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Combined Effect of Different Thermal Regimes and Row Spacing on Growth Parameters of Wheat Cultivars

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ABSTRACT

The productivity of wheat (*Triticum aestivum* L.) is critically influenced by environmental conditions and agrometeorological practices, especially under the emerging challenges of climate change. This two-year field study (2023–24 and 2024–25), conducted at the Student's Instructional Farm, Acharya Narendra Deva University of Agriculture and Technology, Ayodhya, India, evaluated the combined 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 cultivars (V1: DBW 187, V2: HD 2967, V3: HD 3271) on key wheat growth parameters including plant height, leaf area index (LAI), and dry matter accumulation (DMA). The experiment employed a factorial Randomized Complete Block Design (RCBD) with four replications. Results revealed that early sowing (T1) significantly improved plant height, LAI and DMA across all stages compared to later sowings (T2 and T3), highlighting the detrimental impact of delayed sowing and thermal stress. Among cultivars, V1 consistently recorded the highest values across all traits, indicating superior adaptability and growth potential. Conventional row spacing (S2) outperformed narrow (S1) and wider (S3) spacings in promoting vegetative growth and resource utilization. These findings underscore the importance of optimizing sowing time, cultivar selection and row spacing to enhance wheat productivity under variable thermal regimes. The study provides critical insights for developing climate-resilient strategies to sustain wheat production in subtropical agro-ecosystems.

Keywords Wheat, Thermal regimes, Row spacing, Cultivars, Plant height, Leaf area index, Dry matter accumulation.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most widely cultivated cereal crops, contributing significantly to

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global food security. Its productivity is highly sensitive to environmental factors, particularly temperature and plant spacing, which collectively influence key physiological and phenological processes (Asseng *et al.* 2015, Sadras & Monzon 2006). As climate change continues to drive shifts in temperature patterns, understanding how different thermal regimes interact with agronomic management practices such as row spacing is essential for optimizing wheat growth and yield (Lobell *et al.* 2012). Variations in temperature can alter the duration of critical growth phases, while row spacing influences competition for resources such as light, water, and nutrients, thereby affecting overall plant development and yield potential (Fischer *et al*. 2019).

Effect of thermal regimes on wheat growth

Temperature plays a crucial role in regulating wheat growth and development, with significant effects on germination, vegetative growth, reproductive development, and grain filling (Farooq *et al*. 2011). Moderate temperatures during early growth stages promote tillering and canopy expansion, whereas extreme temperatures can impair physiological processes, leading to poor stand establishment and reduced biomass accumulation (Nizamani *et al*. 2014). High temperatures, particularly during reproductive stages, accelerate phenological development, shortening the grain-filling period and reducing kernel weight and overall yield (Farhad *et al.* 2023). In contrast, lower temperatures can extend vegetative growth, delay flowering, and increase yield potential in some cases, provided that frost damage is avoided.

Additionally, temperature fluctuations influence photosynthetic efficiency, respiration rates, and assimilate partitioning, which are critical for determining wheat productivity (Khan *et al.* 2020). Heat stress is particularly detrimental when it occurs during anthesis and grain filling, leading to pollen sterility, reduced seed set, and lower harvest index (Lobell *et al.* 2012). Recent studies indicate that wheat genotypes exhibit varying degrees of temperature resilience, emphasizing the need to evaluate cultivar-specific responses to different thermal regimes (Bapela *et al.* 2022).

Impact of row spacing on wheat performance

Row spacing is a key agronomic practice affecting wheat canopy structure, light interception, and intra-specific competition (Fischer *et al*. 2019). Narrow row spacing enhances ground cover, reduces soil evaporation, and suppresses weed growth, thereby improving resource-use efficiency (Andrade *et al*. 2002). However, excessive plant density in closely spaced rows may lead to competition for light, water, and nutrients, particularly under moisture-limited conditions. In contrast, wider row spacing can improve air circulation within the canopy, reducing disease incidence and improving photosynthetic efficiency, but may also leave more exposed soil, increasing the risk of weed infestation and moisture loss (Zhang *et al*. 2023).

Row spacing also interacts with temperature conditions, influencing thermal microclimates within the crop canopy. For instance, narrow row spacing may mitigate temperature extremes by maintaining a cooler microclimate through enhanced shading, whereas wider spacing could increase soil surface exposure, potentially exacerbating heat stress effects (Liu *et al.* 2019). These interactions suggest that optimal row spacing should be tailored to specific thermal conditions to maximize wheat growth and yield stability.

Need for an integrated approach

While extensive research has been conducted on the individual effects of temperature and row spacing on wheat growth, their combined influence remains underexplored. The interaction between these factors may have synergistic or antagonistic effects, depending on the cultivar, environmental conditions, and management practices (Pandey *et al*. 2013). Identifying the optimal combination of thermal regime and row spacing for different wheat cultivars is crucial for developing climate-resilient agronomic strategies.

This study aims to investigate how different thermal regimes and row spacing configurations influence key growth phases of wheat cultivars. By evaluating growth dynamics, phenological responses, and yield components, this research will contribute to a better understanding of how to optimize wheat production under varying climatic conditions. The findings will have significant implications for agronomic decision-making, particularly in the context of climate adaptation and food security.

MATERIALS AND METHODS

Soil and climate of the soil : Geographically, Ayodhya falls under semi-arid and sub-tropical climate of Indo-Gangatic plains having sandy loam soil, flat and well drained. The average annual precipitation is about 1001 mm of which 85–90% received during monsoon period i.e. between June to September with 5–7% in winter season. The maximum temperature reaches to its peak (40–45°C) during May while the minimum temperature is quite low (4–10°C) during December and January.

Experimental details : The experiment was conducted during *rabi* 2023-24 and 2024-25 at Student's Instructional Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (UP), India, which is geographically situated between 26°. 47'N latitude to 82°.12'E longitude and at an altitude of 113 m above mean sea level to study the effect of thermal regime and row spacing on radiation use efficiency of wheat cultivars. The experiment was conducted in a factorial Randomized Complete Block Design (RCBD) with four replications. The treatments consisted of a combination of three levels of 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 2023–24 and 2024–25 seasons, respectively; three levels of row spacing—S1 (15 cm, narrow), S2 (22 cm, conventional), and S3 (30 cm, wider), and three wheat cultivars—V1 (DBW 187), V2 (HD 2967), and V3 (HD 3271). This resulted in 27 treatment combinations (3 × 3 × 3), which were randomized independently within each block. The field was ploughed twice with tractor drawn disc harrow and cultivator, after that pre-sowing irrigation was given. Planker was used for preparing fine seedbed for sowing of crop when the field reached at field capacity.

Three wheat cultivars (DBW 187, HD 2967 and HD 3271) were sown in line under three thermal regimes (12th November, 26th November and 10th December) with three different row spacing (narrow spacing 15 cm, conventional spacing 22 cm and wider spacing 30 cm) at the depth of 5 cm during year 2023 and 2024 respectively. The crop was sown with pre-sowing irrigation. The recommended dose of phosphorus (60 kg P_2O_5 ha^{-1}) was applied through diammonium phosphate (DAP) as basal dose at time of sowing. Recommended dose of nitrogen for wheat crop was 150 kg ha^{-1}. Nitrogen was applied in two splits half as basal dose at time of sowing through DAP and Urea and rest was applied after first irrigation through Urea. Two hand weeding was done after first irrigation during both experimental years. The crop was harvested manually with the help of sickles. The crop in the respective plots was left for sun drying after tagging. Before threshing, the biological yield (straw + grain) was recorded with spring balance. The crop was threshed plot-wise with the help of the power-drawn plot thresher and grain yield was recorded accordingly. A small sample of grain was drawn from each plot for estimating 1000 grain weight and other yield attributes.

Experimental methods : Daily maximum and minimum temperature, morning and evening relative humidity, bright sunshine hours, rainfall and open pan evaporation were recorded from the meteorological instruments installed at the Agrometeorological Observatory of Department of Agricultural Meteorology, ANDAU & T, Kumarganj, Ayodhya. To assess plant height in each plot, five randomly selected plants were marked for measurement, with the initial measurement conducted at 15 days after sowing (DAS). With the use of a meter scale, height was measured from the ground surface to the tip of the top most leaf before heading and up to the base of the ear head after heading at 15, 30, 45, 60, 75 and 90 days after sowing and at harvest stage. The leaf area was measured at 30, 60 and 90 DAS for leaf area index. Five plants were selected randomly and leaves were separated out to record their surface area by automatic leaf area meter. All the leaves were grouped into three viz., small, medium and large. Five leaves from each group were taken and their surface area was measured. The average areas of five leaves were multiplied with respective leaf number of group and sum of all three gave the total leaf area. The LAI was computed by following formula :

$$LAI = \frac{\text{Leaf area (cm}^2)}{\text{Ground area (cm}^2)}$$

To assess the dry matter accumulation (gm^{-2}), plants were sampled randomly from 1 meter row length at all crop stages starting from CRI, leaves and roots were separated from stem. These samples were first sun-dried and then put in oven at 65°C for 48 hrs to attain constant dry weight. The dried samples were weighed for dry matter accumulation in different plant parts. The fractional weight of stems and leaves were then added to achieve the total weight per plant.

Statistical analysis : The data were statistically analyzed using analysis of variance (ANOVA) as applicable to factorial Randomized Complete Block Design (RCBD). F test was employed to see the significance of the treatment effects. The difference between the means was estimated using least significance difference at 5% probability level.

RESULTS AND DISCUSSION

Weather: It was observed that during 2023-24 the crop received the total rainfall 33.4 mm against 32.6 mm rainfall received during 2024-25. January was wettest month during 2023-24 and 2024-25. The average bright sunshine hour during 2023-24 (6.67) was less than 2024-25 (7.3). The mean relative humidity during 2023-24 (72%) was lower than 2024-25 (65.2%).

Plant height : Plant height of wheat was significantly influenced by thermal regimes across both years at most growth stages. The results indicate that plants grown under T1 (optimal thermal regime) consistently exhibited higher plant heights throughout all growth stages, followed by T2 and T3. At harvest, T1 recorded the highest plant height (100.09 cm in 2023–24 and 99.09 cm in 2024–25), while the lowest height was observed under T3 (97.72 cm and 96.75 cm, respectively) (Table 1).

The trend of decreasing plant height under T3 may be attributed to heat stress and unfavorable temperature conditions during critical growth phases, which likely hindered cell elongation and division. These findings are supported by previous studies (Farooq *et al*. 2011), which reported a decline in wheat growth and development under high temperature regimes.

The critical difference (CD) at 5% was significant

Table 1. Plant height of wheat cultivars as influenced by different thermal regimes and row spacing during 2023-24 and 2024-25.

Treatments	20 DAS		40 DAS		60 DAS	
Thermal regimes	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
T1 (21.5°C, 22.6°C)	18.04	17.86	25.44	26.15	42.322	42.75
T2 (19.5°C, 17.9°C)	17.58	17.40	24.42	24.55	40.922	41.33
T3 (15.4°C, 13.7°C)	16.66	16.49	23.56	23.35	37.478	37.85
SEm	0.03	0.031	0.04	0.112	0.93	0.108
CD at 5%	0.11	0.106	0.15	0.385	NS	0.373
Cultivars						
V1 (DBW 187)	18.28	18.10	26.27	26.00	42.64	42.38
V2 (HD 2967)	17.09	16.92	24.41	24.17	42.71	39.86
V3 (HD 3271)	16.91	16.74	22.74	22.52	40.60	39.69
SEm	0.13	0.133	0.19	0.236	0.75	0.309
CD at 5%	0.38	0.374	0.53	0.673	NS	0.87
Row spacing						
S1 (15 cm/narrow)	16.54	16.38	23.80	23.88	42.32	39.27
S2(22 cm/ conventional)	18.18	18.00	25.58	25.77	40.21	42.13
S3 (30 cm/wider)	17.56	17.38	24.04	24.40	43.41	40.54
SEm	0.13	0.133	0.19	0.236	0.75	0.309
CD at 5%	0.38	0.374	0.53	0.673	2.19	0.87

Table 1. Continued.

Treatments	80 DAS		100 DAS		At harvest	
Thermal regimes	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
T1 (21.5°C, 22.6°C)	66.29	66.95	92.51	91.59	100.09	99.09
T2 (19.5°C, 17.9°C)	64.64	65.29	91.23	90.32	99.00	98.01
T3 (15.4°C, 13.7°C)	60.91	61.52	89.81	88.91	97.72	96.75
SEm	0.11	0.104	0.05	0.053	0.04	0.034
CD at 5%	0.37	0.359	0.18	0.182	0.15	0.118
Cultivars						
V1 (DBW 187)	65.79	66.45	92.97	92.04	101.71	100.69
V2 (HD 2967)	63.77	64.40	91.27	90.35	98.38	97.39
V3 (HD 3271)	62.29	62.91	89.32	88.43	96.72	95.76
SEm	0.48	0.486	0.68	0.676	0.74	0.733
CD at 5%	1.36	1.37	1.93	1.907	2.09	2.066
Row spacing						
S1 (15 cm/narrow)	62.47	63.09	89.69	88.79	97.94	96.97
S2 (22 cm/ conventional)	65.89	66.55	92.91	91.98	99.97	98.97
S3 (30 cm/wider)	63.49	64.12	90.96	90.05	98.90	97.91
SEm	0.48	0.486	0.68	0.676	0.74	0.733
CD at 5%	1.36	1.37	1.93	1.907	NS	2.066

at all stages except at 60 DAS in 2023-24, indicating consistent thermal effects.

Significant variation was observed among wheat cultivars (V1, V2 and V3) in terms of plant height. Cultivar V1 recorded the maximum plant height at all growth stages, including at harvest (101.71 cm and 100.69 cm in 2023-24 and 2024-25, respectively). Conversely, V3 consistently exhibited the lowest plant height across both years and all stages (Table 1).

The genetic potential of cultivars is a determining factor for plant height. The superior performance of V1 can be linked to its better adaptability and possibly greater vegetative vigour, as suggested by Hamam and Khaled (2009).

Table 2. Leaf area index of wheat cultivars as influenced by different thermal regimes and row spacing during 2023-24 and 2024-25.

Treatments	30 DAS		60 DAS		90 DAS	
Thermal regimes	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
T1 (21.5°C, 22.6°C)	1.49	1.503	4.83	4.88	4.97	4.92
T2 (19.5°C, 17.9°C)	1.45	1.465	4.79	4.84	4.86	4.81
T3 (15.4°C, 13.7°C)	1.38	1.396	4.60	4.64	4.77	4.72
SEm	0.003	0.003	0.009	0.009	0.008	0.008
CD at 5%	0.01	0.01	0.03	0.03	0.028	0.029
Cultivars						
V1 (DBW 187)	1.47	1.486	4.78	4.83	4.92	4.87
V2 (HD 2967)	1.44	1.454	4.75	4.80	4.87	4.82
V3 (HD 3271)	1.41	1.423	4.69	4.74	4.80	4.75
SEm	0.011	0.011	0.035	0.036	0.036	0.036
CD at 5%	0.03	0.031	NS	NS	NS	NS
Row spacing						
S1 (15 cm/narrow)	1.403	1.417	4.71	4.76	4.867	4.82
S2 (22 cm/ conventional)	1.477	1.491	4.777	4.82	4.963	4.91
S3 (30 cm/wider)	1.44	1.454	4.736	4.78	4.764	4.72
SEm	0.011	0.011	0.035	0.036	0.036	0.036
CD at 5%	0.03	0.031	NS	NS	0.102	0.101

Table 3. Dry matter accumulation of wheat cultivars as influenced by different thermal regimes and row spacing during 2023-24 and 2024-25.

Treatments	30 DAS		60 DAS		90 DAS		At harvest	
Thermal regimes	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**	**2023-24**	**2024-25**
T1 (21.5°C, 22.6°C)	207.87	212.02	661.422	668.04	961.639	990.49	1,027.56	1,048.11
T2 (19.5°C, 17.9°C)	204.47	208.56	637.022	643.39	861.883	887.74	967.278	986.62
T3 (15.4°C, 13.7°C)	202.29	206.34	535.744	541.10	755.911	778.59	864.744	882.04
SEm	0.158	0.119	2.489	2.515	3.893	4.004	3.127	3.177
CD at 5%	0.544	0.412	8.59	8.679	13.437	13.818	10.791	10.965
Cultivars								
V1 (DBW 187)	205.92	210.04	617.5	623.68	876.572	902.87	966.167	985.49
V2 (HD 2967)	204.81	208.91	609.756	615.85	864.75	890.69	954.6	973.69
V3 (HD 3271)	203.89	207.97	606.933	613.00	838.111	863.26	938.811	957.59
SEm	1.527	1.558	4.568	4.614	6.472	6.666	7.156	7.300
CD at 5%	NS	NS	NS	NS	18.249	18.797	20.179	20.582
Row spacing								
S1 (15 cm/narrow)	203.94	208.02	610.111	616.21	843.8	869.11	937.833	956.59
S2 (22 cm/ conventional)	206.11	210.23	613.433	619.57	878.267	904.62	970.044	989.45
S3 (30 cm/wider)	204.57	208.66	610.645	616.75	857.367	883.09	951.7	970.73
SEm	1.527	1.558	4.568	4.614	6.472	6.666	7.156	7.300
CD at 5%	NS	NS	NS	NS	18.249	18.797	20.179	20.582

Row spacing also significantly influenced plant height at all growth stages. S2 (moderate spacing) showed the highest plant height at harvest (99.98 cm and 98.97 cm), while S1 (narrow spacing) recorded the lowest (97.94 cm and 96.97 cm) (Table 1). The enhanced growth under wider spacing (S2 and S3) may be due to reduced intra-specific competition for light, nutrients and moisture, which favors better canopy development and internodal elongation.

These results are consistent with the findings of Pandey *et al.* (2013) who highlighted the beneficial effects of optimum row spacing on wheat growth and productivity.

At harvest, the CD at 5% was significant in 2024–25 but not in 2023–24, suggesting year-to-year environmental interactions with spacing effects.

Leaf area index (LAI) : Thermal regimes significantly influenced the leaf area index (LAI) of wheat at all growth stages (30, 60 and 90 DAS) during both crop years. Among the treatments, T1 (optimal thermal regime) consistently produced the highest LAI values across all stages, with maximum values observed at 90 DAS (4.97 in 2023-24 and 4.92 in 2024-25). Conversely, T3 (stressful thermal conditions) recorded the lowest LAI values, indicating that increased thermal stress adversely affected canopy development (Table 2).

These results suggest that optimal temperature conditions during the early and mid-vegetative stages enhance leaf expansion and photosynthetic area, while elevated temperatures may inhibit leaf development by affecting cell elongation and turgor pressure (Bita and Gerats 2013, Pandey *et al*. 2024). The significant CD at 5% values across all stages confirm the sensitivity of LAI to thermal regimes.

Wheat cultivars exhibited significant differences in LAI at 30 DAS in both years, with V1 recording the highest LAI (1.47 in 2023-24 and 1.486 in 2024-25), followed by V2 and V3. However, at 60 and 90 DAS, the differences among cultivars were not statistically significant (Table 2).

The initial advantage of V1 in early LAI development could be attributed to its genetic vigor and early leaf emergence. However, as the crop progressed, environmental factors may have moderated the cultivar-specific responses, leading to convergence in

LAI among the genotypes. These results align with the findings of Poudel *et al.* (2020) who reported that LAI is strongly influenced by genotype during the initial stages of growth.

Row spacing had a significant effect on LAI at 30 DAS in both years. The maximum LAI was observed in S2 (moderate row spacing), with values of 1.477 in 2023-24 and 1.491 in 2024-25. At later stages (60 and 90 DAS), the differences in LAI due to spacing were not significant, although a consistent trend of higher LAI in S2 was maintained (Table 2).

Wider or optimal spacing can enhance light interception and reduce competition for nutrients during early growth, promoting better leaf expansion. However, the diminishing differences in LAI at later stages suggest a canopy compensation effect where plants adjust leaf growth according to available resources and space. Similar findings have been reported by Dhaliwal *et al.* (2019), highlighting that LAI response to spacing is most prominent during early vegetative stages.

Dry matter accumulation (DMA): Thermal regimes exerted a significant influence on dry matter accumulation (DMA) in wheat across all growth stages. Among the thermal regimes, T1 (favorable temperature conditions) consistently led to the highest DMA at 60 DAS (661.42 and 668.04 g/m²), 90 DAS (961.64 and 990.49 g/m²), and at harvest (1027.56 and 1048.11 g/m²) during 2023–24 and 2024–25, respectively (Table 3).

In contrast, T3 (thermal stress conditions) resulted in significantly reduced DMA values, particularly at later stages, indicating the adverse effect of heat stress on assimilate accumulation and partitioning (Table 3). The reduced photosynthetic efficiency and faster senescence under elevated temperatures may explain the observed lower biomass under T3 (Reynolds *et al.* 2001, Farooq *et al.* 2011).

These findings affirm that optimal temperature during critical growth phases, especially post-anthesis, enhances biomass production and translocation, ultimately improving crop yield.

The varietal influence on DMA was statistically non-significant during the early stages (30 and 60 DAS), indicating similar biomass accumulation among the tested cultivars. However, significant differences were noted at 90 DAS and at harvest.

Among the cultivars, V1 consistently accumulated the highest dry matter across both years, reaching 966.17 and 985.49 g/m² at harvest in 2023–24 and 2024–25, respectively (Table 3). This suggests a better photosynthetic capacity, higher source-sink relationship efficiency, or superior adaptability to prevailing conditions in V1. Similar patterns were reported by Kumar *et al.* (2023), highlighting the importance of genotype in dry matter partitioning and yield potential.

Row spacing significantly affected DMA during later growth stages (90 DAS and at harvest). The highest DMA was recorded under S2 (moderate spacing), with values of 970.04 and 989.45 g/m² at harvest in 2023–24 and 2024–25, respectively (Table 3). The increased spacing likely facilitated better canopy structure, light penetration, and reduced intra-specific competition, enhancing photosynthetic efficiency and biomass production (Dhaliwal *et al.* 2019).

Although the differences at 30 and 60 DAS were non-significant, a consistent trend of higher values under S2 was observed throughout, confirming that moderate row spacing supports efficient resource utilization.

These results agree with the findings of Dhaliwal *et al.* (2019), who observed improved biomass and yield under optimal row spacing in wheat, especially under heat stress conditions.

CONCLUSION

The study clearly demonstrated that thermal regimes, cultivars, and row spacing significantly influenced the growth attributes of wheat, including plant height, leaf area index (LAI), and dry matter accumulation (DMA) across both years. Among the thermal regimes, T1 (favorable thermal conditions) consistently enhanced plant growth, canopy development, and biomass accumulation, while T3 (stressful conditions) negatively affected these traits. The cultivar V1 outperformed others in terms of plant height, LAI, and DMA, indicating its superior adaptability and biomass partitioning ability. Row spacing S2 (moderate spacing) proved optimal for maximizing LAI and dry matter accumulation, likely due to improved light interception and reduced competition. Overall, the findings highlight the importance of selecting suitable cultivars and optimizing planting geometry under specific thermal conditions to enhance wheat productivity under changing climatic scenarios.

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