



RESEARCH ARTICLE

Impact of sowing dates and plant growth regulators on productivity and economics of wheat (*Triticum aestivum* L.) varieties under sub-tropical conditions of Jammu

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Abstract

A field experiment was conducted during rabi 2022–23 at the Research Farm, Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu. The soil of the experimental site was sandy clay loam, slightly alkaline with low organic carbon and available nitrogen (N), medium available phosphorus (P) and potassium (K). The experiment consisted of three sowing dates (viz., D₁: 25th November, D₂: 15th December and D₃: 5th January) in main plot, two wheat varieties (viz., V₁: JAUW 672 and V₂: DBW 303) in sub plot and two plant growth regulators (viz., T₁: Control, T₂: *Bacillus subtilis* at 5 g/kg seed + paclobutrazol at 50 ppm at 30 and 60 DAS and T₃: *B. subtilis* at 5 g/kg seed + kinetin at 10 ppm applied at 30 and 60 DAS) in sub-sub plot replicated thrice in split-split plot design. The experimental results revealed that among different treatments 25th November sowing dates, variety DBW 303 and plant growth regulators paclobutrazol at 50 ppm along with *B. subtilis* at 5 g/kg seed, recorded significantly higher leaf area index (LAI) (3.91, 3.61 and 3.63), soil plant analysis development (SPAD) (42.48, 39.68 and 39.74), dry matter (1056.42 g/m², 941.94 g/m² and 949 g/m²), yield attributes {number of effective tillers/m² (316.98, 298.72 and 291.50), number of grains/spike (42.58, 41.10 and 41.74), yield (4793.23 kg/ha, 4133.58 kg/ha and 4177.7923 kg/ha), net returns (121919.67 ₹/ha, 877203.52 ₹/ha and 102681.10 ₹/ha) and B:C ratio (3.93, 3.44 and 3.15)}. Also, the interaction has been found significant in the case of dates of sowing and varieties for the number of effective tillers per square metre, grain yield and straw yield. Hence, under sub-tropical conditions of Jammu, the wheat crop variety DBW 303 can be sown on 25th November along with the application of *B. subtilis* at 5 g/kg seed + paclobutrazol at 50 ppm for higher productivity and profitability.

Keywords: B:C ratio; date of sowing; DBW 303; paclobutrazol; yield

Introduction

Wheat (*Triticum aestivum* L.) is the most significant cereal crop worldwide (1). It is the second most abundant crop in the world, which is physiologically classified under the C₃ plant species. About two billion people (36 % of the world's population) consume it as a staple diet, providing almost 55 % of the carbohydrate and 20 % of the food calories (2). Globally, wheat occupied 220.61 million hectares of cultivated land, with production of 789.49 million tonnes and productivity of 3.58 t/ha. In India, wheat is grown as a rabi crop on 30.46 million hectares of land with production of 110 million tonnes and productivity of 3.5 t/ha (3). The Union Territory of Jammu and Kashmir has 243.93 thousand hectares of wheat cultivated land, with production of 690 thousand tonnes and productivity 2.09 t/ha. The entire area under wheat cultivation in the Jammu region is 242.65 thousand hectares, with a production of 486.9 thousand tonnes and a productivity of 2.06 t/ha (4). It has been observed that the average production of wheat has declined by 50 % due to abiotic factors such as drought (9 %), high temperature (20 %), low temperature (7 %) and salinity (10 %) in districts such as Pulwama

and Budgam (5). Sowing dates are a basic factor for deciding the crop yield (6). Under sub-tropical conditions of the Jammu region, wheat is sown late (20th November–25th December) and very late (26th December–15th January) due to delayed harvesting of basmati rice, which decreases the productivity of the crop to the tune of 1–1.5 % per day (7). An ideal sowing window under sub-tropical conditions of Jammu is 1st–25th November, which can improve the wheat grain productivity and baking quality by allowing for better adaptation to physiology, phenology and environmental circumstances. Furthermore, the optimal sowing date influences the crops' availability of water, temperature and sun radiation, which affects the nutrient uptake by plants and crop yield (8). The varieties considered for the experiment were JAUW 672 and DBW 303.

Plant growth regulators are natural or synthetic substances that can also improve crop yield by rerouting assimilate metabolism and partitioning under heat stress conditions. Exogenously applied plant growth regulators promote plant growth and development in both normal and stressed conditions (9). Under a range of environmental situations, foliar sprays of plant growth regulators have been shown to increase wheat productivity. It has been

discovered that plant growth regulators play an important role in raising the harvest index by increasing photosynthate partitioning towards the reproductive sink or enhancing crop productivity by improving the metabolic imbalances produced in a cell during stress (10). The use of growth retardant, viz., paclobutrazol, a triazole derivative, helps in plant stress adaptation by preserving relative water content, electrolyte leakage, protecting photosynthetic apparatus, which contributes to plant growth and yield (11). The use of growth promoters, viz., kinetin, a type of cytokinin, promotes cell division, nucleic acid metabolism, further retard senescence and keeps the leaf green under adverse conditions (12).

Materials and Methods

The current study was performed at the Research Farm, Chatha, Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu during rabi, 2022–23. The soil was sandy clay loam, pH 7.5, low in organic carbon (0.43 %), moderate in available nitrogen (N) (245.21 kg/ha), phosphorus (P) (14.84 kg/ha) and potassium (K) (129.03 kg/ha). The trial was put out in a split-split plot design including of three sowing dates (D₁: 25th November 2022, D₂: 15th December 2022 and D₃: 5th January 2023) in main plot, two varieties (V₁: JAUW 672 and V₂: DBW 303) in sub plot and three plant growth regulator treatments (T₁: control, T₂: *B. subtilis* at 5 g/kg seed + paclobutrazol at 50 ppm at 30 and 60 days after sowing (DAS) and T₃: *B. subtilis* at 5 g/kg seed + kinetin at 10 ppm at 30 and 60 DAS) in sub-sub plot. The fertiliser dose for JAUW 672 was 100 : 50 : 25 and DBW 303 was 150 : 60 : 40 kg/ha of N : P₂O₅ : K₂O. The seed rate was 100 kg/ha for normal sowing and 125 kg/ha for delayed sowing. The gross plot size was 4 × 3 m and the net plot size was 3.2 × 2 m. The data were analysed by using ANOVA (*F*-test).

Results

Growth parameters

The data for wheat growth parameters, viz., plant height, dry matter accumulation, leaf area index (LAI) and chlorophyll content, were

recorded at different intervals.

Plant height

The height of the plant is a crucial indicator of the vertical phenotypic development of the plant. The results of the experiment showed that plant height was affected significantly by varying dates of sowing (Table 1 and Fig. 1). It was observed that as a plant aged, its height continued to rise. At 30 DAS, the highest plant was recorded with 25th November sowing, which was significantly higher than 15th December. A similar trend was found at 90 DAS and at harvest.

The height of plants, recorded at different stages of growth during the experiment, was found to differ significantly among varieties. At all growth stages, viz., 30, 60, 90 DAS and at harvest, the significantly maximum height was recorded by DBW 303 as compared to JAUW 672 (Fig. 2). The height of plants, recorded at different stages of growth during the experiment, was found to differ significantly with plant growth regulators. At 30 DAS, kinetin recorded numerically taller plants than paclobutrazol. At 60 DAS, the maximum height was recorded in kinetin, which was statistically at par with the plant heights obtained under control and significantly taller than paclobutrazol and similar results were found at 90 DAS and at harvest. The interaction effects of dates of sowing, varieties and plant growth regulators were non-significant during all the stages (Fig. 3).

Dry matter accumulation

Dry matter accumulation of wheat varieties increased with the progression of crop growth, regardless of sowing dates and was lowest at 30 DAS and maximum at harvest (Table 2). At 30 DAS, the highest dry matter was recorded under 25th November sowing, which was statistically at par with 15th December sowing but significantly higher than the crop sown under 5th January. Whereas at 60, 90 DAS and at harvest, 25th November sowing accumulated significantly higher dry matter, which was significantly higher than 15th December and 5th January, respectively (Fig. 4).

Varieties differed significantly in relation to dry matter accumulation at all growth stages (Table 2). Although at 30 DAS, a non-significantly higher accumulation of dry matter was recorded by variety DBW 303. However, at 60, 90 DAS and at harvest, significantly

Table 1. Effect of sowing dates and plant growth regulators on plant height (cm) of wheat varieties

Treatment details	30 DAS	60 DAS	90 DAS	At harvest
Date of sowing				
D ₁ : 25 th November	26.82	53.71	82.60	100.20
D ₂ : 15 th December	24.98	47.63	77.69	90.61
D ₃ : 5 th January	19.46	40.94	72.75	84.08
SEm (±)	1.15	1.88	1.07	2.55
CD (5 %)	3.46	5.66	3.23	7.66
Varieties				
V ₁ : JAUW 672	21.60	45.57	75.27	88.95
V ₂ : DBW 303	25.90	49.29	80.08	94.31
SEm (±)	1.07	0.41	1.06	1.30
CD (5 %)	3.23	1.24	3.18	3.90
Plant growth regulator				
T ₁ : Control	22.26	48.65	78.73	93.15
T ₂ : Paclobutrazol at 50 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	23.64	43.45	73.52	86.60
T ₃ : Kinetin at 10 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	25.35	50.18	80.79	95.14
SEm (±)	0.88	1.44	1.90	1.87
CD (5 %)	NS	4.34	5.71	5.62
Interaction				
Sowing date × varieties	NS	NS	NS	NS
Sowing date × plant growth regulator	NS	NS	NS	NS
Varieties × plant growth regulator	NS	NS	NS	NS
Sowing date × varieties × plant growth regulator	NS	NS	NS	NS

DAS: Days after sowing, NS: Not significant.

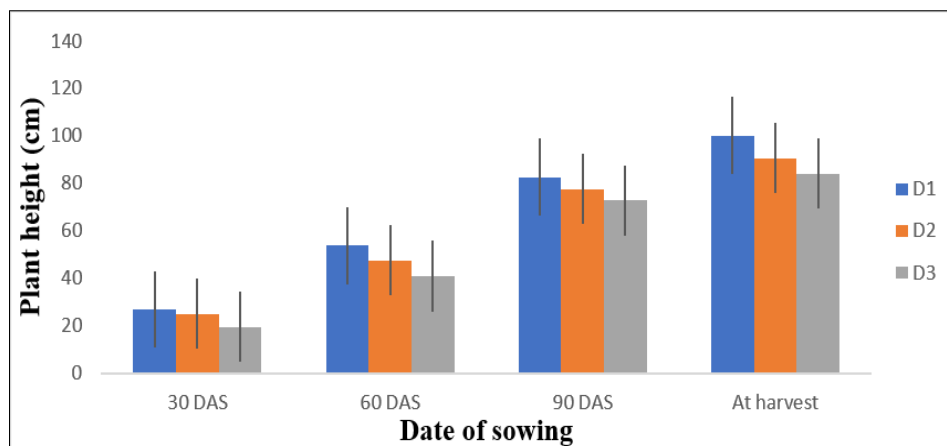


Fig. 1. Effect of sowing dates on plant height (cm) of wheat crop.

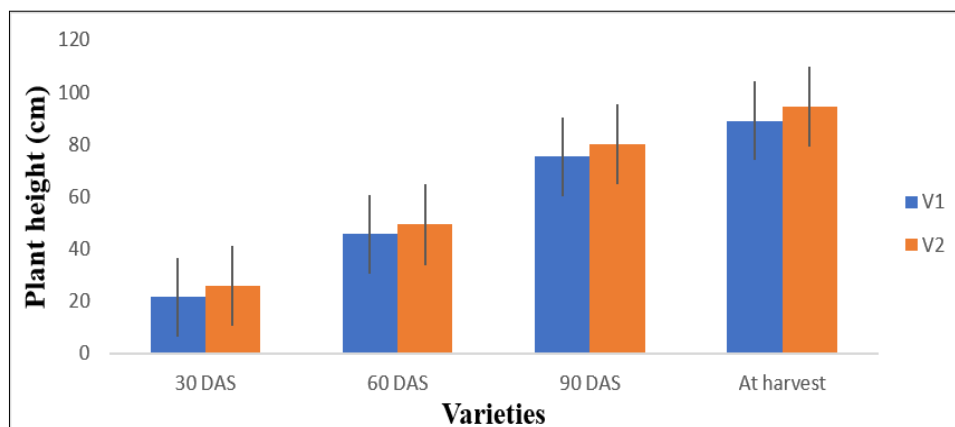


Fig. 2. Effect of varieties on plant height (cm) of wheat crop.

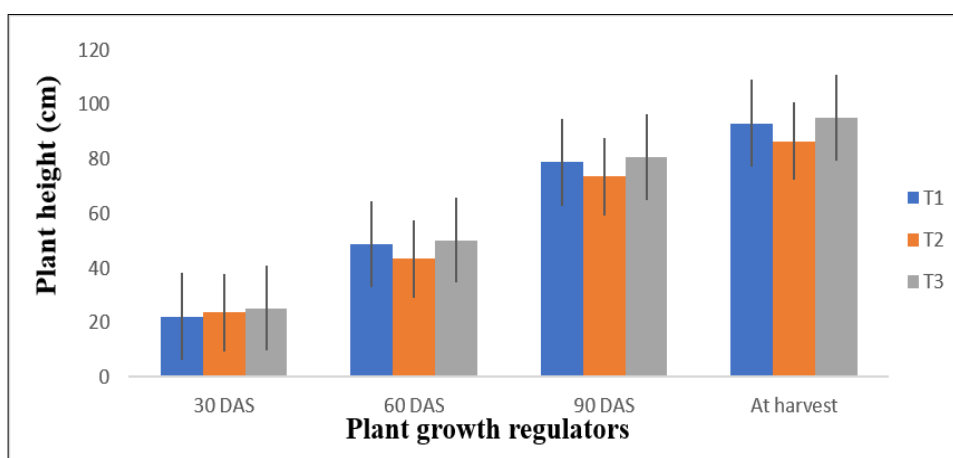


Fig. 3. Effect of plant growth regulators on plant height (cm) of wheat crop.

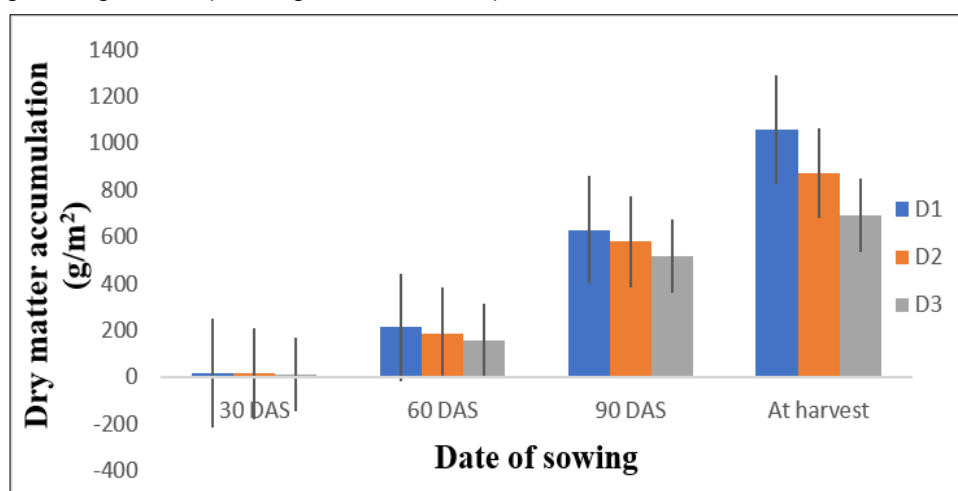


Fig. 4. Effect of sowing dates on periodical dry matter accumulation (g/m²) of wheat crop.

Table 2. Effect of sowing dates and plant growth regulators on dry matter accumulation (g/m²) of wheat varieties

Treatment details	30 DAS	60 DAS	90 DAS	At harvest
Date of sowing				
D ₁ : 25 th November	16.06	212.24	628.79	1056.42
D ₂ : 15 th December	14.65	187.85	578.50	870.38
D ₃ : 5 th January	11.14	154.86	517.66	688.85
SEm (±)	1.16	4.50	8.07	15.18
CD (5 %)	3.49	13.51	24.23	45.54
Varieties				
V ₁ : JAUW 672	12.94	177.74	565.85	801.83
V ₂ : DBW 303	14.96	192.23	584.12	941.94
SEm (±)	1.42	1.24	1.93	27.80
CD (5 %)	NS	3.73	5.79	83.40
Plant growth regulator				
T ₁ : Control	12.32	175.70	563.65	812.99
T ₂ : Paclobutrazol at 50 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	15.66	198.27	586.82	949.57
T ₃ : Kinetin at 10 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	13.87	180.97	574.48	853.10
SEm (±)	0.96	2.42	2.80	8.53
CD (5 %)	NS	7.28	8.41	25.59
Interaction				
Sowing date × varieties	NS	NS	NS	NS
Sowing date × plant growth regulator	NS	NS	NS	NS
Varieties × plant growth regulator	NS	NS	NS	NS
Sowing date × varieties × plant growth regulator	NS	NS	NS	NS

DAS: Days after sowing, NS: Not significant.

higher dry matter was recorded by variety DBW 303 with respective values of significantly, respectively (Fig. 5).

Plant growth regulators differed significantly in relation to dry matter accumulation at all growth stages. At 30 DAS, the highest dry matter was recorded in paclobutrazol, which was non-significantly higher than kinetin and control. However, at 60, 90 DAS and at harvest, the highest dry matter was recorded by paclobutrazol, respectively, which was significantly higher than kinetin and control, respectively (Fig. 6). The interaction effects of dates of sowing, varieties and plant growth regulators were non-significant during all the stages.

Soil plant analysis development (SPAD)

The soil plant analysis development (SPAD) meter reading of wheat crop was recorded at 30, 60 and 90 DAS to get an idea of chlorophyll content in leaves and presented in Table 3. The data indicated that SPAD reading was higher at 60 DAS as compared to 90 DAS. At 30 DAS, the highest SPAD value was recorded with crop sown on 25th November (39.96), which was significantly higher than 15th December (35.70) and 5th January (32.07). A similar trend was followed at 60 and 90 DAS (Fig. 7). Varieties differed significantly in relation to the SPAD reading at all growth stages (Table 3). At 30 DAS, the highest SPAD reading was recorded in the variety DBW 303 (37.17), which was significantly higher than JAUW 672 (34.65). Similar

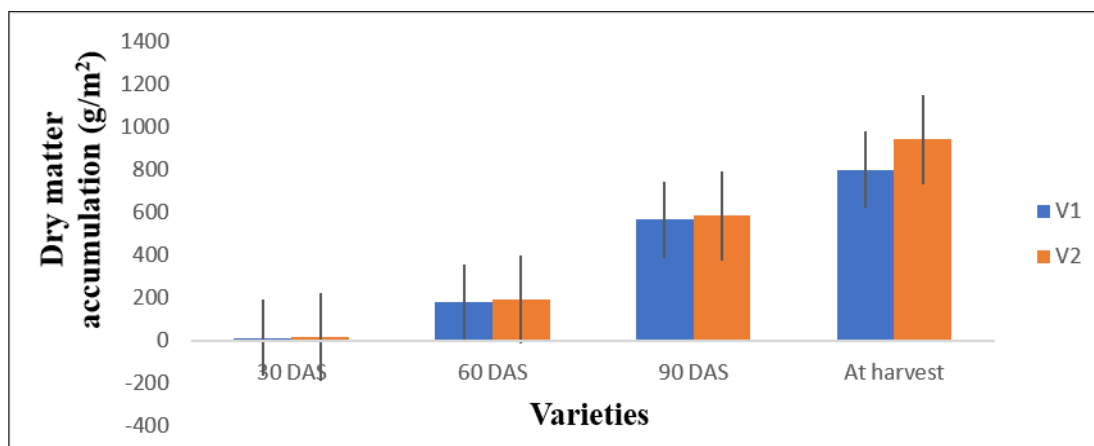
trends were noted with the variety DBW 303 at 60 and 90 DAS, having SPAD values of 39.68 and 34.86, respectively (Fig. 8).

Plant growth regulators differed significantly in relation to SPAD reading at all growth stages. Although at 30 DAS, the nonsignificant highest chlorophyll content was recorded by paclobutrazol (36.64). However, at 60 and 90 DAS the highest SPAD reading was recorded by paclobutrazol (39.74 and 35.03, respectively) which was significantly higher than kinetin (38.40 and 33.42, respectively) and control (37.33 and 31.90, respectively) (Fig. 9). The interaction effects of dates of sowing, varieties and plant growth regulators were non-significant during all the stages.

Leaf area index (LAI)

Among the sowing dates, the highest LAI was recorded by the crop sown on 25th November (0.53), which was statistically at par with 15th December (0.45) and significantly higher than 5th January (0.28) at 30 DAS (Table 4). However, at 60 DAS, the highest LAI was recorded by the crop sown under 25th November (2.59), which was significantly higher than 15th December (2.25) and 5th January (1.59). Similar trends were observed at 90 DAS and at harvest (Fig. 10).

Wheat varieties also significantly influenced LAI (Table 4). The highest LAI was recorded in DBW 303 (0.45), which was non significantly higher than JAUW 672 (0.39) at 30 DAS. However, at

**Fig. 5.** Effect of varieties on periodical dry matter accumulation (g/m²) of wheat crop.

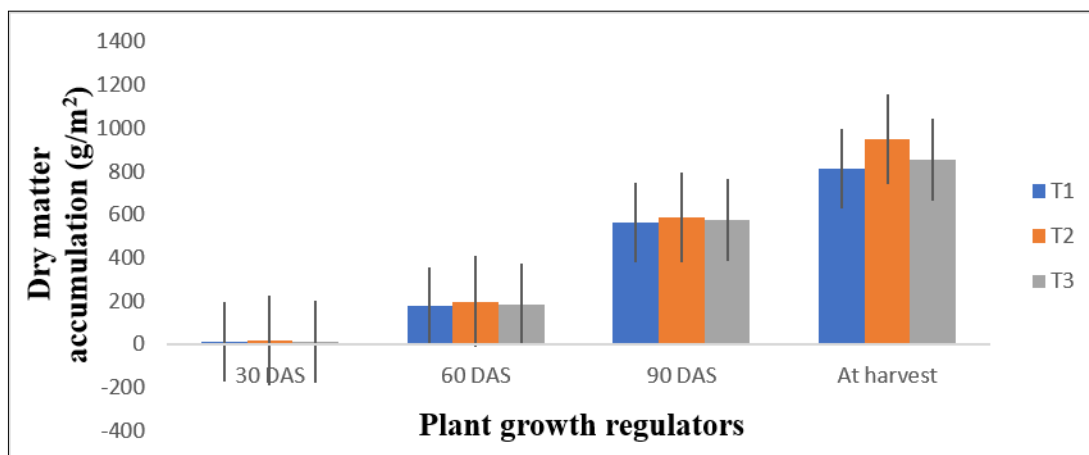


Fig. 6. Effect of plant growth regulators on periodical dry matter accumulation (g/m^2) of wheat crop.

Table 3. Effect of sowing dates and plant growth regulators on soil plant analysis development of wheat varieties

Treatments details	30 DAS	60 DAS	90 DAS
Date of sowing			
D ₁ : 25 th November	39.96	42.48	37.40
D ₂ : 15 th December	35.70	38.87	33.73
D ₃ : 5 th January	32.07	34.12	29.22
SEm ($\pm$)	0.72	0.46	0.78
CD (5 %)	2.17	1.38	2.36
Varieties			
V ₁ : JAUW 672	34.65	37.31	32.04
V ₂ : DBW 303	37.17	39.68	34.86
SEm ($\pm$)	0.26	0.32	0.32
CD (5 %)	0.78	0.98	0.98
Plant growth regulator			
T ₁ : Control	34.90	37.33	31.90
T ₂ : Paclobutrazol at 50 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	36.64	39.74	35.03
T ₃ : Kinetin at 10 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	36.19	38.40	33.42
SEm ($\pm$)	0.53	0.38	0.47
CD (5 %)	NS	1.14	1.42
Interaction			
Sowing date $\times$ varieties	NS	NS	NS
Sowing date $\times$ plant growth regulator	NS	NS	NS
Varieties $\times$ plant growth regulator	NS	NS	NS
Sowing date $\times$ varieties $\times$ plant growth regulator	NS	NS	NS

DAS: Days after sowing, NS: Not significant.

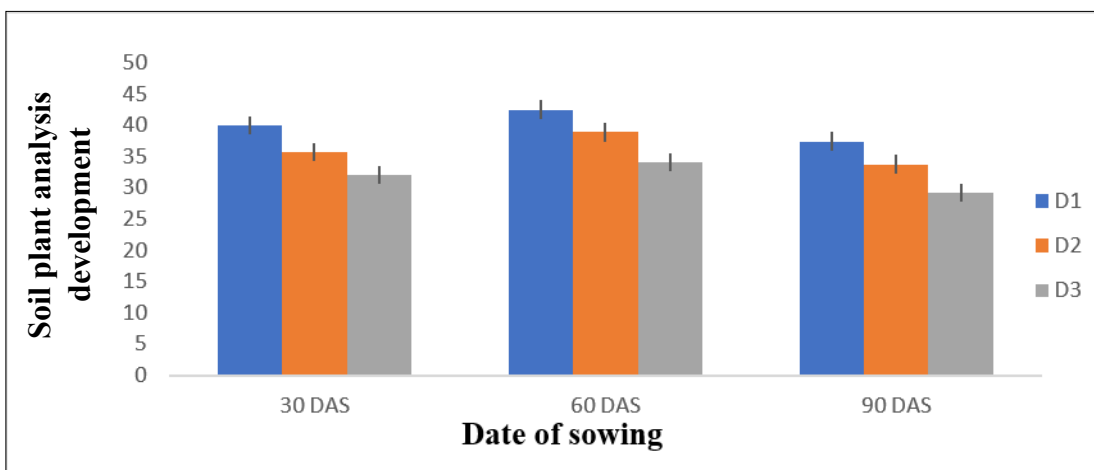


Fig. 7. Effect of sowing dates on soil plant analysis development of wheat crop.

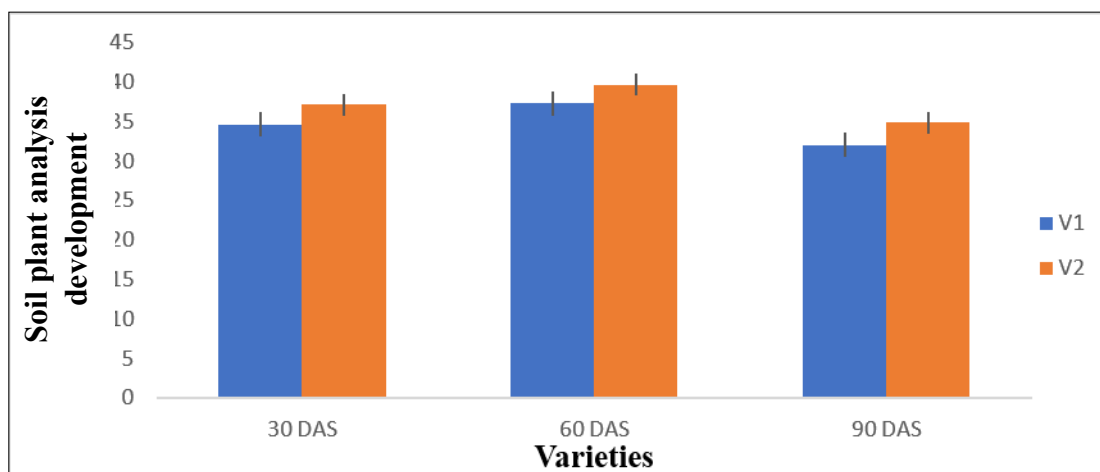


Fig. 8. Effect of varieties on soil plant analysis development of wheat crop.

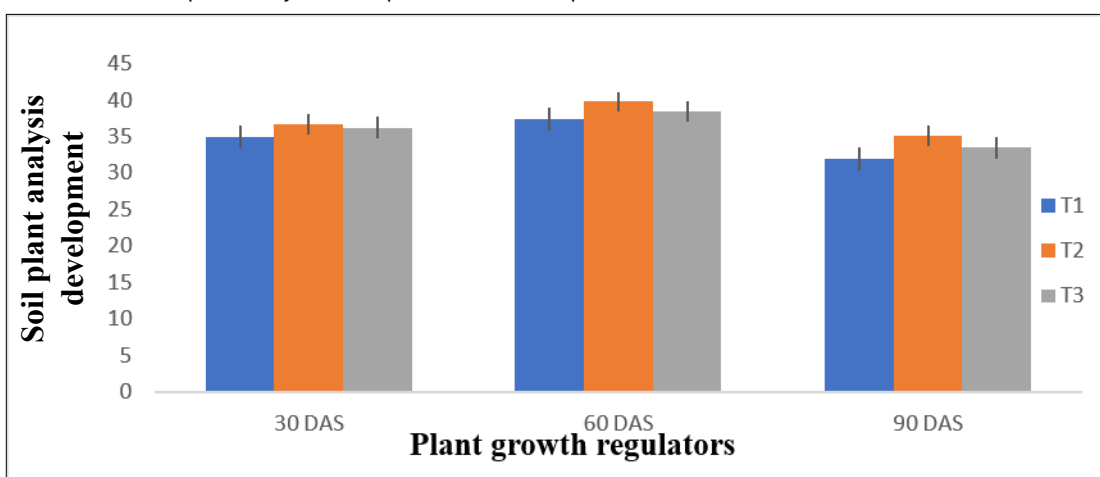


Fig. 9. Effect of plant growth regulators on soil plant analysis development of wheat crop.

Table 4. Effect of sowing dates and plant growth regulators on leaf area index of wheat varieties

Treatments details	30 DAS	60 DAS	90 DAS	Harvest
Date of sowing				
D ₁ : 25 th November	0.53	2.59	3.91	2.69
D ₂ : 15 th December	0.45	2.25	3.82	2.53
D ₃ : 5 th January	0.28	1.59	2.92	2.05
SEm (±)	0.03	0.06	0.04	0.04
CD (5 %)	0.11	0.18	0.12	0.13
Varieties				
V ₁ : JAUW 672	0.39	2.07	3.49	2.34
V ₂ : DBW 303	0.45	2.22	3.61	2.51
SEm (±)	0.02	0.02	0.01	0.03
CD (5 %)	NS	0.07	0.03	0.09
Plant growth regulator				
T ₁ : Control	0.41	2.09	3.48	2.34
T ₂ : Paclobutrazol at 50 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	0.42	2.21	3.63	2.53
T ₃ : Kinetin at 10 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	0.42	2.13	3.54	2.40
SEm (±)	0.02	0.02	0.02	0.03
CD (5 %)	NS	0.06	0.07	0.10
Interaction				
Sowing date × Varieties	NS	NS	NS	NS
Sowing date × Plant growth regulator	NS	NS	NS	NS
Varieties × Plant growth regulator	NS	NS	NS	NS
Sowing date × Varieties × Plant growth regulator	NS	NS	NS	NS

DAS: Days after sowing, NS: Not significant.

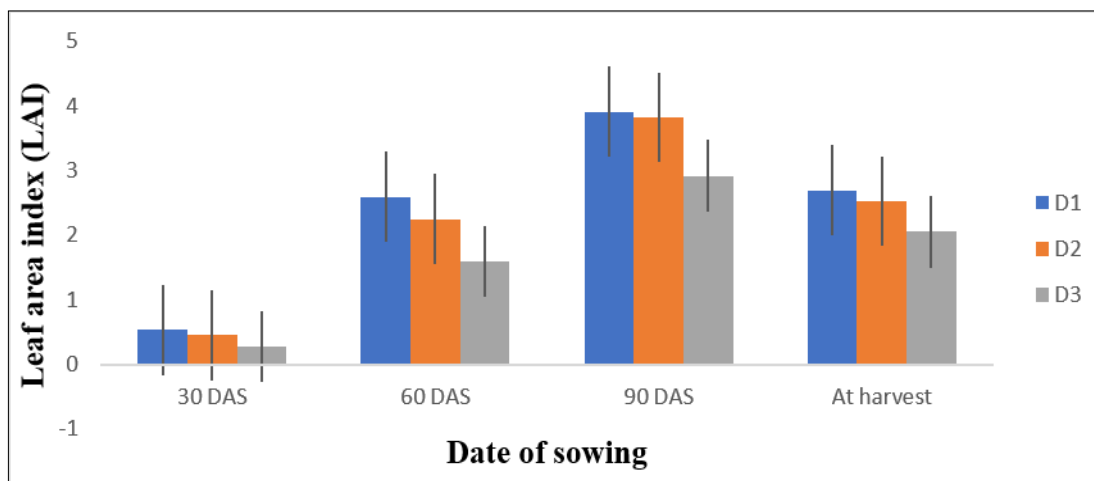


Fig. 10. Effect of sowing dates on periodical leaf area index of wheat crop.

60 DAS, the highest LAI was recorded in DBW 303 (2.22), which was significantly higher than JAUW 672 (2.07). Similar results were found at 90 DAS and at harvest, where DBW 303 (3.61 and 2.51, respectively) recorded significantly higher LAI than JAUW 672 (3.49 and 2.34, respectively) (Fig. 11).

Plant growth regulators differed significantly in relation to LAI at all growth stages. Although at 30 DAS, numerically the highest LAI was recorded by paclobutrazol (0.42) and kinetin (0.42) than the control (0.41). Although at 60, 90 DAS and at harvest the highest LAI was recorded by paclobutrazol (2.21, 3.63 and 2.53) which was significantly higher than kinetin (2.13, 3.54 and 2.40, respectively) and

control (2.09, 3.48 and 2.34, respectively) (Fig. 12). The interaction effects of dates of sowing, varieties and plant growth regulators were non-significant during all the stages.

Phenological studies

Among the different sowing dates, the crop sown on 25th November took a higher number of days to complete the different phenophases, viz., 86 days were taken for the booting, 99 days for heading, 108 days for flowering, 128 days for milking, 142 days for dough and 152 days for physiological maturity. Whereas the respective days taken for 15th December were 82, 95, 105, 119, 129 and 137, respectively (Table 5). Whereas 5th January took the least

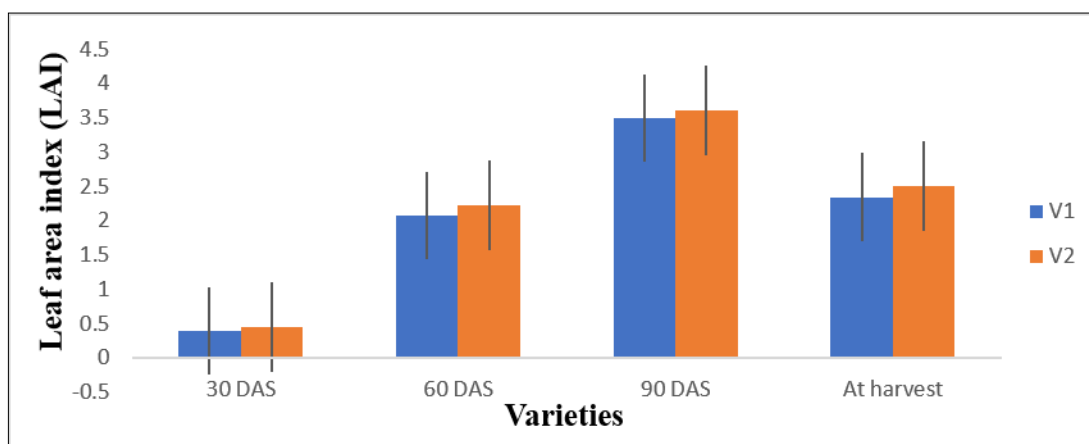


Fig. 11. Effect of varieties on periodical leaf area index (LAI) of wheat crop.

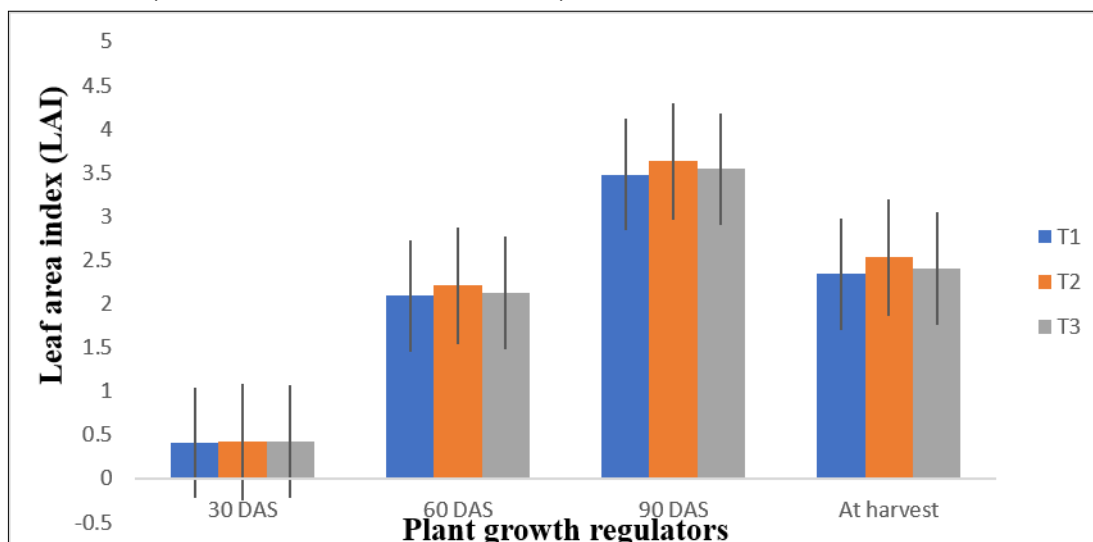


Fig. 12. Effect of plant growth regulators on periodical leaf area index (LAI) of wheat crop.

number of days for the completion of different phenophases, with corresponding values being 77 days for booting, 88 days for heading, 99 days for flowering, 110 days for milking, 117 days for dough and 125 days for physiological maturity, respectively (Fig. 13).

Among the varieties the highest number of days was taken by DBW 303 at different phenophases viz., booting (84 days), heading (96 days), flowering (108 days), milking (121 days), dough (132 days) and physiological maturity (147 days) as compared to JAUW 672 which have complete the booting at 80 days, heading at 93 days, flowering at 104 days, milking at 118 days, dough at 128 days and physiological maturity at 143 days (Fig. 14). As shown in Table 5, the plant growth regulators had significant effect on wheat crop to achieve different phenophases. Among the plant growth regulators paclobutrazol was taken highest number of days for completion of

phenophases viz., booting (83 days), heading (97 days), flowering (107 days), milking (122 days), dough (131 days) and physiological maturity (146 days) as compared to kinetin with corresponding days taken for booting was 82 days, heading-95 days, flowering-106 days, milking-120 days, dough-130 days and physiological maturity-145 days whereas control treatments took least days with corresponding values were 80 days, 92 days, 103 days, 117 days, 126 days and 143 days, respectively (Fig. 15). The interaction effects of dates of sowing, varieties and plant growth regulators were non-significant during all the stages.

Yields and harvest index

Yield parameters such as effective tillers, spike length, grains per spike and 1000 grain weight were significantly higher in

Table 5. Effect of sowing dates and plant growth regulators on phenological studies (days) of wheat varieties

Treatments	Booting	Heading	Flowering	Milking	Dough	Physiological maturity
Days						
Date of sowing						
D ₁ : 25 th November	86	99	108	128	142	152
D ₂ : 15 th December	82	95	105	119	129	137
D ₃ : 5 th January	77	88	99	110	117	125
Varieties						
V ₁ : JAUW 672	80	93	104	118	128	143
V ₂ : DBW 303	84	96	108	121	132	147
Plant growth regulator						
T ₁ : Control	80	92	103	117	126	143
T ₂ : Paclobutrazol at 50 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	83	97	107	122	131	146
T ₃ : Kinetin at 10 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	82	95	106	120	130	145

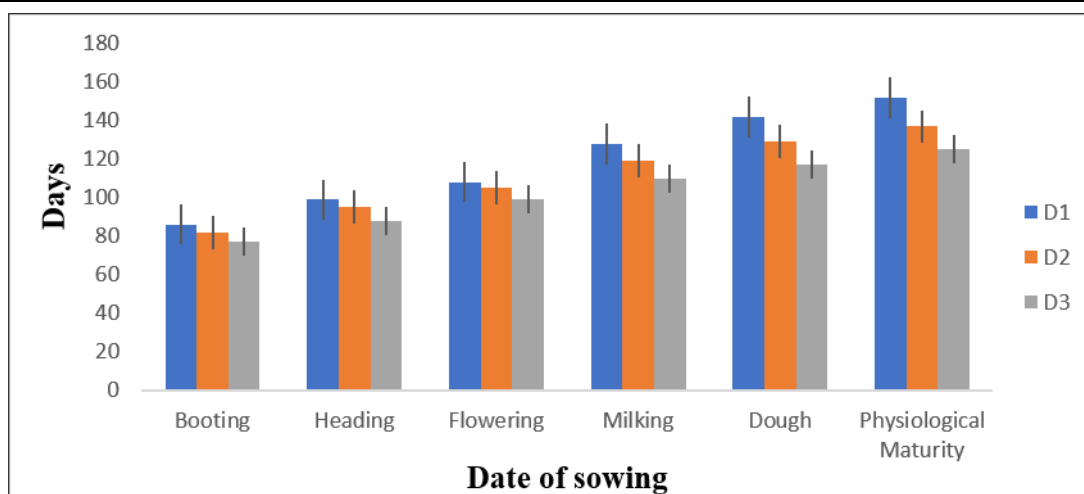


Fig. 13. Effect of sowing dates on phenological studies of wheat varieties.

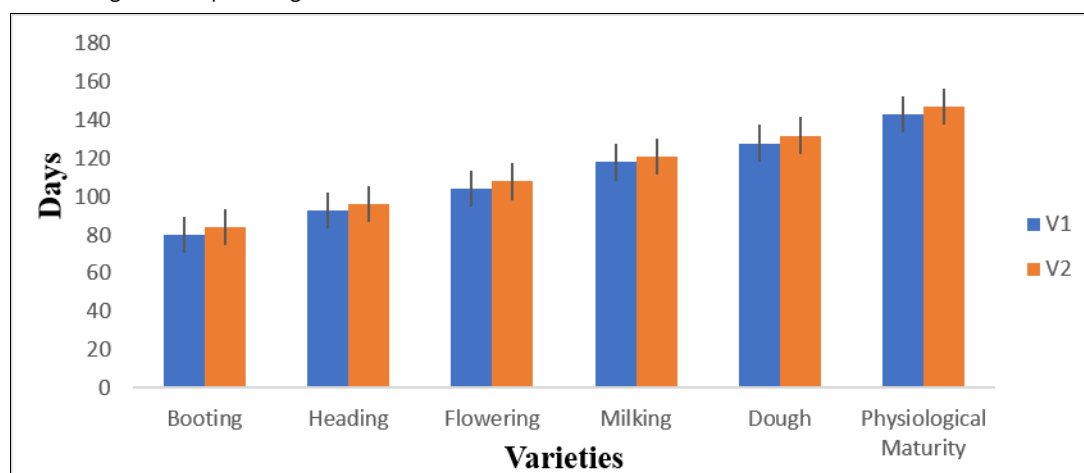


Fig. 14. Effect of varieties on phenological studies of wheat varieties.

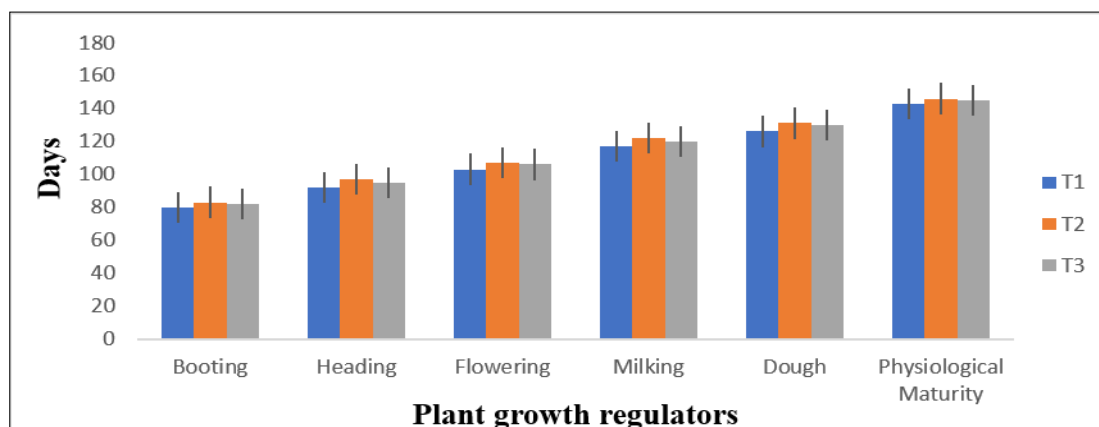


Fig. 15. Effect of plant growth regulators on phenological studies of wheat varieties.

25th November sowing as shown in Tables 6 and 7. Variety DBW 303 showed better performance in all yield traits than JAUW 672. Among regulators, paclobutrazol led to the highest values across these parameters. Significant interaction between date and variety was observed in tiller count and yield, as given in Fig. 16.

Grain yield

Among the sowing dates, the highest grain yield was recorded for the crop sown on 25th November (4793.23 kg/ha), which was significantly higher than the crop sown on 15th December (3831.88 kg/ha) and the crop sown on 5th January (2937.30 kg/ha), as shown in Table 8. The crop sown on 25th November increased grain yield to the tune of 25.08 % and 63.18 % over 15th December and 5th January, respectively (Fig. 17). Among the varieties, the highest grain yield was recorded in DBW 303 (4133.58 kg/ha), which was significantly higher than JAUW 672 (3574.69 kg/ha). The variety DBW 303 produced 15.63 % higher grain yield over variety JAUW 672 (Fig. 18). Among the plant growth regulators, the highest grain yield was recorded in paclobutrazol (4177.76 kg/ha), which was significantly higher than kinetin (3811.81 kg/ha) and control (3625.93 kg/ha). The plant growth regulator paclobutrazol hiked the grain yield to the tune of 9.6 % and 16.93 % over kinetin and control (Fig. 19). However, the interaction effect of dates of sowing and variety was found to be significant, as presented in Table 9. Variety DBW 303 (5350.09 kg/ha and 4125.15 kg/ha) performed better than JAUW 672 (4236.36 kg/ha and 3538.61 kg/ha) when sown on

25th November and 15th November. However, DBW 303 and JAUW 672 performed equally when sown on 5th January (Fig. 20).

Straw yield

Data recorded with respect to straw yield (kg/ha) was affected significantly by sowing dates, varieties and plant growth regulators as presented in Table 8. Among the sowing dates, the highest straw yield was recorded for the crop sown under 25th November (5653.09 kg/ha), which was significantly higher than the crop sown under 15th December (4902.73 kg/ha) and the crop sown under 5th January (3644.49 kg/ha), as shown in Table 8. The crop sown on 25th November increased straw yield to the tune of 18.49 % and 47.92 % over 15th December and 5th January (Fig. 17). Whereas, among the varieties, the highest straw yield was recorded in DBW 303 (4998.88 kg/ha), which was significantly higher than variety JAUW 672 (4467.99 kg/ha). The variety DBW 303 increased straw yield to the tune of 11.55 % over variety JAUW 672 (Fig. 18). However, among the plant growth regulators, the highest straw yield was recorded in paclobutrazol (5188.53 kg/ha), which was significantly higher than kinetin (4597.51 kg/ha) and control (4414.27 kg/ha). However, in plant growth regulators, paclobutrazol increased straw yield to the tune of 12.50 % and 17.04 % over kinetin and control (Fig. 19).

However, the interaction effect of dates of sowing and variety was found to be significant for straw yield, as presented in Table 10. Variety DBW 303 (6249.36 kg/ha and 5116.69 kg/ha)

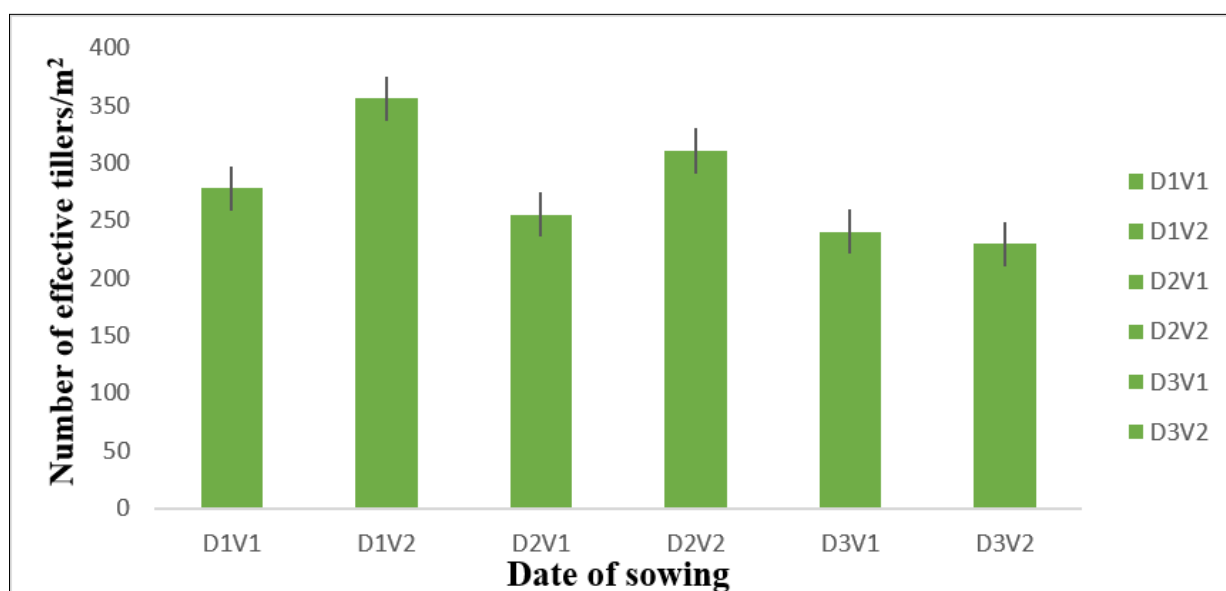
Table 6. Effect of sowing dates and plant growth regulators on yield attributes of wheat varieties

Treatments	Number of effective tillers/m ²	Spike length (cm)	Number of grain per spike	1000 grain weight (g)
Date of sowing				
D ₁ : 25 th November	316.98	11.30	42.58	39.20
D ₂ : 15 th December	283.01	10.95	40.59	38.43
D ₃ : 5 th January	234.97	8.36	37.43	37.02
SEm (±)	5.27	0.27	0.61	0.43
CD (5 %)	13.00	0.82	1.83	1.30
Varieties				
V ₁ : JAUW 672	257.92	9.89	39.30	36.82
V ₂ : DBW 303	298.72	10.52	41.10	39.60
SEm (±)	6.78	0.15	0.37	0.84
CD (5 %)	13.95	0.45	1.13	2.52
Plant growth regulator				
T ₁ : Control	266.45	9.70	38.39	37.18
T ₂ : Paclobutrazol at 50 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	291.50	10.73	41.74	39.01
T ₃ : Kinetin at 10 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	277.01	10.18	40.46	38.46
SEm (±)	2.87	0.17	0.32	0.78
CD (5 %)	6.88	0.53	0.97	NS
Interaction				
Sowing date × Varieties	24.16	NS	NS	NS
Sowing date × Plant growth regulator	NS	NS	NS	NS
Varieties × Plant growth regulator	NS	NS	NS	NS
Sowing date × Varieties × Plant growth regulator	NS	NS	NS	NS

Table 7. Interaction effect of date of sowing and varieties on number of effective tillers per/m² of wheat

Treatments	V ₁	V ₂	Mean D
D ₁	277.83	356.13	316.98
D ₂	255.46	310.56	283.01
D ₃	240.45	229.49	234.97
Mean V	257.92	298.72	
SEm (±)		8.05	
CD (5 %)		24.16	
CD (5 %)		11.12	

D₁: 25th November; D₂: 15th December; D₃: 5th January; V₁: JAUW 672; V₂: DBW 303.

**Fig. 16.** Interaction effect of date of sowing and varieties on number of effective tillers/m² of wheat.**Table 8.** Effect of sowing dates and plant growth regulators on yield of wheat varieties

Treatments	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)
Date of sowing			
D ₁ : 25 th November	4793.23	5653.09	45.40
D ₂ : 15 th December	3831.88	4902.73	43.90
D ₃ : 5 th January	2937.30	3644.49	42.89
SEm (±)	23.09	27.44	0.27
CD (5 %)	69.29	82.33	0.83
Varieties			
V ₁ : JAUW 672	3574.69	4467.99	43.92
V ₂ : DBW 303	4133.58	4998.88	44.21
SEm (±)	15.86	18.59	0.12
CD (5 %)	47.59	55.77	NS
Plant growth regulator			
T ₁ : Control	3572.84	4414.27	43.86
T ₂ : Paclobutrazol at 50 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	4177.76	5188.53	43.87
T ₃ : Kinetin at 10 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	3811.81	4597.51	44.46
SEm (±)	22.49	38.92	0.23
CD (5 %)	67.49	116.78	NS
Interaction			
Sowing date × varieties	82.43	96.60	NS
Sowing date × plant growth regulator	NS	NS	NS
Varieties × plant growth regulator	NS	NS	NS
Sowing date × varieties × plant growth regulator	NS	NS	NS

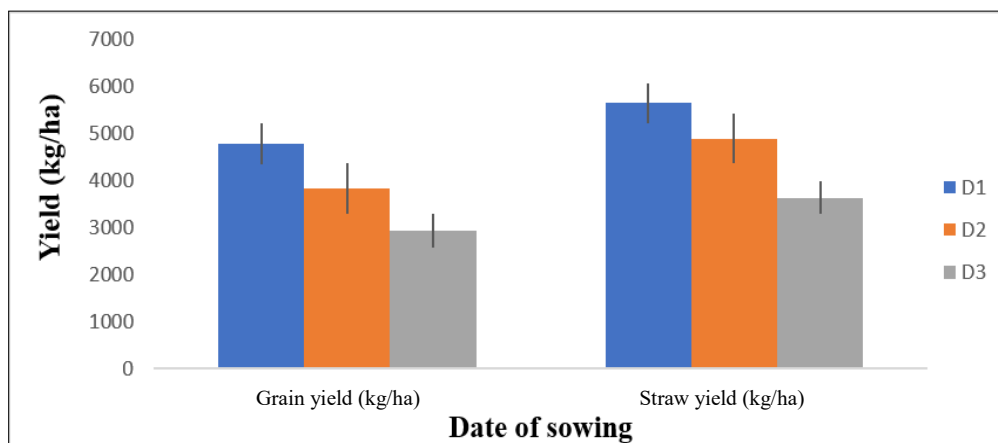


Fig. 17. Effect of sowing dates on yield (kg/ha) of wheat varieties.

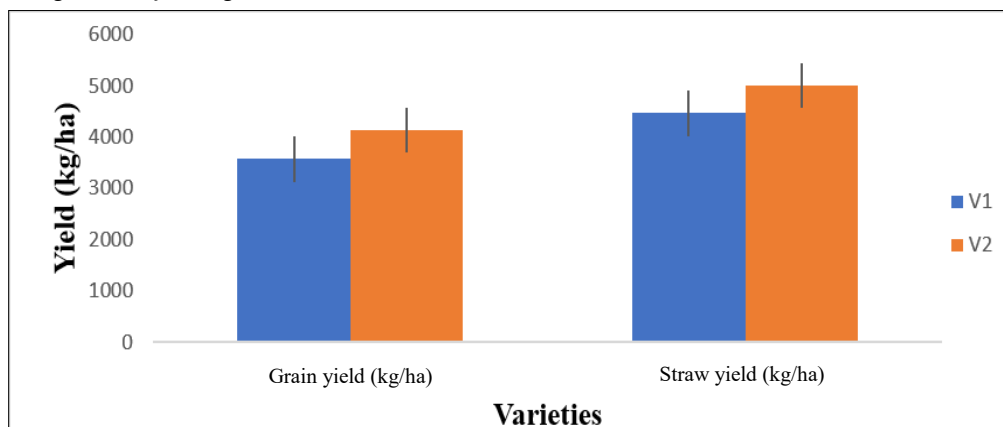


Fig. 18. Effect of varieties on yield (kg/ha) of wheat varieties.

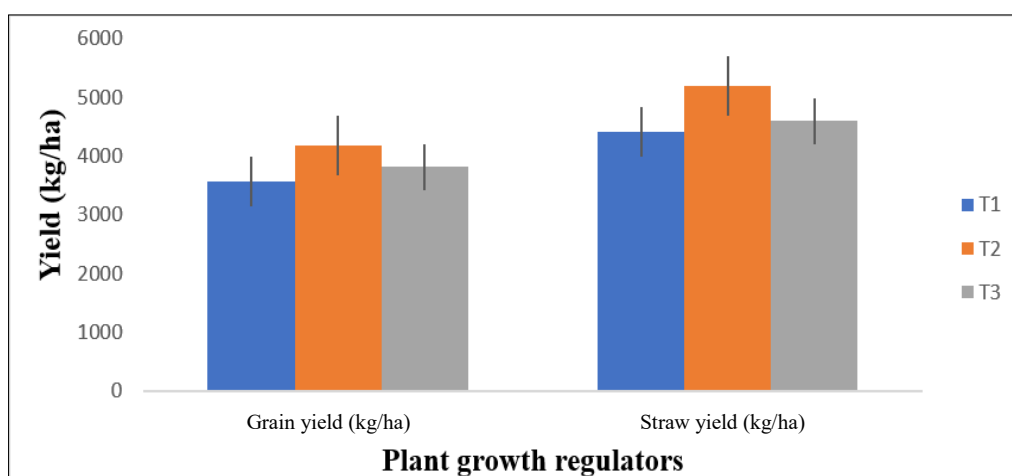


Fig. 19. Effect of plant growth regulators on yield (kg/ha) of wheat varieties.

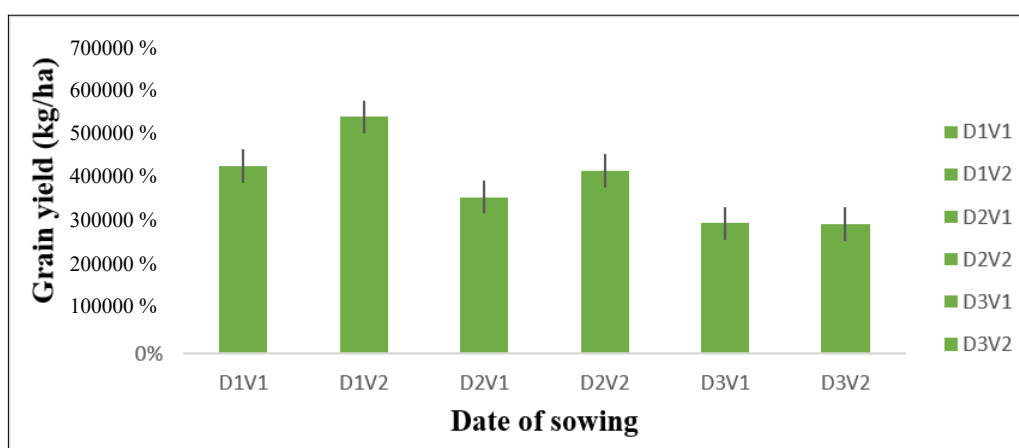


Fig. 20. Interaction effect of date of sowing and varieties on grain yield (kg/ha) of wheat.

Table 9. Interaction effect of date of sowing and varieties on grain yield (kg/ha) of wheat

Treatments	V ₁	V ₂	Mean D
D ₁	4236.36	5350.09	4793.23
D ₂	3538.61	4125.15	3831.88
D ₃	2949.10	2925.50	2937.30
Mean V	3574.69	4133.58	
SEm (±)		27.47	
CD (5 %)		82.43	
CD (5 %)		41.38	

D₁: 25th November; D₂: 15th December; D₃: 5th January; V₁: JAUW 672; V₂: DBW 303.

performed better than JAUW 672 (5056.82 kg/ha and 4688.77 kg/ha) when sown on 25th November and 15th November. However, DBW 303 and JAUW 672 performed equally when sown on 5th January (Fig. 21).

Harvest index (HI)

Data recorded with respect to HI were significantly affected by sowing dates, but non-significant effects were realised with varieties and plant growth regulators, as presented in Table 8. Among the sowing dates, the highest HI was recorded for the crop sown on 25th November (45.40 %), which was significantly higher than 5th January (43.90 %) and 15th December (42.89 %). However, among the varieties, the numerical value of HI was recorded by variety DBW 303 (44.21 %), compared to variety JAUW 672 (43.92 %). Similarly, among the plant growth regulators, the numerically higher HI was recorded by paclobutrazol (44.46 %) than kinetin (43.87 %) and control (43.86 %). The interaction effects of dates of sowing, varieties and plant growth regulators were non-significant with respect to HI.

Soil characteristics

The soil properties like pH, electrical conductivity (EC), organic carbon and nutrient availability showed a non-significant change due to treatments at harvest. The higher values for organic carbon and available nutrients were seen in controlled treatments and on the date of sowing, 5th January. This suggests that short-term agronomic treatments have minimal impact on soil properties, as shown in Table 11.

Table 10. Interaction effect of date of sowing and varieties on straw yield (kg/ha) of wheat

Treatments	V ₁	V ₂	Mean D
D ₁	5056.82	6249.36	5653.08
D ₂	4688.77	5116.69	4902.73
D ₃	3658.39	3630.53	3644.49
Mean V	4467.99	4998.88	
SEm (±)		32.20	
CD (5 %)		96.60	
CD (5 %)		45.86	

D₁: 25th November; D₂: 15th December; D₃: 5th January; V₁: JAUW 672; V₂: DBW 303.

Economics

The economics of sowing dates, varieties and plant growth regulators was worked out and is depicted in Table 12. Among sowing dates, 25th November incurred maximum gross returns (₹153154.96/ha), net returns (₹121919.67/ha) and B:C ratio (3.93) as compared to 15th December with corresponding values of ₹124239.81/ha, ₹93004.52/ha and 2.99 and 5th January having values of ₹96414.31/ha, ₹65179.02/ha and 2.09, respectively. The crop sown on 25th November increased net returns to the tune of ₹28915.15/ha and ₹56740.65/ha over late sowing (15th December) and very late sowing (5th January), respectively.

Among the varieties, the variety DBW 303 gave higher gross returns (₹133028.10/ha), net returns (₹103056.98/ha) and B:C ratio (3.44) as compared to variety JAUW672 (₹116177.96 gross returns/ha), (₹87203.72 net returns/ha) and (2.57 B:C ratio), respectively. The variety DBW 303 incurred ₹15853.26/ha more net returns over the variety JAUW 672. Among the plant growth regulators, paclobutrazol gave higher gross returns (₹135393.89/ha), net returns (₹102681.10/ha) and B:C ratio (3.15) followed by kinetin with gross returns of ₹122656.81/ha, net returns of ₹92126.52/ha and B:C ratio of 3.04 and control (₹115758.38 gross returns/ha, ₹90583.42 net returns/ha and 2.82 B:C ratio, respectively). However, in plant growth regulators, paclobutrazol increased net returns to the tune of ₹10554.58/ha and ₹12097.68/ha over kinetin and control.

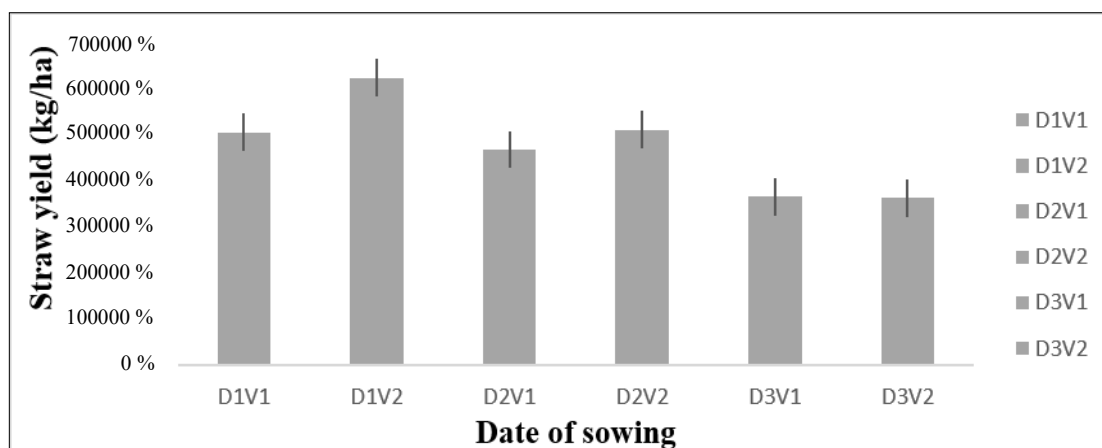
**Fig. 21.** Interaction effect of date of sowing and varieties on straw yield (kg/ha) of wheat.

Table 11. Effect of different treatments on soil properties after harvest of wheat crop

Treatments	pH	EC (dS/m)	Organic carbon (g/kg)	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)
Date of sowing						
D ₁ : 25 th November	7.40	0.20	0.40	228.33	14.17	126.61
D ₂ : 15 th December	7.41	0.21	0.43	236.61	14.28	126.87
D ₃ : 5 th January	7.46	0.22	0.41	240.50	14.53	127.88
SEm (±)	0.02	0.01	0.01	2.37	0.10	0.28
CD (5 %)	NS	NS	NS	NS	NS	NS
Varieties						
V ₁ : JAUW 672	7.42	0.22	0.41	237.43	14.39	127.26
V ₂ : DBW 303	7.41	0.21	0.43	232.87	14.27	126.98
SEm (±)	0.01	0.01	0.00	1.44	0.08	0.42
CD (5 %)	NS	NS	NS	NS	NS	NS
Plant growth regulator						
T ₁ : Control	7.41	0.21	0.43	238.52	14.40	128.09
T ₂ : Paclobutrazol at 50 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	7.43	0.22	0.41	232.43	14.25	126.30
T ₃ : Kinetin at 10 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	7.42	0.21	0.42	234.50	14.33	126.97
SEm (±)	0.01	0.02	0.03	1.24	0.03	0.21
CD (5 %)	NS	NS	NS	NS	NS	NS
Interaction						
Sowing date × Varieties	7.5	0.24	0.43	245.21	14.84	129.03

EC: Electrical conductivity; NS: Not significant.

Table 12. Effect of different treatments on economics of wheat crop

Treatments	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B : C
Date of sowing				
D ₁ : 25 th November	31235.29	153154.96	121919.67	3.93
D ₂ : 15 th December	31235.29	124239.81	93004.52	2.99
D ₃ : 5 th January	31235.29	96414.31	65179.02	2.09
Varieties				
V ₁ : JAUW 672	28974.24	116177.96	87203.72	2.57
V ₂ : DBW 303	29971.12	133028.10	103056.98	3.44
Plant growth regulator				
T ₁ : Control	25174.96	115758.38	90583.42	2.82
T ₂ : Paclobutrazol at 50 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	32712.79	135393.89	102681.10	3.15
T ₃ : Kinetin at 10 ppm + <i>Bacillus subtilis</i> at 5 g/kg seed	30530.29	122656.81	92126.52	3.04

Discussion

Plant height

Plant height increased significantly until 90 DAS, with no notable difference afterwards. Early-sown wheat (25th November) exhibited the tallest plants, benefiting from optimal temperature and solar radiation. The variety DBW 303 achieved greater height than JAUW 672 due to genetic advantages (13, 14). Kinetin boosted height, while paclobutrazol reduced it (15).

Dry matter accumulation

Dry matter was highest in early-sown crops, supported by favourable conditions and efficient plant growth regulator usage. DBW 303 outperformed JAUW 672, attributed to better tillering and LAI (16). Paclobutrazol enhanced dry matter accumulation via improved photosynthesis and canopy development (17).

Soil plant analysis development

Higher SPAD values were recorded for early sowing (25th November) and DBW 303, owing to better nitrogen uptake and genetic factors. Paclobutrazol enhanced SPAD through increased chlorophyll biosynthesis and photosynthetic pigment accumulation (18).

Leaf area index

Leaf area index peaked at 90 DAS in early-sown crops and declined thereafter. Early sowing led to higher LAI due to extended vegetative growth and tillering (19). DBW 303 maintained superior LAI due to its genetic potential. Paclobutrazol resulted in the highest LAI, aiding

photosynthesis, which aligned with findings from previous studies (20).

Phenological studies

Phenophases such as booting, heading, flowering and physiological maturity were delayed under early sowing due to prolonged vegetative growth. In contrast, late sowing accelerated phenological development, shortening the grain filling period and impacting productivity. DBW 303 took more days to complete phenophases, which translated into higher grain filling duration and yield. Paclobutrazol delayed phenology due to delayed senescence, enhancing reproductive duration and synchronising development stages more effectively.

Yield attributes and yield

Yield-contributing traits such as effective tillers per m², spike length, number of grains per spike and 1000-grain weight were significantly higher in early-sown crops. Among varieties, DBW 303 consistently recorded superior performance in all yield attributes. The PGR paclobutrazol also significantly enhanced these traits by modulating assimilate partitioning from source to sink, resulting in higher test weight and better grain setting.

Grain and straw yield were highest in 25th November sowing, driven by longer reproductive phases, favourable temperatures during anthesis and greater photosynthate translocation. DBW 303 yielded more than JAUW 672 due to its superior growth parameters and genetic adaptability. Paclobutrazol again led in grain and straw yield, attributed to enhanced leaf area, chlorophyll content and

improved physiological resilience under heat stress. Harvest Index also followed a similar trend, indicating better economic partitioning in early sowing, DBW 303 and paclobutrazol treatment (20).

Soil studies

At harvest, all the treatments did not significantly affect soil organic carbon, available N, P and K; numerical trends showed higher residual nutrients under late sowing and in JAUW 672, likely due to reduced uptake caused by poor biomass accumulation. Paclobutrazol, promoting better growth and nutrient utilisation, recorded lower residual nutrient levels, implying higher crop extraction and use efficiency.

Economics

Economic analysis revealed the highest returns and B : C ratio with 25th November sowing due to superior yields. DBW 303 outperformed JAUW 672 in gross and net returns due to its higher productivity (21). Paclobutrazol achieved the highest economic returns among PGRs, attributed to significant yield enhancement (22).

Conclusion

Based on the study findings, it can be concluded that the wheat crop sown on 25th November exhibited superiority over those sown on 15th December and 5th January across various parameters, including growth, yield and economics. Normal sowing on 25th November resulted in 25.08 % and 63.18 % higher grain yield compared to late (15th December) and very late (5th January) sowing dates, respectively. In terms of plant growth regulators, paclobutrazol outperformed kinetin and the control across various aspects, including growth, yield attributes, yield and economics.

Authors' contributions

SS carried out an experimental trial on the wheat crop and tabulated the results. MK conceived the experimental study, compiled the results and edited the manuscript. VT compiled the graphs. RS, BRB and AS contributing analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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