Yield and Yield Related Attributes of Wheat Cultivars Grown under Different Thermal Regimes and Plant Densities

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ABSTRACT

This field study, conducted over two years (2023–24 and 2024–25) at the Student's Instructional Farm, Acharya Narendra Deva University Agriculture and Technology, Ayodhya, India, aimed to evaluate the effects of three thermal regimes (T1: 12th Nov, T2: 26th Nov, T3: 10th Dec), three row spacings (S1: 15 cm, S2: 22 cm, S3: 30 cm), and three wheat cultivars (V1: DBW 187, V2: HD 2967, V3: HD 3271) on wheat yield (grain, straw, biological yield, and harvest index) and yield attributes (spike length, number of spikes per plant, number of grains per spike, test weight, and effective tillers). A factorial Randomized Complete Block Design (RCBD) with four replications was employed for the experiment. The findings indicated that the optimal thermal regime (T1) significantly enhanced yield and yield attributes at all stages compared to delayed sowing (T2 and T3), revealing the negative impacts of late sowing and thermal stress. Among the cultivars, V1 consistently demonstrated superior growth and adaptability, yielding the highest values for all traits. Moderate row spacing (S2) was more effective than narrow (S1) and wide (S3) spacings in promoting effective tillers and harvest index. These results highlight the importance of careful selection of sowing time, cultivar, and row spacing for improving wheat productivity under diverse thermal conditions. The study offers valuable insights for developing strategies to build climate-resilient wheat production in subtropical agro-ecosystems.

Keywords Wheat, Yield, Yield attributes, Thermal regimes, Row spacing, Cultivars.

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INTRODUCTION

The productivity of wheat (*Triticum aestivum* L.) is strongly affected by environmental factors and agro-meteorological practices, particularly in light of the growing challenges posed by climate change. Wheat is one of the most important cereal crops globally, providing a major source of calories and protein for

the human population. However, wheat productivity is increasingly threatened by rising temperatures and irregular climatic patterns associated with climate change. Thermal regimes, particularly terminal heat stress during the reproductive and grain-filling stages, have been reported to cause substantial reductions in wheat yields by shortening the grain-filling period, reducing biomass accumulation, and impairing photosynthetic efficiency (García *et al.* 2015). Studies have shown that wheat exposed to elevated temperatures during critical growth phases experiences significant declines in grain number and grain weight (Mirosavljević *et al.* 2024). Plant density is another crucial agronomic factor that interacts with environmental variables to influence wheat growth and productivity. Optimal plant density ensures efficient use of light, nutrients, and water resources, contributing to higher yields (Berski *et al.* 2025). In contrast, suboptimal densities—whether too high or too low—can exacerbate the negative effects of heat stress by altering canopy microclimate, reducing tiller numbers, and increasing inter-plant competition for resources (Kumar *et al.* 2023). Higher planting densities, in particular, have been suggested to compensate for reduced tillering capacity and shortened growth periods under late sowing and heat stress conditions (Shoukat *et al.* 2023). Moreover, genotypic differences among wheat cultivars play a significant role in their adaptability to varying thermal regimes and planting densities. Heat-tolerant cultivars tend to exhibit traits such as stay-green phenotypes, higher chlorophyll retention, efficient root systems, and improved reproductive resilience under stress conditions (Lamba *et al.* 2023). The identification and utilization of cultivars that can maintain stable yields under diverse environmental conditions are critical for sustaining wheat production in a warming climate.

In India, wheat is the second most important cereal crop after rice. During the 2022–23 seasons, India recorded a wheat cultivation area of approximately 31.7 million hectares, producing around 110.55 million tonnes of wheat, with an average productivity of about 3.49 tonnes per hectare (Ministry of Agriculture & Farmers Welfare 2024). Uttar Pradesh, the leading wheat-producing state, accounted for about 9.75 million hectares of the total area, with a production of 34.06 million tonnes and an average productivity of approximately 3.49 tonnes per hectare (Government of Uttar Pradesh 2024). Despite substantial contributions, the productivity levels are often affected by factors such as heat stress during the terminal growth stages, improper sowing times, and suboptimal plant densities.

Given the complex interplay between genotype, thermal regime, and plant density, it is essential to understand their combined effects on yield and yield-related attributes. Therefore, the present study aims to investigate the performance of different wheat cultivars grown under varying thermal environments and plant densities, with the goal of identifying cultivars and management practices that optimize productivity under climate change scenarios.

MATERIALS AND METHODS

Climate of the experimental site: Ayodhya is located within the semi-arid and subtropical climatic zone of the Indo-Gangetic plains. The region features sandy loam soil that is flat and well-drained. It receives an average annual rainfall of approximately 1001 mm, with 85–90% occurring during the monsoon season from June to September, and about 5–7% during the winter months. Temperatures peak in May, reaching between 40°C and 45°C, while the coldest months, December and January, see minimum temperatures ranging from 4°C to 10°C.

Experimental details: The experiment was carried out during the *rabi* seasons of 2023–24 and 2024–25 at the Student's Instructional Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (UP), India. The site is geographically positioned at 26°.47'N latitude and 82°.12'E longitude, with an elevation of 113 meters above mean sea level. The study aimed to assess the influence of thermal regimes and row spacing on the radiation use efficiency of different wheat cultivars. A factorial Randomized Complete Block Design (RCBD) with four replications was employed. The treatments included three thermal regimes—T1 (12th November, 21.5°C and 22.6°C), T2 (26th November, 19.5°C and 17.9°C), and T3 (10th December, 15.4°C and 13.7°C) for the respective 2023–24 and 2024–25 seasons; three row spacings—S1 (15 cm, narrow),

S2 (22 cm, conventional), and S3 (30 cm, wide); and three wheat cultivars—V1 (DBW 187), V2 (HD 2967), and V3 (HD 3271). This configuration produced 27 treatment combinations (3 × 3 × 3), which were randomly allocated within each block. Prior to sowing, the field was prepared by two passes with a tractor-drawn disc harrow and a cultivator, followed by pre-sowing irrigation. A planker was then used to create a fine seedbed once the soil reached field capacity. The crop was sown following pre-sowing irrigation. The recommended phosphorus dose (60 kg P_2O_5 ha^{-1}) was applied at the time of sowing as a basal application using diammonium phosphate (DAP). The recommended nitrogen dose for wheat, 150 kg ha^{-1}, was administered in two splits: half was supplied at sowing through DAP and urea, while the remaining half was applied after the first irrigation using urea. Two rounds of hand weeding were performed after the first irrigation during both experimental seasons. The crop was manually harvested using sickles, and the plants in each plot were tagged and left to dry under the sun. Prior to threshing, the biological yield (grain + straw) was measured using a spring balance. Threshing was conducted plot-wise using a power-operated plot thresher, and the grain yield was recorded accordingly. Additionally, a small grain sample was collected from each plot to determine the 1000-grain weight and other yield parameters.

The meteorological instruments installed at the Agrometeorological Observatory of the Department of Agricultural Meteorology, ANDAU & T, Kumarganj, Ayodhya, recorded daily maximum and minimum temperature, morning and evening relative humidity, bright sunshine hours, rainfall, and open pan evaporation.

Yield attributes: To determine the number of tillers per square meter in each plot, tiller counts were taken at five randomly selected locations at 30, 60, and 90 days after sowing. The mean value of these counts was then calculated. For assessing the number of effective tillers per square meter, counts were performed just before harvest by selecting a one-meter row length from each treatment plot. Spike length (cm) was measured by recording the lengths of sampled spikes, from the node at the base of the spike to the tip of the terminal spikelet, and the average spike length

was calculated. The number of spikes per plant and the number of spikelets per spike were determined using ten randomly selected spikes from each plot at maturity. For estimating the number of grains per spike, all ten sampled spikes were manually threshed, cleaned, and the grains were counted. The average number of grains per spike was then computed.

Yield: Grain yield (q ha^{-1}) was determined by recording the total bundle weight from each plot at harvest. After threshing, the grains were separated, weighed, and the yield was expressed in quintals per hectare. Straw yield (q ha^{-1}) was calculated by subtracting the grain weight from the total harvested biomass of each net plot, and the resulting straw weight was also expressed on a per-hectare basis. For estimating the biological yield (q ha^{-1}), the entire harvested crop was bundled, weighed per plot in kilograms, and the values were converted to quintals per hectare. The ratio of economic yield (grain yield) to biological yield is known as harvest index, and was computed using the following formula, which expresses the fraction of photosynthesis that is directed toward grains:

$$HI = \frac{Grain\ yield}{Biological\ yield} \times 100$$

Analysis: Statistical evaluation of the data was conducted through the analysis of variance (ANOVA) procedure suited to the experimental design. The Critical Difference (CD) at a 5% significance level was subsequently calculated to compare treatment means.

RESULTS AND DISCUSSION

During 2023–24, the crop received a total rainfall of 33.4 mm, compared to 32.6 mm recorded in 2024–25. January was identified as the wettest month in both years. The average bright sunshine hours were lower in 2023–24 (6.67 hours) than in 2024–25 (7.3 hours). Similarly, the mean relative humidity was 72% in 2023–24, slightly higher than the 65.2% recorded in 2024–25.

Yield attributes

The data presented in Table 1 clearly shows that the thermal regimes, cultivars, and row spacings signifi-

Table 1. Yield attributes of wheat cultivars as influenced by different thermal regimes and row densities during 2023-24 and 2024-25.

Treatments	Spike length (cm)		No. of spike per plant		No. of grains per spike		Test weight		No. of effective tillers	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Thermal regimes										
T1	14.04	14.18	8.86	8.94	53.98	55.06	52.33	52.86	352.97	364.91
T2	13.03	13.16	7.82	7.90	51.23	52.26	51.20	51.71	360.69	364.30
T3	11.66	11.77	6.72	6.79	45.02	45.92	50.59	51.10	359.57	363.16
SE (m)	0.048	0.048	0.04	0.04	0.174	0.18	0.04	0.018	4.823	0.047
CD at 5%	0.165	0.167	0.137	0.139	0.6	0.62	0.139	0.062	NS	0.163
Cultivars										
V1	13.78	13.92	8.23	8.32	52.60	53.65	53.16	53.69	355.86	367.83
V2	12.76	12.88	7.80	7.88	49.98	50.98	51.56	52.07	360.18	363.78
V3	12.19	12.31	7.37	7.44	47.66	48.61	49.41	49.91	357.19	360.76
SE (m)	0.099	0.1	0.06	0.061	0.381	0.388	0.392	0.396	5.225	2.716
CD at 5%	0.28	0.283	0.17	0.171	1.074	1.095	1.104	1.116	NS	NS
Row spacing										
S1	12.31	12.44	7.40	7.47	48.63	49.61	48.93	49.423	349.87	361.78
S2	13.84	13.98	8.27	8.35	51.70	52.73	53.93	54.47	363.43	367.07
S3	12.57	12.70	7.73	7.81	49.90	50.90	51.26	51.77	359.92	363.52
SE (m)	0.099	0.1	0.06	0.061	0.381	0.388	0.392	0.396	5.225	2.716
CD at 5%	0.28	0.283	0.17	0.171	1.074	1.095	1.104	1.116	NS	NS

cantly influenced various yield attributes of wheat such as spike length, number of spikes per plant, number of grains per spike, test weight, and number of effective tillers.

Effect of thermal regimes: Among thermal regimes, T1 (earlier sowing) recorded the highest values across most yield attributes in both years. It exhibited the maximum spike length (14.18 cm in 2024–25), number of spikes per plant (8.94), grains per spike (55.06), and test weight (52.86 g), Table 1. T3 (likely representing delayed sowing) had significantly reduced values, with the lowest spike length (11.77 cm), spikes per plant (6.79), and grains per spike (45.92), indicating the adverse effect of higher temperatures on yield components, Table 1. These results align with the findings of Poudel and Poudel (2020) and Asseng *et al.* (2015), who reported that, delayed sowing or heat stress significantly reduces grain number and weight in wheat.

Effect of cultivars: Among the cultivars, V1 outperformed others, producing longer spikes (13.92 cm), more spikes per plant (8.32), and higher grains per spike (53.65) across both years, Table 1. V3 consistently showed inferior performance, suggesting genetic differences in thermal tolerance and yield potential among cultivars. These observations are consistent with the findings of Salaria *et al.* (2024) and Kumar *et al.* (2014), who emphasized the importance of cultivar selection for maximizing yield under varying thermal environments.

Effect of row spacing: Regarding row spacing, S2 (presumably optimal spacing) resulted in the highest yield attributes: Spike length (13.98 cm), number of spikes per plant (8.27), and test weight (53.93 g) during 2024–25, Table 1. Wider spacing (S1) and narrower spacing (S3) had comparatively lower values, highlighting the significance of optimum plant population in maximizing resource use and productivity. Similar trends were reported by Soleymani and Shahrajabian (2011), who observed that moderate row spacing ensures better aeration, solar radiation interception, and ultimately higher wheat yield.

Interestingly, the number of effective tillers was found non-significant (NS) under thermal regimes and cultivars in 2023–24 but showed significance in 2024–25 under thermal regimes and row spacing. T1 again showed superiority with the maximum tiller number (364.91), while S2 recorded higher

Table 2. Yield of wheat cultivars as influenced by different thermal regimes and row densities during 2023-24 and 2024-25.

Treatments	Grain yield		Straw yield		Biological yield		Harvest index	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
Thermal regimes								
T1	46.78	47.71	62.44	63.69	109.22	111.41	42.78	41.94
T2	46.22	47.15	60.22	61.43	106.44	108.57	43.41	42.56
T3	36.67	37.40	53.00	54.06	89.67	91.46	40.87	40.07
SE (m)	0.217	0.221	0.184	0.188	0.396	0.41	0.047	0.041
CD at 5%	0.748	0.761	0.636	0.65	1.365	1.415	0.163	0.142
Cultivars								
V1	45.00	45.90	60.78	61.99	105.78	107.89	42.45	41.62
V2	43.78	44.65	58.56	59.73	102.33	104.38	42.66	41.82
V3	40.89	41.71	56.33	57.46	97.22	99.17	41.96	41.13
SE (m)	0.333	0.34	0.756	0.445	0.769	0.784	0.32	0.314
CD at 5%	0.939	0.957	1.231	1.255	2.168	2.211	NS	NS
Row spacing								
S1	41.44	42.27	58.44	59.61	99.89	101.89	41.41	40.60
S2	45.89	46.81	60.33	61.54	106.22	108.35	43.11	42.27
S3	42.33	43.18	56.89	58.03	99.22	101.21	42.54	41.71
SE (m)	0.333	0.34	0.756	0.445	1.332	0.784	0.32	0.314
CD at 5%	0.939	0.957	1.231	1.255	2.168	2.211	NS	NS

tiller production compared to S1 and S3, Table 1. This highlights that favorable thermal regimes and optimal row spacing collectively enhance tillering, ultimately contributing to grain yield, corroborating the observations of Farooq *et al.* (2011).

Yield performance

The data summarized in Table 2 demonstrates that thermal regimes, cultivars, and row spacings significantly influenced the grain yield, straw yield, biological yield, and harvest index of wheat during both 2023–24 and 2024–25 seasons.

Effect of thermal regimes: The T1 thermal regime consistently produced the highest yields, achieving a grain yield of 47.71 q/ha and a biological yield of 111.41 q/ha in 2024–25. Similarly, it recorded higher straw yield (63.69 q/ha) and a harvest index of 41.94%. T3, which likely represents higher temperature or delayed sowing conditions, exhibited the lowest grain yield (37.40 q/ha) and biological yield (91.46 q/ha), emphasizing the negative impact of heat stress, Table 2. These findings are supported by Asseng *et al.* (2015) and Lobell *et al.* (2011), who highlighted that elevated temperatures during

the grain filling period substantially reduce wheat productivity due to shortened growth phases and impaired photosynthesis.

Effect of cultivars: Among the cultivars, V1 consistently performed better, producing the highest grain yield (45.90 q/ha) and biological yield (107.89 q/ha) across both years. V3 showed inferior performance, with a grain yield of only 41.71 q/ha and a biological yield of 99.17 q/ha, indicating genetic variation in yield potential under similar environmental conditions, Table 2. Similar trends were reported by Kumar *et al.* (2022) and Poudel and Poudel (2020), emphasizing that genotypic differences among wheat cultivars significantly affect their yield performance under varying climatic conditions.

Effect of row spacing: S2 (likely optimum row spacing) produced the highest grain yield (46.81 q/ha) and biological yield (108.35 q/ha) in 2024–25, followed by S3 and S1, Table 2. This suggests that proper row spacing promotes better resource utilization, including light interception and nutrient uptake, thereby enhancing yield. The results are in accordance with Soleymani and Shahrajabian (2011) and Saini and Tiwana (2023), who demonstrated that optimum

plant density improves crop canopy structure, photo-synthetic efficiency, and overall wheat yield.

The harvest index ranged between 40.07% (T3) and 43.41% (T2) across thermal regimes and was relatively stable across cultivars and row spacings, Table 2. No significant differences in harvest index were observed among cultivars and row spacings, indicating that partitioning of dry matter between grain and straw was not substantially altered by these factors. This outcome is corroborated by Fischer (2011), who noted that modern wheat varieties show limited variability in harvest index when exposed to different agronomic treatments.

CONCLUSION

The present study clearly demonstrated that thermal regimes, wheat cultivars, and row spacing significantly influenced the yield attributes (spike length, number of spikes per plant, number of grains per spike, test weight, number of effective tillers) and yield (grain yield, straw yield, biological yield, and harvest index) of wheat during the 2023–24 and 2024–25 seasons. Among the thermal regimes, T1 (optimal temperature conditions) consistently outperformed T2 and T3, leading to the highest grain yield, better yield attributes, and superior biological yield. Conversely, T3, representing stress conditions (likely higher temperature at grain filling or delayed sowing), exhibited pronounced reductions in all yield-related traits, confirming the detrimental effects of thermal stress on wheat productivity. Regarding cultivars, V1 emerged as the most promising genotype, showing superior performance in terms of yield and yield attributes compared to V2 and V3 across both years. This underlines the importance of selecting thermotolerant and high-yielding cultivars to ensure wheat productivity under variable climatic conditions. In terms of plant row density management, S2 row spacing (likely the optimal spacing) was found to maximize grain yield and improve associated traits, emphasizing that proper plant density plays a critical role in enhancing resource use efficiency and yield potential. Overall, the findings highlight that maintaining an optimal thermal environment, choosing suitable cultivars, and adopting proper row spacing are crucial strategies for sustaining and enhancing wheat productivity under changing climatic scenarios. These insights can guide future wheat breeding programs and agronomic practices aimed at achieving food security.

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