

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 \times 3 replications). Statistical analysis using R programming showed that sowing on 5th December with Gibberellic Acid (GA₃) 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 GA₃ 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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Commented [AD2]: Please rewrite as “.....sowing date and plant growth regulators (PGRs) on growth and yield of wheat cv BARI Gom-33. The experiment was conducted in a split-plot design with three replications.....”

Commented [AD3]: Please replace as “results reveal that sowing on 5th December with Gibberellic

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Commented [AD5]: Add IAA, GA₃, NAA

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

Commented [AD6]: Sustainable agronomic

30 **One** of the most influential factors in wheat yield optimization is managing environmental
31 conditions, particularly through the timing of sowing. Optimal sowing timing aligns wheat's
32 vegetative and reproductive phases with favorable environmental conditions, such as temperature,
33 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
34 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
35 to either premature high temperatures or late-season cold, both of which reduce growth potential
36 and productivity (Gupta, 2017). **For example, late sowing often exposes wheat to elevated**
37 **temperatures during the grain-filling stage, which accelerates senescence and lowers yields. In**
38 **contrast, early sowing may result in excessive vegetative growth, increasing susceptibility to pests**
39 **and diseases (Atar, 2024; Tian *et al.*, 2024; Zhiipao *et al.*, 2024).**

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42 **In addition** to optimal sowing timing, the application of plant growth regulators (PGRs) presents
43 a promising strategy to improve wheat performance. PGRs are compounds that influence plant
44 physiology and biochemistry, significantly contributing to growth regulation, stress tolerance, and
45 yield enhancement (Farman *et al.*, 2019). Common PGRs, such as gibberellic acid (GA₃), indole-
46 3-acetic acid (IAA), and naphthalene acetic acid (NAA), each play distinct roles in plant
47 development. For instance, GA₃ promotes cell elongation, seed germination, and grain filling,
48 making it a valuable tool for enhancing plant stature and yield traits (Yuying *et al.*, 2024). In
49 certain wheat varieties, foliar application of GA₃ has shown improvements in biological and grain
50 yields under drought conditions, achieving increases of 12.12% and 1.47%, respectively (Haque
51 *et al.*, 2022). By regulating growth parameters such as tillering, spike length, and grain weight,
52 PGRs enable crops to better withstand environmental stressors while maximizing yield potential.

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

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

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

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66 2. Materials and Methods

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67 2.1 Experimental Site and Soil

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

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77 **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

78

79 **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

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81 **2.2 Experimental Design and Treatments**

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

87 The experiment consisted of the following treatments:

88 • **Factor A: Sowing Date**

- 89 i. S₁: 20 November
90 ii. S₂: 5 December
91 iii. S₃: 20 December

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92 • **Factor B: Plant Growth Regulators (PGRs)**

- 93 i. P₀: Water only (Control)
94 ii. P₁: Indole-3-Acetic Acid (IAA)
95 iii. P₂: Gibberellic Acid (GA₃)
96 iv. P₃: Naphthalene Acetic Acid (NAA)

97 **2.3 Management of The Crop**

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

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 m² area (1 m × 1 m) at full maturity.

Commented [AD23]: Plz mention the Recommended dose of the fertilizers

Commented [AD24]: Also mention the application time and dose of remaining nutrients

Commented [AD25]: Mention the concentration and dose of PGR applied

Commented [AD26]: Mention the date of harvesting

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.
- **GA₃ (Gibberellic Acid):** 0.1 g of GA₃ 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 NaHCO₃ (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% CaCl₂ extraction (Williams and Steinbergs, 1959).

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 that significant variations in plant-crop growth characteristics due to different sowing dates was recorded (Table 3). Plants-Wheat sown on 20th December (S_3) 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 at par 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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1) Effect of Sowing date and PGR on growth parameters of wheat (include plant height, dry matter accumulation, LAI, and other parameter if present)
2) Effect of Sowing date and PGR on yield parameters and yield of wheat (include all yield parameters and yield). Just reorganize. The content is perfect. Add the tables and figures in the respected sections. This would make the manuscript more scientific and better to read.

Commented [AD28]: Parameters in place of factors

Commented [AD29]: 1000 seed weight is a yield parameters. Donot add this in growth parameter.

157 **Table 3. Effect of date of sowing on the growth factors-parameters 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

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Commented [AD31]: SEm

158 Means with the same letter within the same column do not differ significantly.
 159 ** :—Significant at 1% level of probability, * :—Significant at 5% level of probability, NS :—Not
 160 significant. (S₁= 20th November; S₂= 5th December; S₃= 20th December)
 161
 162

163 3.2 Influence of Plant Growth Regulators (PGRs) on Plant Growth 164 Characteristics

165 Remarkable variations in plant growth characteristics were observed with the application of
 166 different PGRs (Table 4). Specifically, plants treated with GA₃ hormone achieved the greatest
 167 plant height (103.68 cm), the maximum number of effective tillers (3.89), the longest spike length
 168 (13.58 cm), the heaviest grains (49.59 g), and the highest number of effective spikelets (15.82). In
 169 contrast, the lowest values for these growth parameters were recorded under control conditions
 170 where no PGRs were applied. These results were consistent with the findings of Chen *et al.* (2014);
 171 Lu *et al.* (2022); Al-Tahir (2014).

Commented [AD32]: Significant variations

172 **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

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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. (P₀= Water only; P₁= IAA; P₂= GA₃; P₃= 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 GA₃. However, other growth parameters reached their maximum under the S₂:P₂ interaction, where GA₃ 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 S₁:P₀ 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 GA₃ 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). GA₃ 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

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.

(S₁= 20 November; S₂= 5 December; S₃= 20 December)

(P₀= Water only; P₁= IAA; P₂= GA₃; P₃= NA)

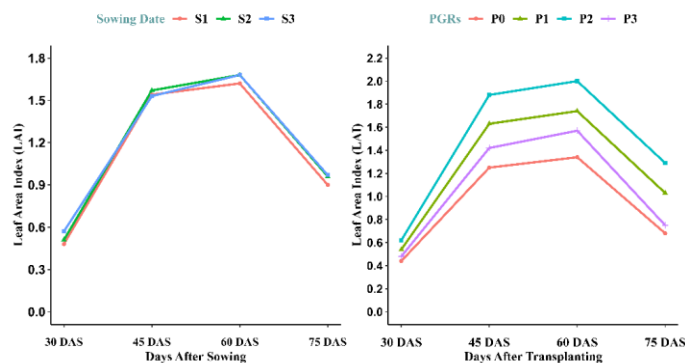
3.4 Leaf Area Index (LAI) as Influenced by Sowing Date, PGRs, and Their Interaction

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 GA₃, 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, GA₃ application significantly improved LAI, corroborating the results of Shahzad *et al.* (2021), who found that GA₃-treated plants maintained higher LAI under stress conditions than non-treated plants. This enhancement may be attributed to GA₃'s stimulation of leaf growth, which

Commented [AD35]: LAI is a growth parameter of wheat. Plz attach this part with growth parameters.

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



216
217 **Figure 1. LAI of wheat as influenced by different dates of sowing and PGRs. (Data are presented as**
218 **mean; n = 3; $\alpha=0.05$)**
219 **(S₁= 20 November; S₂= 5 December; S₃= 20 December)**
220 **(P₀= Water only; P₁= IAA; P₂= GA₃; P₃= NA)**

221
222
223
224
225 **Table 6. Interaction effect of date of sowing and plant growth regulators on the leaf area**
226 **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

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

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0.60ac; 1.67ac, etc

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.

(S₁= 20 November; S₂= 5 December; S₃= 20 December)

(P₀= Water only; P₁= IAA; P₂= GA₃; P₃= NA)

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

Commented [AD37]: Rewrite as Dry matter accumulation (DMA)

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 GA₃, 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.

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Moreover, GA₃ 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 GA₃ 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).

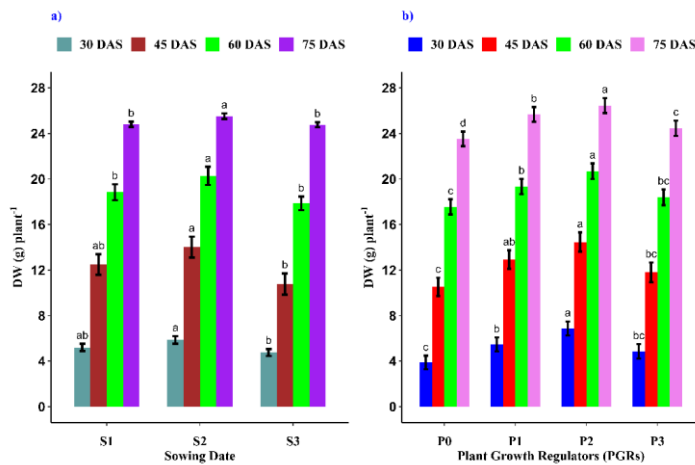


Figure 2. Dry weight (DW) of wheat as influenced by sowing date and PGRs. a) DW affected by sowing date; b) DW affected by PGRs (Data are presented as mean \pm SE; n = 3; $\alpha=0.05$)
 (S₁= 20 November; S₂= 5 December; S₃= 20 December)
 (P₀= Water only; P₁= IAA; P₂= GA₃; P₃= NA)

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

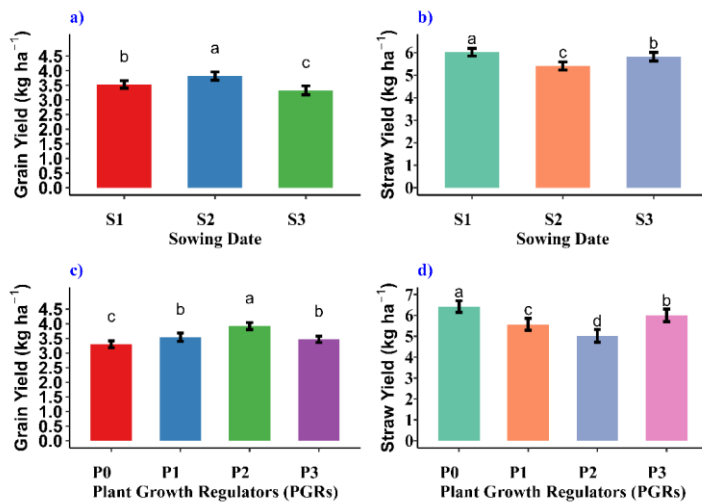
** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant.
(S₁ = 20 November; S₂ = 5 December; S₃ = 20 December)
(P₀ = Water only; P₁ = IAA; P₂ = GA₃; P₃ = NA)

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 GA₃. However, the maximum straw yield was recorded under the S₁:P₃ treatment, where NA was applied, and seeds were sown on 20th November. In contrast, the control plot (S₁:P₀) 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.

Commented [AD39]: In yield attribute only grain and stover yield are talked about. Plz add the other yield attributes like 1000 seed weight, grain/ panicle, etc which you have studied in this section

285 The increased yield in GA₃-treated plants corroborated findings by Dawar *et al.* (2022), who
 286 reported that GA₃ may have enhanced grain filling, resulting in heavier and more numerous grains
 287 that directly contributed to higher yields. GA₃ also promoted nutrient uptake and translocation,
 288 ensuring essential nutrients were available during critical growth stages, thus enhancing plant
 289 health and productivity, as observed by Rahman *et al.* (2018). Additionally, GA₃ may have
 290 increased leaf area, facilitating more photosynthesis and improving grain count per spike,
 291 indirectly leading to higher yields as suggested by Farman *et al.* (2019) and Tajdari *et al.* (2024).



292
 293 **Figure 3. Yield parameters of wheat as influenced by sowing date and PGRs. a) Grain yield affected**
 294 **by sowing date; b) Straw yield affected by sowing date; c) Grain yield affected by PGRs; d) Straw**
 295 **yield affected by PGRs (Data are presented as mean \pm SE, n = 3; $\alpha=0.05$)**
 296 (S₁= 20 November; S₂= 5 December; S₃= 20 December)
 297 (P₀= Water only; P₁= IAA; P₂= GA₃; P₃= NA)

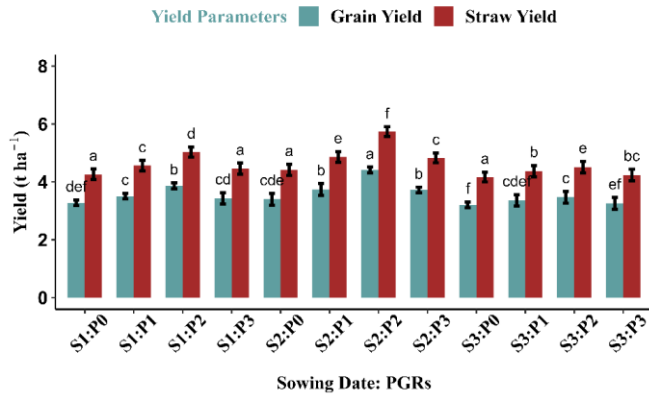


Figure 4. Yield parameters of wheat as influenced by interaction between sowing date and PGRs. (Data are presented as mean \pm SE, n = 3; $\alpha=0.05$)
(S₁= 20 November; S₂= 5 December; S₃= 20 December)
(P₀= Water only; P₁= IAA; P₂= GA₃; P₃= NA)

Conclusion

The study demonstrated that both sowing date and [gibberellic acid \(GA₃\) PGR](#) application [especially GA₃](#) significantly influenced wheat growth and yield. Sowing at an optimal time ([mention early/late](#)) 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, GA₃ 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 GA₃ application (S₂:P₂) could serve as an effective strategy for boosting wheat production [and productivity](#). However, further research across diverse regions and wheat cultivars is recommended to validate these findings and develop more comprehensive guidelines for optimal GA₃ application in wheat cultivation.

319 References

- 320 1. Maity, S., & Shrivastav, S. P. (2024). Understanding heat stress and tolerance mechanisms
321 in wheat (*Triticum aestivum* L.): A comprehensive review. *Journal of Advances in Biology*
322 & *Biotechnology*, 27(7), 1196-1211.
- 323 2. Dixit, A. K., Sen, B., Bijla, S., Maiti, S., & Kathayat, B. (2023). Contribution of Wheat in
324 Global Food Security in Changing Climatic Conditions: Challenges Ahead and Coping
325 Strategies. In *Wheat Science* (pp. 107-124). CRC Press.
- 326 3. Kheiralipour, K., Brandão, M., Holka, M., & Choryński, A. (2024). A Review of
327 Environmental Impacts of Wheat Production in Different Agrotechnical
328 Systems. *Resources*, 13(7), 93.
- 329 4. Liu, J., He, Q., Zhou, G., Song, Y., Guan, Y., Xiao, X., Sun, W., Shi, Y., Zhou, K., Zhou,
330 S., Wu, Y., Ma, S., & Wang, R. (2023). Effects of Sowing Date Variation on Winter Wheat
331 Yield: Conclusions for Suitable Sowing Dates for High and Stable Yield. *Agronomy*,
332 13(4), Article 4. <https://doi.org/10.3390/agronomy13040991>
- 333 5. Qiao, S., Harrison, S. P., Prentice, I. C., & Wang, H. (2023). Optimality-based modelling
334 of wheat sowing dates globally. *Agricultural Systems*, 206, 103608.
- 335 6. Liu, Y., Cai, W., Zhu, K., Xu, Y., Wang, W., Zhang, H., ... & Yang, J. (2024). Comparison
336 of population photosynthesis characteristics and grain yield of wheat under various sowing
337 dates and seeding rates. *Crop Science*.
- 338 7. Gupta, S. (2017). Effect of different sowing dates on growth and yield attributes of wheat
339 in Udham Singh Nagar district of Uttarakhand, India. *Plant Archives*, 17(1), 232-236.
- 340 8. Atar, B. (2024). YIELD LOSS AFTER BELATED SOWING AND EFFECTIVENESS
341 OF SEED VERNALIZATION IN WHEAT. *Applied Ecology & Environmental*
342 *Research*, 22(2).
- 343 9. Tian, Z., Yin, Y., Li, B., Zhong, K., Liu, X., Jiang, D., ... & Dai, T. (2024). Optimizing
344 planting density and nitrogen application to mitigate yield loss and improve grain quality
345 of late-sown wheat under rice-wheat rotation.
- 346 10. Zhiipao, R. R., Pooniya, V., Kumar, D., Biswakarma, N., Bainsla, N. K., Saikia, N., ... &
347 Jat, R. D. (2024). Late-sown stress afflict post-anthesis dry matter and nutrient partitioning

- and their remobilization in aestivum wheat genotypes. *Journal of Agronomy and Crop Science*, 210(2), e12693.
11. Farman, S., Mushtaq, A., & Azeem, M. W. (2019). Plant growth regulators (PGRs) and their applications: A review. *Int. J. Chem. Biochem. Sci*, 15, 94-103.
12. Yuying, Y., Ji, L., Guo, B., Li, T., Guohua, M., Wu, K., Yang, F., Zhu, G., Fang, L., & Zeng, S. (2022). Exogenous GA₃ promotes flowering in *Paphiopedilum callosum* (Orchidaceae) through bolting and lateral flower development regulation. *Horticulture Research*, 9, <https://doi.org/10.1093/hr/uhac091>
13. Haque, M. N., Pramanik, S. K., Hasan, M. A., Islam, M. R., & Sikder, S. (2022). Foliar application of potassium and gibberellic acid (GA₃) to alleviate drought stress in wheat. *Journal of Science and Technology*, 1, 10.
14. Gavlak, R., Horneck, D., & Miller, R. (2005). *Plant, soil, and water reference methods for the Western Region* (Western Regional Extension Publication No. 125). WERA-103 Technical Committee. <http://www.naptprogram.org/files/napt/western-states-method-manual-2005.pdf>
15. Michael, A. M. (1965). Determination of soil pH by glass electrode pH meter. *Journal of Agricultural Science*, 65(2), 143-145.
16. Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, 37(1), 29-38.
17. Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen-total. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties* (pp. 595-624). American Society of Agronomy, Soil Science Society of America.
18. Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *U.S. Department of Agriculture Circular*, (939).
19. Knudsen, D., Peterson, G. A., & Pratt, P. F. (1982). Lithium, sodium, and potassium. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties* (pp. 225-246). American Society of Agronomy, Soil Science Society of America.

20. Williams, C. H., & Steinbergs, A. (1959). Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. *Australian Journal of Agricultural Research*, 10(3), 340-352.
21. Gomez, K. A. (1984). Statistical procedures for agricultural research. John NewYork: Wiley and Sons.
22. Uddin, R., Islam, M., Ullah, M., Hore, P., & Paul, S. (2016). Grain Growth and Yield of Wheat as Influenced by Variety and Sowing Date. *Bangladesh Agronomy Journal*, 18(2), 97–104. <https://doi.org/10.3329/baj.v18i2.28911>
23. Jamal, W. M., & Mohammed, F. H. A. H. (2023). Effect of hierarchy of the production of tillers in wheat (*Triticum aestivum* L.) cultivar (KM5180) under the influence of planting dates. *Research on Crops*, 24(2), 236-240.
24. Wahid, S. A., & Al-Hilfy, I. H. H. (2018). Growth and yield components of some bread wheat cultivars as affected by different sowing dates. *The Iraqi Journal of Agricultural Science*, 49(2), 171-178.
25. Chen, L., Hao, L., Condon, A. G., & Hu, Y. G. (2014). Exogenous GA₃ application can compensate the morphogenetic effects of the GA-responsive dwarfing gene Rht12 in bread wheat. *PloS one*, 9(1), e86431.
26. Lu, Q., Lu, S., Wang, M., Cui, C., Condon, A. G., Jatayev, S., ... & Hu, Y. G. (2022). The exogenous GA₃ greatly affected the grain-filling process of semi-dwarf gene Rht4 in bread wheat. *Physiologia Plantarum*, 174(3), e13725.
27. Al-Tahir, F. M. (2014). Relationship between tiller development and productivity with yield and its components for wheat and oat under the influence of AII and GA₃. *European Academic Research*, 9(2), 11466-11485.
28. Kanapickas, A., Vagusevičienė, I., & Sujetovienė, G. (2024). The Effects of Different Sowing Dates on the Autumn Development and Yield of Winter Wheat in Central Lithuania. *Atmosphere*, 15(6), 738.
29. Sarwar, G., Anwar, T., Malik, M., Rehman, H. ur, Danish, S., Alahmadi, T. A., & Ansari, M. J. (2023). Evaluation of potassium-enriched biochar and GA₃ effectiveness for Improving wheat growth under drought stress. *BMC Plant Biology*, 23(1), 615. <https://doi.org/10.1186/S12870-023-04613-0>
30. Anwar, T., Shehzadi, A., Qureshi, H., Shah, M. N., Danish, S., Salmen, S. H., & Ansari,

- M. J. (2023). Alleviation of cadmium and drought stress in wheat by improving growth and chlorophyll contents amended with GA₃ enriched deashed biochar. *Scientific Reports*, 13(1), 18503.
31. Liu, J., He, Q., Zhou, G., Song, Y., Guan, Y., Xiao, X., Sun, W., Shi, Y., Zhou, K., Zhou, S., & others. (2023). Effects of sowing date variation on winter wheat yield: Conclusions for suitable sowing dates for high and stable yield. *Agronomy*, 13(4), 991. <https://doi.org/10.3390/agronomy13040991>
32. Wahid, S. A., Al-Hilfy, I. H. H., & Al-Abodi, H. M. K. (2017). *Effect of sowing dates on the growth and yield of different wheat cultivars and their relationship with accumulated heat units*.
33. Kiss, T., Balla, K., Bányai, J., Veisz, O., & Karsai, I. (2014). Effect of Different Sowing Times on the Plant Developmental Parameters of Wheat (*Triticum aestivum* L.). *Cereal Research Communications*, 42(2), 239–251. <https://doi.org/10.1556/CRC.2013.0064>
34. Shahzad, K.; Hussain, S.; Arfan, M.; Hussain, S.; Waraich, E.A.; Zamir, S.; Saddique, M.; Rauf, A.; Kamal, K.Y.; Hano, C.; et al. Exogenously Applied Gibberellic Acid Enhances Growth and Salinity Stress Tolerance of Maize through Modulating the Morpho-Physiological, Biochemical and Molecular Attributes. *Biomolecules* 2021, 11, 1005. <https://doi.org/10.3390/biom11071005>
35. Chen, L., Hao, L., Condon, A. G., & Hu, Y.-G. (2014). Exogenous GA₃ Application Can Compensate the Morphogenetic Effects of the GA-Responsive Dwarfing Gene Rht12 in Bread Wheat. *PLOS ONE*, 9(1), e86431. <https://doi.org/10.1371/journal.pone.0086431>
36. Shah, S. H., Islam, S., Mohammad, F., & Siddiqui, M. H. (2023). Gibberellic Acid: A Versatile Regulator of Plant Growth, Development and Stress Responses. *Journal of Plant Growth Regulation*, 42(12), 7352–7373. <https://doi.org/10.1007/s00344-023-11035-7>
37. Liu, K., Zhang, C., Guan, B., Yang, R., Liu, K., Wang, Z., ... & Wang, X. (2021). The effect of different sowing dates on dry matter and nitrogen dynamics for winter wheat: an experimental simulation study. *PeerJ*, 9, e11700.
38. Guoping, Z. (1997). Gibberellic Acid₃ Modifies Some Growth and Physiologic Effects of Paclobutrazol (PP₃₃₃) on Wheat. *Journal of Plant Growth Regulation*, 16(1), 21–25. <https://doi.org/10.1007/PL00006970>

39. Wang, Y., Ren, T., Lu, J., Cong, R., Hou, W., Liu, T., Hussain, S., & Li, X. (2016). Exogenously applied gibberellic acid improves the growth and yield performance of inferior rice tillers grown under different nitrogen levels. *Acta Physiologiae Plantarum*, 39(1), 5. <https://doi.org/10.1007/S11738-016-2307-3>
40. Jarecki, W. (2024). Response of Winter Wheat to Delayed Sowing and Varied Nitrogen Fertilization. *Agriculture*, 14(1), Article 1. <https://doi.org/10.3390/agriculture14010121>
41. Solanke, A. P., Raut, D., Kalbhor, S. U., Nalbale, S. R., & Lande, S. S. (2024). Impact of Varied Sowing Dates on Seed Quality Parameters in Wheat. *Journal of Advances in Biology & Biotechnology*, 27(9), 116-122.
42. Dawar, K., Rahman, U., Alam, S. S., Tariq, M., Khan, A., Fahad, S., Datta, R., Danish, S., Saud, S., & Noor, M. (2022). Nitrification Inhibitor and Plant Growth Regulators Improve Wheat Yield and Nitrogen Use Efficiency. *Journal of Plant Growth Regulation*, 41(1), 216–226. <https://doi.org/10.1007/s00344-020-10295-x>
43. Rahman, H. M. A., Ahmed, B. E. A. M., & Ahmed, M. O. (2018). Effect of plant growth regulators (GA₃, NAA) and water stress on leaf area and yield attributes of wheat. *International Journal of Innovative Science and Research Technology*, 3(5), 1–5.
44. Tajdari, H. R., Soleymani, A., Montajabi, N., Naderi Darbaghshahi, M. R., & Javanmard, H. R. (2024). The effect of foliar application of plant growth regulators on functional and qualitative characteristics of wheat (*Triticum aestivum* L.) under salinity and drought stress conditions. *Applied Water Science*, 14(6), 126. <https://doi.org/10.1007/S13201-024-02203-5>