Enhancing Wheat Performance: Impact of Sowing Timing and Growth Regulators on Yield Traits

Abstract

A field experiment was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh, from November 2019 to March 2020 to assess the combined effects of sowing date and plant growth regulators (PGRs) on wheat growth and yield. BARI Gom-33 was used as the test crop in a split-plot design with three replications, with sowing dates in the main plots and PGRs in the sub-plots, totaling 36 plots (12 treatments × 3 replications). Statistical analysis using R programming showed that sowing on 5th December with Gibberellic Acid (GA_3) application increased grain yield by 25.62% over the control. This sowing date also produced 7.59% and 12.83% higher yields than early and late sowing dates, respectively. The results suggest that sowing on 5th December combined with GA_3 application effectively optimizes wheat growth and yield, providing a promising approach for enhancing wheat production and supporting sustainable agriculture.

Keywords: Plant growth regulators, yield, BARI, Split-plot, Sustainable agriculture

1. Introduction

Wheat (*Triticum aestivum L.*) is a cornerstone of global food security, providing essential nutrition and economic support to millions of people worldwide. Accounting for approximately 30% of the world's grain production, wheat serves as a staple food in over 40 countries, supplying vital calories and protein to a significant portion of the global population (Maity & Shrivastav, 2024; Dixit *et al*., 2023). However, as demand for wheat continues to grow, so does the need to improve production efficiency and yield quality, especially in regions facing climate variability and resource constraints (Kheiralipour *et al*., 2024). Climate change, along with fluctuating weather patterns and seasonal temperatures, introduces further complexities to wheat production (Liu *et*

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al., 2023). Thus, adopting agronomic practices that optimize wheat growth and maximize yield is essential for sustaining and enhancing global food security.

One of the most influential factors in wheat yield optimization is managing environmental conditions, particularly through the timing of sowing. Optimal sowing timing aligns wheat's vegetative and reproductive phases with favorable environmental conditions, such as temperature, photoperiod, and rainfall, leading to improved plant height, spike length, and grain filling (Qiao *et al*., 2023). Indeed, research shows that optimal combinations of sowing dates and seeding rates can increase yields by 7.48% to 41.6%, depending on specific environmental conditions (Liu *et al*., 2024). Conversely, improper sowing timing—whether too early or too late—can subject wheat to either premature high temperatures or late-season cold, both of which reduce growth potential and productivity (Gupta, 2017). For example, late sowing often exposes wheat to elevated temperatures during the grain-filling stage, which accelerates senescence and lowers yields. In contrast, early sowing may result in excessive vegetative growth, increasing susceptibility to pests and diseases (Atar, 2024; Tian *et al*., 2024; Zhiipao *et al*., 2024).

In addition to optimal sowing timing, the application of plant growth regulators (PGRs) presents a promising strategy to improve wheat performance. PGRs are compounds that influence plant physiology and biochemistry, significantly contributing to growth regulation, stress tolerance, and yield enhancement (Farman *et al*., 2019). Common PGRs, such as gibberellic acid (GA_3), indole-3-acetic acid (IAA), and naphthalene acetic acid (NAA), each play distinct roles in plant development. For instance, GA_3 promotes cell elongation, seed germination, and grain filling, making it a valuable tool for enhancing plant stature and yield traits (Yuying *et al*., 2024). In certain wheat varieties, foliar application of GA_3 has shown improvements in biological and grain yields under drought conditions, achieving increases of 12.12% and 1.47%, respectively (Haque *et al*., 2022). By regulating growth parameters such as tillering, spike length, and grain weight, PGRs enable crops to better withstand environmental stressors while maximizing yield potential.

While extensive research has explored the effects of optimal sowing timing and PGR application individually, studies on their combined impact remain limited and largely inconclusive. It is plausible that integrating these two factors could produce a synergistic effect, allowing for more robust plants that are better adapted to local environmental conditions. Aligning sowing dates with

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favorable weather conditions can maximize the growing season, while PGRs further bolster plant resilience and productivity by enhancing physiological growth processes. This gap in existing research underlines the need for further study to clarify the interactions between sowing timing and PGR application.

To address this gap, the present study aimed to investigate the combined effects of sowing timing and PGR application on yield traits in the wheat variety BARI gom33 under field conditions. By examining key parameters such as plant height, tiller number, spike length, and grain weight, this study seeks to develop insights into optimizing agronomic practices for enhanced wheat production in diverse environmental contexts.

2. Materials and Methods

2.1 Experimental Site and Soil

The experiment was conducted at the Agronomy Field Laboratory of Bangladesh Agricultural University, Mymensingh, from November 2019 to March 2020. The experimental site is situated at 24.75°N latitude and 90.50°E longitude, with an elevation of 18 meters above sea level. The local climate is subtropical, characterized by high temperatures and heavy rainfall during the Kharif season (April to September), and scant rainfall, along with moderately low temperatures and ample sunshine, during the Rabi season (October to March). The soil at the experimental site belongs to the Sonatala series within the Old Brahmaputra Floodplain (AEZ-9). The detailed physiochemical characteristics of the experimental field's soil are presented in Table 1, Table 2, and Table 3.

Table 1. Physical properties of initial soil

A. Physical Characteristics of Soil	Results
Sand (%) (0.0-0.02 mm)	20
Silt (%) (0.02-0.002 mm)	67
Clay (%) (<0.002 mm)	13
Soil textural class	Silt loam
Particle density (g/cc)	2.60
Bulk density (g/cc)	1.35
Porosity (%)	46.67

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Table 2. Chemical properties of initial soil

B. Chemical Characteristics of Soil	
pH	6.80
Organic carbon (%)	1.29
Total Nitrogen (%)	0.101
Available Phosphorus (P) (ppm)	6.00
Exchangeable Potassium (K) (me%) %)	0.087
Available Sulfur (S) (ppm)	10.5
Available Zinc (Zn) (ppm)	0.90

2.2 Experimental Design and Treatments

BARI gom33 was used as the test crop. The experiment was laid out in a split-plot design with three replications. Sowing dates were assigned to the main plots, and PGRs were allocated to the sub-plots. A total of 36 plots (12 treatments × 3 replications) were used, with a unit plot size of 2.5 m × 2.5 m (5 m²). The planting method followed a continuous row system, with distances of 1 m between replications and 0.75 m between plots.

The experiment consisted of the following treatments:

- **Factor A: Sowing Date**

  i. S_1: 20 November
  ii. S_2: 5 December
  iii. S_3: 20 December

- **Factor B: Plant Growth Regulators (PGRs)**

  i. P_0: Water only (Control)
  ii. P_1: Indole-3-Acetic Acid (IAA)
  iii. P_2: Gibberellic Acid (GA_3)
  iv. P_3: Naphthalene Acetic Acid (NAA)

2.3 Management of The Crop

The crop was planted in continuous rows, with 1 m spacing between replications and 0.75 m between plots. Sowing was carried out at a rate of 120 kg/ha, maintaining 5 cm between plants and

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20 cm between rows. Nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) were applied in recommended doses as urea, triple superphosphate (TSP), muriate of potash (MoP), and gypsum, respectively. Urea was top-dressed in three equal splits: the first at the early tillering stage (28 DAS), the second at the booting stage (46 DAS), and the third at the reproductive stage (64 DAS).

Plant growth regulators (PGRs) were sprayed at 35 and 55 days after sowing (DAS) using a sprayer. Irrigation and intercultural operations, such as weeding, thinning, and gap filling, were performed as needed to support optimal growth. Harvesting was conducted on three separate dates according to crop maturity, determined by the three sowing dates. For yield assessment, plants were harvested from a 1.0 m^2 area (1 m × 1 m) at full maturity.

2.4 Preparation of PGR solution

To prepare a 100 ppm stock solution of each plant growth regulator (PGR), the following steps were taken:

- **IAA (Indole-3-Acetic Acid)**: 0.1 g of IAA powder was fully dissolved in 50 ml of 95% ethanol. Distilled water was then added to bring the total volume to 1 liter, resulting in a 100 ppm concentration. This solution was used directly in the experiment.
- **NAA (Naphthalene Acetic Acid):** 0.1 g of NAA powder was dissolved in 1 liter of water, yielding a 100 ppm stock solution. A 40 ppm solution was then prepared from this stock by further dilution for experimental use.
- **GA_3 (Gibberellic Acid):** 0.1 g of GA_3 powder was dissolved in 1 liter of water to produce a 100 ppm stock solution, which was used directly in the experiment.

2.5 Soil Chemical Analysis

Soil texture was determined by hydrometer method as indicated by Gavlak *et al.* (2005). Soil pH was measured with a glass electrode pH meter in a 1:2.5 soil-to-water suspension (Micheal, 1965). Organic carbon was determined by the Walkley and Black wet oxidation method (1934), and total nitrogen by the semi-micro Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was extracted with 0.5 M $NaHCO_3$ (pH 8.5) (Olsen *et al.*, 1954), and exchangeable potassium with 1.0 N ammonium acetate (pH 7), measured via flame photometry (Knudsen, 1982). Available sulfur was assessed using 0.15% $CaCl_2$ extraction (Williams and Steinbergs, 1959).

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2.6 Recording of Different Growth and Yield Components

Growth and yield traits, including plant height, tiller count, dry matter, spikelets per spike, and 1000-grain weight, were recorded from five randomly selected plants per plot and averaged. Leaf area was measured using an automatic leaf area meter (Type AAN-7, Hayashi DamKo Co., Japan), and leaf area index (LAI) was calculated as the ratio of total leaf area to ground area (LAI = LA/P), where LA represents total leaf area (cm^2) and P is the ground area (cm^2). Grain yield was determined from a 1 m^2 area at each plot's center and expressed in tons per hectare ($t\ ha^{-1}$) at 14% moisture content, while straw yield was based on sun-dried weight.

2.7 Statistical Analysis

Analysis of variance (ANOVA) was performed on all parameters using F-statistics to assess treatment effects. Means were calculated, and Tukey's HSD test at a 5% significance level was used for pairwise comparisons (Gomez, 1984). Data analysis was conducted by R programming language.

3. Result and Discussion

3.1 Plant Growth Factors as Influenced by Sowing Date

The statistical analysis revealed significant variations in plant growth characteristics due to different sowing dates (Table 3). Plants sown on 20th December exhibited the greatest plant height (101.13 cm), spike length (14.90 cm), and the highest number of effective spikelets (14.90), which were statistically similar to those sown on 5th December (S_2). These findings contrasted with Uddin *et al*. (2016), who observed that wheat sown on 20th November reached the maximum plant height and spike length.

In contrast, the 20th November sowing date in the current study resulted in the highest number of effective tillers (3.16) and the greatest 1000-seed weight (48.34 g). However, crops sown on this earlier date also recorded the highest number of sterile spikelets (2.31) and the lightest grains (48 g). These results aligned with those of Jamal and Mohammed (2023) and Wahid *et al*. (2018), who found that earlier sowing provided favorable environmental conditions, such as optimal temperatures, that enhanced photosynthesis and growth, leading to greater 1000-seed weight and an increased number of effective tillers in wheat.

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Table 3. Effect of date of sowing on the growth factors of wheat

Date of sowing	Plant height (cm)	Effective tillers hill^{-1}	Spike length (cm)	Effective spikelets spike^{-1}	Sterile spikelets spike^{-1}	1000-grain weight (g)
S_1	90.24b	3.16a	11.47b	13.26b	2.31a	48.34a
S_2	98.76a	2.98b	12.49ab	14.61a	1.56b	48.00b
S_3	101.13a	3.01b	13.38a	14.90a	1.58b	48.03b
SE (±)	3.31	0.06	0.55	0.51	0.25	0.11
Level of significance	**	*	*	**	**	*
CV (%)	2.50	12.10	7.80	4.40	4.10	5.50

Means with the same letter within the same column do not differ significantly.
** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant. (S_1*= 20 November;* S_2*= 5 December;* S_3*= 20 December)*

3.2 Influence of Plant Growth Regulators (PGRs) on Plant Growth Characteristics

Remarkable variations in plant growth characteristics were observed with the application of different PGRs (Table 4). Specifically, plants treated with GA_3 hormone achieved the greatest plant height (103.68 cm), the maximum number of effective tillers (3.89), the longest spike length (13.58 cm), the heaviest grains (49.59 g), and the highest number of effective spikelets (15.82). In contrast, the lowest values for these growth parameters were recorded under control conditions where no PGRs were applied. These results were consistent with the findings of Chen *et al*. (2014); Lu *et al*. (2022); Al-Tahir (2014).

Table 4. Effect of PGRs on the yield contributing characters of wheat

Plant growth regulators	Plant height (cm)	Effective tillers hill^{-1}	Spike length (cm)	Effective spikelets spike^{-1}	Sterile spikelets spike^{-1}	1000-grain weight (g)
P_0	90.21c	2.32d	11.32c	12.72c	1.74	47.05d
P_1	97.42b	3.16b	12.80ab	14.73b	1.84	48.03b
P_2	103.68a	3.89a	13.58a	15.82a	1.84	49.59a
P_3	95.53b	2.82c	12.09bc	13.92b	1.85	47.80c

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SE (±)	2.78	0.33	0.48	0.65	0.03	0.53
Level of significance	**	**	**	**	NS	**
CV (%)	2.80	5.70	5.10	7.70	5.40	1.40

Means with the same letter within the same column do not differ significantly.
** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant. (*P_0= Water only; P_1= IAA; P_2= GA_3; P_3= NA*)

3.3 Interaction Effect of Sowing Date and PGRs on the Yield Contributing Characters of Wheat

Growth and yield factors varied significantly due to the interaction between sowing date and plant growth regulators (PGRs) (Table 5). The tallest plants (110.53 cm) and the largest spikes were recorded when plants were sown on 20th December and treated with GA_3. However, other growth parameters reached their maximum under the S_2:P_2 interaction, where GA_3 was applied in combination with the 5th December sowing date. In contrast, all growth attributes showed the lowest values when no PGRs were used, as seen in the S_1:P_0 interaction.

These results may be attributed to the optimal sowing periods, which allowed wheat to benefit from favorable environmental factors such as temperature, light, and moisture essential for both vegetative and reproductive growth. Early sowing typically led to excessive vegetative growth, making plants more susceptible to pests and diseases, while late sowing reduced the growing season, thereby limiting nutrient uptake, tillering, and grain yield, as corroborated by Kanapickas *et al*. (2024), Tian *et al*. (2024), and Atar (2024).

Furthermore, the enhanced growth observed with GA_3 application may be attributed to its role in promoting cell division and elongation, which resulted in taller plants with stronger stems, as supported by Sarwar *et al*. (2023). GA_3 treatment also appeared to improve the grain-filling process, producing heavier and more numerous grains (Anwar *et al*., 2023).

Table 5. Interaction effect of date of sowing and PGRs on the yield contributing characters of wheat

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Date of sowing: Plant growth regulators	Plant height (cm)	Effective tillers hill^{-1}	Spike length (cm)	Effective spikelets spike^{-1}	Sterile spikelets spike^{-1}	1000-grain weight (g)
S_1:P_0	85.00g	2.44h	10.19g	11.58f	2.27	47.16i
S_1:P_1	91.20ef	3.38c	11.79d-f	13.29c-f	2.34	48.31d
S_1:P_2	97.13cd	3.92b	12.80b-d	15.23a-d	2.32	49.76b
S_1:P_3	87.64fg	2.91ef	11.10fg	12.97ef	2.3	48.13e
S_2:P_0	93.46de	2.07i	11.32e-g	13.12d-f	1.50	46.83j
S_2:P_1	99.13bc	2.98de	12.81b-d	14.99a-e	1.56	47.62g
S_2:P_2	103.38b	4.05a	13.62a-c	16.31a	1.50	50.13a
S_2:P_3	99.09bc	2.80fg	12.22d-f	14.03b-e	1.67	47.40h
S_3:P_0	92.19ef	2.47h	12.45c-e	13.47c-f	1.45	47.17i
S_3:P_1	101.93bc	3.11d	13.79ab	15.45a-c	1.62	48.17de
S_3:P_2	110.53a	3.70b	14.33a	15.92ab	1.69	48.90c
S_3:P_3	99.87bc	2.74g	12.94b-d	14.78a-e	1.56	47.87f
SE (±)	2.07	0.18	0.35	0.41	0.11	0.30
Level of significance	*	*	*	*	NS	*
CV (%)	2.80	5.70	5.10	7.70	5.40	1.40

Means with the same letter within the same column do not differ significantly.
** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant.
(S_1= *20 November;* S_2= *5 December;* S_3= *20 December)*
(P_0= *Water only;* P_1= *IAA;* P_2= *GA*$_3$*;* P_3= *NA)*

3.4 Leaf Area Index (LAI) as Influenced by Sowing Date, PGRs, and Their Interaction

Significant effects of both sowing date and PGRs on LAI were observed (Table 6, Figure 1). At 30, 45, 60, and 75 DAS, the highest LAI was recorded with seeds sown on 5th December and treated with GA_3, whereas the lowest LAI was observed under control conditions with water application on 20th November. These findings aligned with Liu *et al*. (2023), who reported that timely sowing generally leads to higher LAI due to a longer vegetative growth period, allowing plants to develop more leaves and a larger canopy that enhances photosynthesis. In contrast, delayed sowing reduced LAI, as the shorter growing period limited leaf development, resulting in a smaller canopy that restricts sunlight capture and efficient photosynthesis, consistent with findings by Wahid *et al*. (2017) and Kiss *et al*. (2014).

Furthermore, GA_3 application significantly improved LAI, corroborating the results of Shahzad *et al*. (2021), who found that GA_3-treated plants maintained higher LAI under stress conditions than non-treated plants. This enhancement may be attributed to GA_3's stimulation of leaf growth, which

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increased leaf area and directly contributed to higher LAI, thereby improving sunlight capture and photosynthetic efficiency, as suggested by Chen *et al*. (2014) and Shah *et al*. (2023).

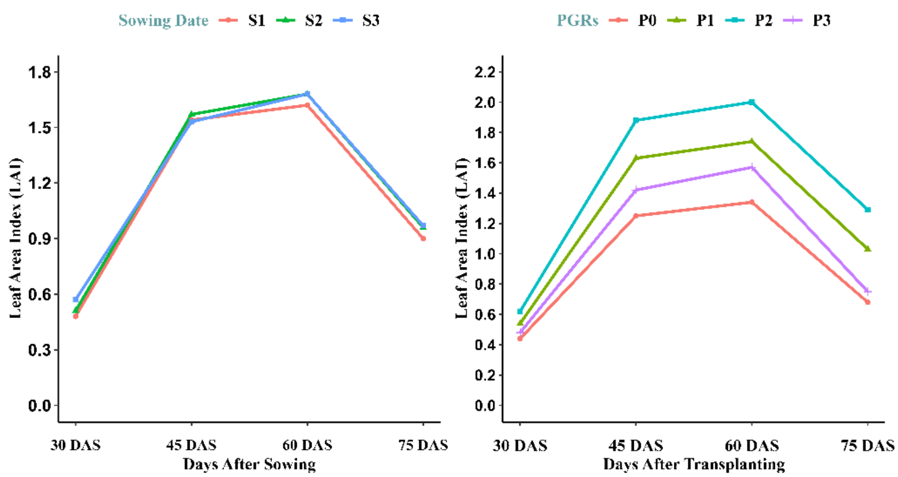

Figure 1. LAI of wheat as influenced by different dates of sowing and PGRs. (Data are presented as mean; n = 3; α=0.05)
(S_1= 20 November; S_2= 5 December; S_3= 20 December)
(P_0= Water only; P_1= IAA; P_2= GA_3; P_3= NA)

Table 6. Interaction effect of date of sowing and plant growth regulators on the leaf area index of wheat

Date of sowing: Plant growth regulators	Leaf area index (LAI)			
	Days after sowing (DAS)			
	30	45	60	75
S_1:P_0	0.41f	1.23e	1.30g	0.60e
S_1:P_1	0.52c-f	1.56b-d	1.71c-e	0.96cd
S_1:P_2	0.56b-d	1.92a	1.96a-c	1.33a
S_1:P_3	0.44ef	1.45c-e	1.50e-g	0.69e
S_2:P_0	0.42ef	1.29de	1.38fg	0.68e
S_2:P_1	0.50c-f	1.66a-c	1.74c-e	1.07bc
S_2:P_2	0.63ab	1.89a	2.02a	1.31a
S_2:P_3	0.47d-f	1.45c-e	1.59d-f	0.76de
S_3:P_0	0.48d-f	1.24de	1.35fg	0.76de

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S_3:P_1	0.60a-c	1.67a-c	1.77b-d	1.05bc
S_3:P_2	0.67a	1.84ab	2.01ab	1.23ab
S_3:P_3	0.52c-e	1.38c-e	1.61d-f	0.81de
SE (±)	0.02	0.07	0.07	0.07
Level of significance	*	*	*	*
CV (%)	10.30	10.90	8.10	13.00

Means with the same letter within the same column do not differ significantly.
** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant.
(S_1= 20 November; S_2= 5 December; S_3= 20 December)
(P_0= Water only; P_1= IAA; P_2= GA_3; P_3= NA)

3.5 Dry Weight of Wheat as Influenced by Sowing Date, PGRs, and Their Interaction

Statistical analysis showed significant variations in dry weight due to differences in sowing date, levels of plant growth regulators (PGRs), and their interaction (Table 7, Figure 2). The highest dry matter was observed when seeds were sown on 5th December and treated with GA_3, while the lowest shoot dry weight occurred in the control treatment, where no PGRs were applied. These findings align with those of Zhiipao *et al*. (2024), who reported that timely sowing promoted better nutrient uptake and remobilization, resulting in an 18.8% increase in post-anthesis dry matter accumulation. Liu *et al*. (2021) similarly noted that wheat sown at an optimal time benefited from a longer growth period, allowing for greater biomass accumulation, whereas late sowing shortened the growth phases, reducing dry matter production.

Moreover, GA_3 treatment enhanced germination rates and seedling growth under both normal and osmotic stress conditions, leading to increases in shoot and root lengths as well as dry weights, as supported by Sarwar *et al*. (2023). Guoping (1997) found that GA_3 improved growth and yield performance by enhancing intercepted photosynthetically active radiation (IPAR) and stimulating enzyme activity related to nitrogen metabolism. This increased nitrogen translocation to tillers, which contributed to better tiller development and overall dry matter accumulation (Wang *et al*., 2016).

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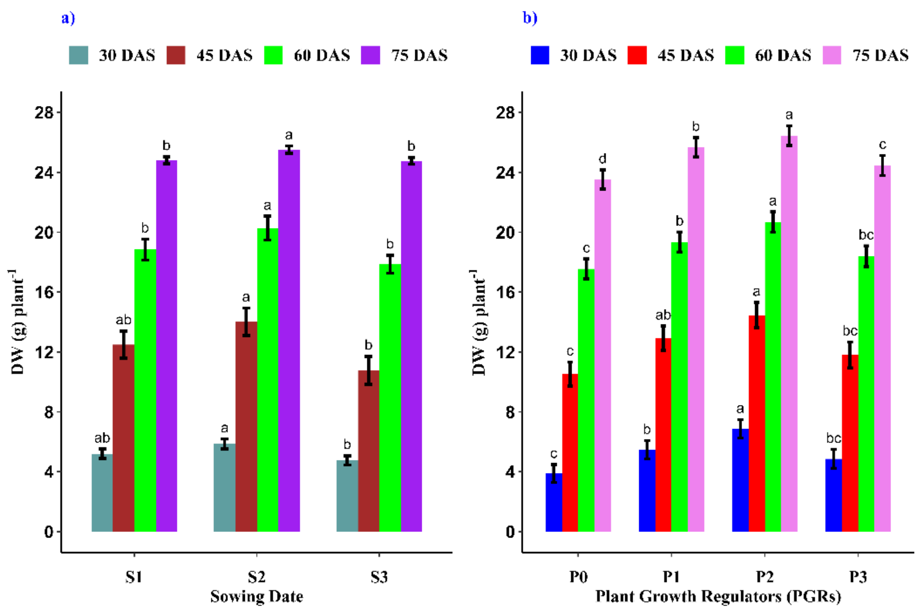

Figure 2. Dry weight (DW) of wheat as influenced by sowing date and PGRs. a) DW affected by sowing date; b) DW affected by PGRs (Data are presented as mean ± SE; n = 3; α=0.05)
(S_1= 20 November; S_2= 5 December; S_3= 20 December)
(P_0= Water only; P_1= IAA; P_2= GA_3; P_3= NA

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Table 7. Interaction effect of date of sowing and plant growth regulators on the dry weight plant^{-1} of wheat

Date of sowing: Plant growth regulators	Dry weight (g) plant^{-1}			
	Days after sowing (DAS)			
	30	45	60	75
S_1:P_0	3.66f	10.35f	17.39f	23.05j
S_1:P_1	5.51cd	13.08bc	19.18cd	25.30e

S_1:P_2	6.89ab	14.79a	20.48b	26.50b
S_1:P_3	4.72de	11.74de	18.30e	24.34g
S_2:P_0	4.31ef	12.35cd	18.81d	24.14h
S_2:P_1	6.06bc	14.69a	20.82b	26.04c
S_2:P_2	7.35a	15.61a	21.95a	26.87a
S_2:P_3	5.72c	13.42b	19.49c	24.98f
S_3:P_0	3.67f	8.90g	16.44g	23.38i
S_3:P_1	4.84de	10.99ef	18.01e	25.67d
S_3:P_2	6.37bc	12.97bc	19.62c	25.97c
S_3:P_3	4.14ef	10.24f	17.37f	24.04h
SE (±)	0.36	0.59	0.46	0.36
Level of significance	*	*	*	**
CV (%)	8.80	4.20	11.30	10.80

** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant.
(S_1= *20 November;* S_2= *5 December;* S_3= *20 December)*
(P_0= *Water only;* P_1= *IAA;* P_2= *GA*$_3$*;* P_3= *NA)*

3.6 Yield Attributes of Wheat as Influenced by Sowing Date, PGRs, and Their Interaction

Significant variations in yield parameters were observed due to differences in sowing date, PGR application, and their interaction, as illustrated in Figures 3 and 4. The highest grain yield (4.41 t ha^{-1}) was achieved when seeds were sown on 5th December (an increase of 7.59% over early sowing and 12.83% over late sowing) and treated with GA_3. However, the maximum straw yield was recorded under the S_1:P_3 treatment, where NA was applied, and seeds were sown on 20th November. In contrast, the control plot (S_1:P_0) produced the lowest yield. These findings align with Wahid *et al*. (2017) who noted that early sowing reduced grain yield due to low temperatures during anthesis, which may have negatively affected pollen viability and thus pollination. Additionally, delaying sowing generally led to a reduction in grain yield, with yield losses of approximately 1% per day of delay due to shorter vegetative and reproductive phases, as reported by Jarecki (2024) and Liu *et al*. (2023). Further supporting this, Liu *et al*. (2024) demonstrated that optimal sowing time could maximize aboveground biomass, nonstructural carbohydrate accumulation, and canopy photosynthesis, all of which may contribute to higher yields. Similarly, Solanke *et al*. (2024) found that optimal sowing might have enhanced germination, shoot length, and seed vigor, collectively improving grain yield.

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The increased yield in GA_3-treated plants corroborated findings by Dawar *et al*. (2022), who reported that GA_3 may have enhanced grain filling, resulting in heavier and more numerous grains that directly contributed to higher yields. GA_3 also promoted nutrient uptake and translocation, ensuring essential nutrients were available during critical growth stages, thus enhancing plant health and productivity, as observed by Rahman *et al*. (2018). Additionally, GA_3 may have increased leaf area, facilitating more photosynthesis and improving grain count per spike, indirectly leading to higher yields as suggested by Farman *et al*. (2019) and Tajdari *et al*. (2024).

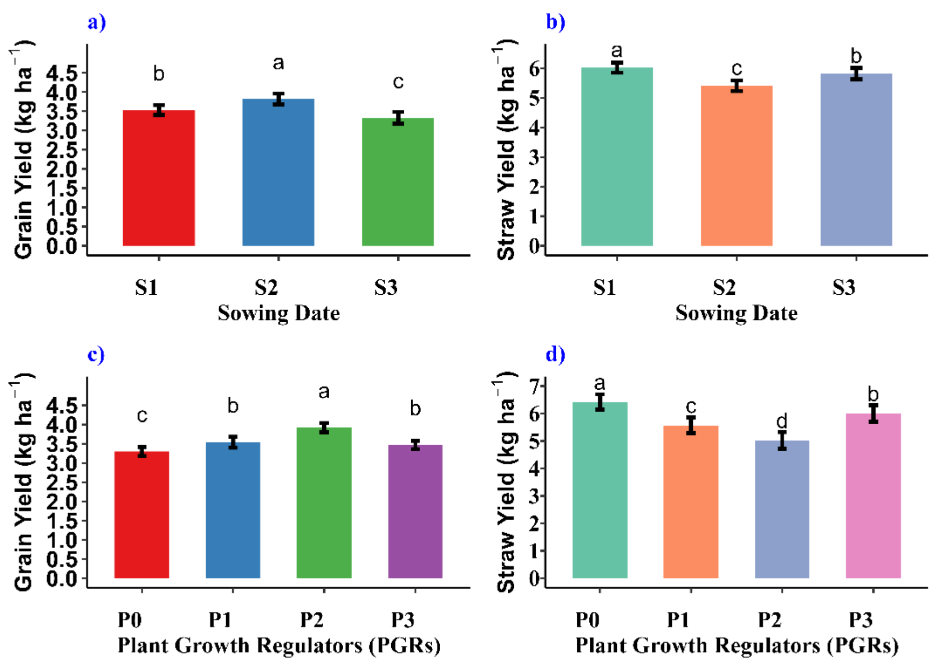

Figure 3. Yield parameters of wheat as influenced by sowing date and PGRs. a) Grain yield affected by sowing date; b) Straw yield affected by sowing date; c) Grain yield affected by PGRs; d) Straw yield affected by PGRs (Data are presented as mean ± SE, n = 3; α=0.05)
(S_1= *20 November;* S_2= *5 December;* S_3= *20 December)*
(P_0= *Water only;* P_1= *IAA;* P_2= *GA_3;* P_3= *NA)*

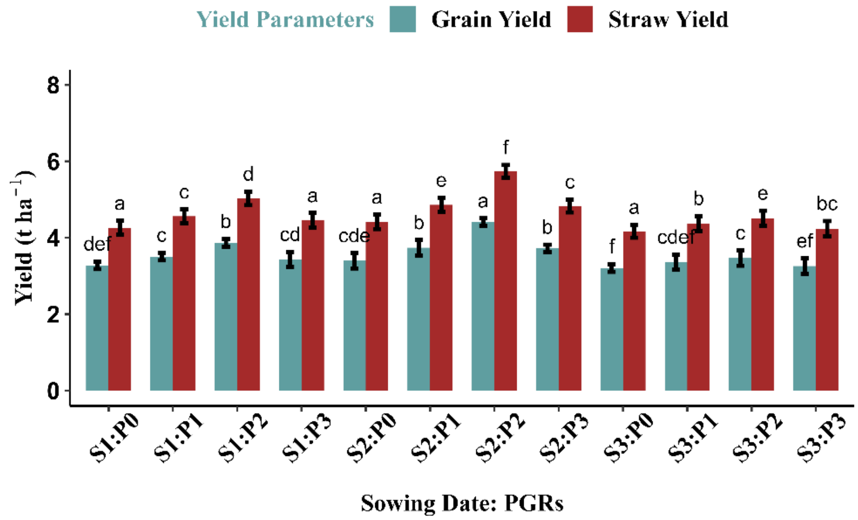

Figure 4. Yield parameters of wheat as influenced by interaction between sowing date and PGRs. (Data are presented as mean ± SE, n = 3; α=0.05)
(S_1= 20 November; S_2= 5 December; S_3= 20 December)
(P_0= Water only; P_1= IAA; P_2= GA_3; P_3= NA)

Conclusion

The study demonstrated that both sowing date and gibberellic acid (GA_3) application significantly influenced wheat growth and yield. Sowing at an optimal time provided a longer growing season, favorable weather, and reduced heat stress, while delayed sowing shortened the growth period and increased exposure to high temperatures. Furthermore, GA_3 application promoted stem elongation, increased leaf area, enhanced nutrient uptake, and improved stress tolerance. Together, these effects contributed to higher biomass, improved grain filling, and overall yield increases. Therefore, sowing on 5th December combined with the GA_3 application (S_2:P_2) could serve as an effective strategy for boosting wheat production. However, further research across diverse regions and wheat cultivars is recommended to validate these findings and develop more comprehensive guidelines for optimal GA_3 application in wheat cultivation.

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