895.5	46,867.0
12 th December	3,778.3	8,314.8	23,604.4	28,525.5	49,241.2
CD (P=0.05)	632.5	964.1	2,700.7	NA	2,169.4
SEm±	156.9	239.1	669.8	795.4	538.1
<i>Varieties</i>					
PBW-826	5,091.4	9,962.4	20,649.6	26,741.9	46,213.4
PBW-766	5,456.7	10,702.4	22,460.3	29,667.1	54,477.1
Unnat PBW-550	4,729.3	9,298.7	18,912.1	24,211.2	41,464.4
CD (P=0.05)	NS	NS	2,643.5	3,546.8	4,647.3
SEm±	343.6	363.5	848.5	1,138.4	1,491.7
Accumulated Hygrothermal unit (°C day %)					
<i>Sowing dates</i>					
6 th November	20,096.6	42,214.9	66,326.4	83,136.7	117,039.5
24 th November	18,220.9	34,589.4	63,117.8	76,521.0	108,492.9
12 th December	14,714.3	31,140.2	64,676.2	73,450.6	100,941.9
CD (P=0.05)	2,185.9	3,660.1	NA	5,577.4	3,180.9
SEm±	542.2	907.8	1,123.8	1,383.4	788.9
<i>Varieties</i>					
'PBW 826'	17,685.5	35,968.5	64,693.6	77,510.5	107,751.8
'PBW 766'	18,998.4	38,517.1	68,736.6	83,098.1	117,908.0
Unnat 'PBW 550'	16,347.9	33,459.1	60,690.3	72,499.9	100,814.5
CD (P=0.05)	NS	3,643.6	5,462.7	6,649.3	6,198.7
SEm±	1219.3	1,169.5	1,753.4	2,134.3	1,989.7

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