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Effect of Sowing Time, Crop Establishment Method and Weed Control Practices on Nutrient Content and Uptake and Quality of Wheat (*Triticum aestivum* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

A field study was carried out during the *rabi* seasons of 2023-24 and 2024-25 at the Agricultural Research Farm, College of Agriculture, RVSKVV, Gwalior (M. P.), to evaluate the effects of sowing time, crop establishment method and weed control practices on nutrient content, uptake and quality of wheat. The experiment was conducted using a split-plot design (SPD) comprising 27 treatment combinations comprising three sowing times (Second week of November-D_1, Fourth week of November-D_2 and Second week of December-D_3), three crop establishment methods (Normal line sowing at 22.5 cm-M_1, FIRB sowing at 15 cm-M_2 and Line sowing under zero tillage at 22.5 cm-M_3) as main plots and three weed control practices (Clodinafop-propargyl 54 g ai/ha + Metribuzin 120 g ai/ha-W_1, Clodinafop-propargyl 60 g ai/ha + Metsulfuron-methyl 4 g ai/ha-W_2 and Weedy check-W_3) as subplots, with three replications.

Keywords: Sowing time; crop establishment method; weed control; wheat; nutrient content; nutrient uptake and protein content.

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1. Introduction

Wheat cultivation has been symbolic of the Green Revolution, which played a vital role in making India a food-surplus nation. India is the second-largest producer of wheat in the world. Worldwide, it ranks first among cereals in terms of area (220 million ha), with production of 838 million tonnes and productivity of 3.48 tonnes/ha (United States Department of Agriculture, Foreign Agricultural Service, n.d.). In India, it is grown on approximately 33.4 million ha, with production of 120.65 million tonnes and productivity of 3.59 tonnes/ha, respectively (Ministry of Agriculture and Farmers Welfare, 2025). In Madhya Pradesh, wheat is grown over approximately 8.57 million ha, with production of 24.5 million tonnes, indicating that wheat productivity (*i.e.* 3163 kg/ha) is lower than the national average (Government of Madhya Pradesh, n.d.). Wheat productivity depends on several factors, such as crop establishment techniques, irrigation, weed management, sowing methods, sowing time, seed rate, fertiliser management and other cultural practices.

Weeds reduce wheat yield by 37-50%, and weed infestation is a major cause of declining wheat yield (Waheed *et al.*, 2009). Weeds are among the major factors that harm the crop. The most critical period for crop-weed competition in wheat is 30-45 days after sowing. Timely sowing of wheat provides an optimum environment for crop growth, promoting greater biomass accumulation and, ultimately, higher grain yield. Under late-sown conditions, the wheat crop is exposed to low temperatures during germination, which delay crop emergence. Higher temperatures during the reproductive phase lead to forced maturity, resulting in reductions in yield and yield attributes (Gupta *et al.*, 2017).

Field evidence from eastern India has documented reductions in wheat grain yield associated with delayed sowing (Kumar *et al.*, 2024). Variation in wheat photosynthetic characteristics and grain yield across different sowing dates has also been reported (Liu *et al.*, 2024). Studies of wheat weed management have reported changes in growth-related characteristics under herbicide treatments (Gul *et al.*, 2024). Other field evidence indicates that weed-control practices can influence nutrient uptake in wheat (Mishra *et al.*, 2026).

The sowing method is important for proper crop establishment, and the productivity of individual plants depends on the balance of plant-to-plant competition. Zero tillage is a resource-saving, water-conserving method that reduces cultivation costs (Gupta *et al.,* 2019). Sowing crops on ridges and furrows, rather than on flat beds, was found to be preferable for *rabi* crops (Radwan *et al.*, 2013).

Recent experimental research has also reported differences in wheat growth and grain yield among sowing techniques (Ranazai *et al.*, 2024).

Nevertheless, the combined effects of sowing time, crop establishment method and weed control practices on nitrogen, phosphorus and potassium content and uptake in wheat grain and straw, together with grain protein content and yield, warrant evaluation under the conditions of the present study.

Thus, the objective of the present study was to determine how sowing time, crop establishment method and weed control practices affect nutrient content, uptake and quality in wheat.

2. Materials and Methods

2.1 Experimental Site

The present study was carried out during the *rabi* seasons of 2023-24 and 2024-25 at the Agricultural Research Farm, College of Agriculture, RVSKVV, Gwalior (M. P.). The experimental field had uniform topography and a gentle slope that allowed excess water to drain freely, providing suitable conditions for wheat cultivation. The soil of the experimental field was sandy clay loam, with a neutral pH, medium levels of available potassium and phosphorus, and low levels of organic carbon and nitrogen. The "DBW 187" wheat variety was used at a seed rate of 120 kg/ha and 22.5 cm inter-row spacing. 120 kg of nitrogen, 60 kg of phosphorus (P_2O_5) and 40 kg of potassium (K_2O) were supplied through urea, diammonium phosphate (DAP) and muriate of potash (MoP), respectively. Fertilisers providing half the nitrogen dose and the full doses of phosphorus and potash were drilled to a depth of 7 cm in each plot before sowing. The remaining nitrogen was applied in two equal split doses by top dressing at the tillering and panicle initiation stages.

2.2 Experimental Design

The experiment was conducted using a split-plot design (SPD) comprising 27 treatment combinations comprising three sowing times (Second week of November-D_1, Fourth week of November-D_2 and Second week of December-D_3), three crop establishment methods (Normal line sowing at 22.5 cm-M_1, FIRB sowing at 15 cm-M_2 and Line sowing under zero tillage at 22.5 cm-M_3) as main plots and three weed control practices (Clodinafop-propargyl 54 g ai/ha + Metribuzin 120 g ai/ha-W_1, Clodinafop-propargyl 60 g ai/ha + Metsulfuron-methyl 4 g ai/ha-W_2 and Weedy check-W_3) as subplots, with three replications. All parameters were statistically analysed by null method as described by Fisher (1957) and Panse and Sukhatme (1978). The F-test was used to assess the significance of sowing time, crop establishment method, weed control and their interaction effects. Means corresponding to significant effects were compared using the critical difference at the 5% (P=0.05) level of significance.

2.3 Soil Dynamics Study

Representative surface soil samples (0-30 cm depth) were collected from each plot before sowing the wheat crop using a soil auger to determine the physicochemical properties of the soil. Each sample was air-dried and passed through a 2 mm sieve. The prepared samples were used for the following determinations using standard methods (Table 1).

Table 1. Soil analysis of the experimental field

S. No.	Mechanical composition of soil			Methods used
	Year	**2023-24**	**2024-25**	
1.	Sand (%)	63.72	63.73	By International pipette method (Piper, 1950)
2.	Silt (%)	14.22	14.24	
3.	Clay (%)	22.06	22.04	
	Physico-Chemical composition of soil			
1.	Organic Carbon (%)	0.46	0.47	Walkley and Black's method (1934)
2.	Electrical Conductivity (DS/m) at 25°C	0.35	0.36	Solubridge method (Richard, 1954)
3.	pH	7.0	7.1	Glass Electrode pH meter (Jackson, 1973)
4.	Available Nitrogen (kg/ha)	224.23	224.52	Alkaline permanganate method (Subbiah and Asija, 1956)
5.	Available Phosphorus (kg/ha)	16.21	16.36	Ascorbic acid method (Olsen *et al.*, 1954)
6.	Available Potash (kg/ha)	189.01	189.22	Flame photometric method (Black, 1965)

2.4 Sample Preparation

Nitrogen, phosphorus and potassium analyses were performed in grain and straw samples from each treatment at harvest. After a sun-drying period of 48-72 hours, the samples were dried in a hot-air oven set at 65±5°C until they reached a constant weight. After reaching a constant weight, the oven-dried samples were ground separately by treatment using a Willey's mill and stored in butter-paper covers. Chemical analysis was performed using the powdered samples after passing them through a 2 mm sieve.

2.5 Nutrient Content (%) and Uptake by Wheat (kg/ha)

2.5.1 Determination of Nitrogen

Nitrogen in the plant samples was determined using the KEL PLUS nitrogen estimation system (Subbiah and Asija, 1956). The Pelicans KEL PLUS system is designed to perform the Kjeldahl method for nitrogen estimation, which comprises the following three processes:

1. Digestion
2. Distillation
3. Titration

Digestion Process: In this process, 0.5 g of plant sample was transferred to the digestion tube. Ten millilitres of concentrated sulphuric acid and 2 g of digestion activator (salt mixture) were added to the sample. Digestion tubes were loaded into the digester and the digestion block was heated. At the end of the digestion process, the sample became colourless or light green.

Distillation Process: During distillation, the ammonium radicals are converted into ammonia under excess alkaline conditions after the acid in the digested sample is neutralised with 40% alkali (NaOH) during heating. In DISTYL-EM, the digested samples are heated by passing steam, and the ammonia liberated following the addition of 40% NaOH is dissolved in 4% boric acid. The boric acid containing ammonia is then used for titration.

Titration Process: The boric acid solution and mixed indicator containing the distilled ammonia were titrated with standardised H_2SO_4. The titration value for a blank solution of boric acid and mixed indicator was also determined.

$$\% \text{ Nitrogen} = \frac{(\text{Sample titer} - \text{Blank titer}) \times \text{Normality of H2SO4} \times 14 \times 100}{\text{Sample weight (g)} \times 1000}$$

The nitrogen content of grain and straw (%) was multiplied by their respective yields to determine the total nitrogen uptake, which was then expressed in kg/ha.

2.5.2 Determination of Phosphorus & Potassium

One gram of an oven-dried plant sample was digested in a 100 ml conical flask with 10 ml of a di-acid mixture (2:5) consisting of chemically pure concentrated perchloric acid and nitric acid, respectively. The digested material was filtered through Whatman No. 40 filter paper into a 100 ml volumetric flask, and the filtrate was diluted to the mark.

A 10 ml aliquot of the colourless filtrate was transferred to a 25 ml volumetric flask for determination, and 5 ml of ammonium molybdate vanadate mixture was added. After thorough shaking, the volume was made up to 25 ml. The mixture was left for 30 minutes, and colour intensity was measured using a Spectronic 20 at a wavelength of 470 nm after zeroing the instrument with a blank, as described by Jackson (1973).

A 10 ml aliquot of the filtrate was transferred to a 100 ml volumetric flask and diluted to the mark with distilled water. The potassium content of the extract was estimated using a flame photometer (Black, 1965).

2.5.3 Nutrient Uptake (Kg/Ha)

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Grain or Straw yield (kg/ha) x Nutrient content (\%)}}{100}$$

2.6 Protein Content (%) and Protein Yield (kg/ha) in Wheat Grain

Protein content was computed by multiplying the nitrogen content of the seed with a factor of 5.70. The total nitrogen content of the seed was determined using the Kjeldahl method as described by Cunniff (1995).
Protein yield was estimated using the following formula:

$$\text{Protein yield (kg/ha)} = \frac{\text{Grain yield (kg/ha) x Protein content in grain (\%)}}{100}$$

3. Results and Discussion

3.1 Effect of Sowing Time, Crop Establishment Method and Weed Control Practices on N, P and K Content in Grain

The nutrient contents (N, P and K) in grain was significantly affected by sowing time, crop establishment method and weed control practices during both years of investigation, except for grain N content under the crop establishment methods, which showed non-significant variation, as shown in Table 2a. The results are described on the basis of pooled data from the two years.

Effect of Sowing Time (D): The second week of November-D_1 (2.056%) recorded a significantly lower N content; while second week of December-D_3 (0.233 and 0.525%; respectively) recorded lower P and K contents than the other sowing dates.

Effect of Crop Establishment Method (M): The line sowing under zero tillage at 22.5 cm-M_3 (2.107, 0.251 and 0.564%; respectively) showed significantly lower N, P and K contents than the other crop establishment methods; whereas the highest values were reported for FIRB sowing at 15 cm-M_2 (2.190, 0.278 and 0.626%; respectively).

Effect of Weed Control (W): The Clodinafop-propargyl 60 g ai/ha + Metsulfuron-methyl 4 g ai/ha-W_2 (2.247, 0.298 and 0.671%; respectively) recorded significantly higher N, P and K contents than the other treatments; these values were on a par with those under Clodinafop-propargyl 54 g ai/ha + Metribuzin 120 g ai/ha-W_1 (2.221, 0.291 and 0.655%; respectively). The lowest values were recorded under the weedy check-W_3 (1.979, 0.206 and 0.463%; respectively).

Interaction: Grain N, P and K contents showed non-significant variation under the interactions (DxM, MxW & DxMxW).

DxW: A significant interaction between sowing time and weed control treatments was found for grain N, P and K contents. The significantly highest grain N, P and K contents (2.322, 0.338 and 0.760%; respectively) were recorded for the interaction of fourth week of November-D_2 with Clodinafop-propargyl 60 g ai/ha + Metsulfuron-methyl 4 g ai/ha-W_2 compared with the other interactions. The significant interaction effect between sowing time and weed management practices (DxW) on the N, P, and K content in grain highlights the critical role of optimizing microclimatic conditions and minimizing crop-weed competition during key phenological stages.

3.2 Effect of Sowing Time, Crop Establishment Method and Weed Control Practices on N, P and K Content in Straw

The nutrient content (N, P and K) in straw was significantly affected by sowing time, crop establishment method and weed control practices during both years of investigation, as shown in Table 2a. The results are described on the basis of pooled data from the two years.

Effect of Sowing Time (D): Significantly lower N, P and K contents were recorded for second week of December-D_3 (0.302, 0.0410 and 1.879%; respectively) than for the other sowing dates, whereas higher values were observed under fourth week of November-D_2 (0.383, 0.0457 and 2.096%; respectively).

Effect of Crop Establishment Method (M): The line sowing under zero tillage at 22.5 cm-M_3 (0.325, 0.0423 and 1.941%; respectively) recorded significantly lower N, P and K contents than the other crop establishment methods; whereas the highest values were reported for FIRB sowing at 15 cm-M_2 (0.361, 0.0444 and 2.033%; respectively).

Effect of Weed Control (W): The Clodinafop-propargyl 60 g ai/ha + Metsulfuron-methyl 4 g ai/ha-W_2 (0.386, 0.0459 and 2.104%; respectively) recorded significantly higher N, P and K contents than the other treatments; these values were on a par with those

under Clodinafop-propargyl 54 g ai/ha + Metribuzin 120 g ai/ha-W_1 (0.377, 0.0454 and 2.080%; respectively). The lowest values were recorded under the weedy check-W_3 (0.266, 0.0389 and 1.782%; respectively).

Interaction: Straw N, P and K contents showed non-significant variation under the interactions (DxM, MxW & DxMxW).

DxW: A significant interaction between sowing time and weed control treatments was found for straw N content. The significantly highest straw N content (0.437%) was recorded for the interaction of fourth week of November-D_2 with Clodinafop-propargyl 60 g ai/ha + Metsulfuron-methyl 4 g ai/ha-W_2 compared with the other interactions. The significant interaction between sowing time and weed control treatments highlights how proper crop establishment combined with weed management influences nitrogen dynamics in wheat.

Table 2a. Effect of sowing time, crop establishment method and weed control practices on Nitrogen (N) Phosphorus (P) and Potassium (K) content in grain and straw (Pooled)

Wheat	Grain			Straw		
Nutrient content (%)	**N**	**P**	**K**	**N**	**P**	**K**
Sowing times						
D_1	2.056	0.266	0.598	0.344	0.0434	1.991
D_2	2.176	0.296	0.666	0.383	0.0457	2.096
D_3	2.215	0.233	0.525	0.302	0.0410	1.879
SEm	0.024	0.001	0.003	0.002	0.0003	0.013
CD (P=0.05)	0.069	0.004	0.009	0.006	0.0008	0.037
Crop establishment methods						
M_1	2.150	0.266	0.598	0.344	0.0434	1.991
M_2	2.190	0.278	0.626	0.361	0.0444	2.033
M_3	2.107	0.251	0.564	0.325	0.0423	1.941
SEm	0.024	0.001	0.003	0.002	0.0003	0.013
CD (P=0.05)	NS	0.004	0.009	0.006	0.0008	0.037
Weed control treatments						
W_1	2.221	0.291	0.655	0.377	0.0454	2.080
W_2	2.247	0.298	0.671	0.386	0.0459	2.104
W_3	1.979	0.206	0.463	0.266	0.0389	1.782
SEm	0.025	0.003	0.006	0.004	0.0005	0.024
CD (P=0.05)	0.071	0.007	0.017	0.010	0.0014	0.067
Interaction						
D*M	NS	NS	NS	NS	NS	NS
D*W	S	S	S	S	NS	NS
M*W	NS	NS	NS	NS	NS	NS
D*M*W	NS	NS	NS	NS	NS	NS

Table 2b. Interaction effect of sowing times and weed control treatments on NPK content in grain of wheat (pooled)

Nutrient content (%)	**N**			**P**			**K**		
Treatments	**Sowing times**								
Weed control treatments	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**
W_1	2.122	2.290	2.252	0.292	0.331	0.251	0.656	0.745	0.565
W_2	2.148	2.322	2.269	0.298	0.338	0.259	0.671	0.760	0.582
W_3	1.896	1.915	2.125	0.208	0.219	0.190	0.468	0.493	0.428
SEm	**0.049**			**0.004**			**0.010**		
CD (P=0.05)	**0.107**			**0.010**			**0.024**		

Table 2c. Interaction effect of sowing times and weed control treatments on N content in straw of wheat (pooled)

Nutrient content (%)	**N**		
Treatments	**Sowing times**		
Weed control treatments	**D_1**	**D_2**	**D_3**
W_1	0.378	0.429	0.325
W_2	0.386	0.437	0.335
W_3	0.269	0.284	0.247
SEm	**0.006**		
CD (P=0.05)	**0.014**		

**D_1: 2nd Week of November, D_2: 4th Week of November, D_3: 2nd Week of December, M_1: Normal line sowing at 22.5 cm, M_2: FIRB sowing at 15 cm, M_3: Line sowing under zero tillage at 22.5 cm, W_1: Clodinafop-propergyl 54 g a.i./ha + Metribuzin 120 g a.i./ha, W_2: Clodinafop-propergyl 60 g a.i./ha + Metsulfuron-methyl 4 g a.i./ha, W_3: Weedy check*

3.3 Effect of Sowing Time, Crop Establishment Method and Weed Control Practices on N, P and K Uptake by Grain and Straw

The effects of sowing time, crop establishment method and weed control practices on nitrogen (N), phosphorus (P) and potassium (K) uptake by wheat grain and straw were statistically significant during both years of investigation, as shown in Table 3a. The results are described on the basis of pooled data from the two years.

Effect of Sowing Time (D): Significantly lower N, P and K uptake by grain and straw was recorded for second week of December-D_3 (98.93, 10.61, 23.88 kg/ha and 18.31, 2.47, 113.04 kg/ha; respectively); whereas higher values were recorded for fourth week of November-D_2 (124.77, 17.28, 38.89 kg/ha and 28.80, 3.38, 155.13 kg/ha; respectively) compared with the other sowing dates.

Effect of Crop Establishment Method (M): The line sowing under zero tillage at 22.5 cm-M_3 (101.59, 12.51, 28.15 kg/ha and 21.37, 2.74, 125.48 kg/ha; respectively) showed significantly lower N, P and K uptake by grain and straw than the other crop establishment methods; whereas the highest values were reported for FIRB sowing at 15 cm-M_2 (117.42, 15.25, 34.31 kg/ha and 25.58, 3.10, 142.28 kg/ha; respectively).

Effect of Weed Control (W): The Clodinafop-propargyl 60 g ai/ha + Metsulfuron-methyl 4 g ai/ha-W_2 (127.91, 17.16, 38.62 kg/ha and 28.57, 3.38, 154.85 kg/ha; respectively) recorded significantly higher N, P and K uptake by grain and straw than the other treatments; these values were on a par with those under Clodinafop-propargyl 54 g ai/ha + Metribuzin 120 g ai/ha-W_1 (123.53, 16.40, 36.92 kg/ha and 27.39, 3.27, 150.15 kg/ha; respectively). The lowest values were recorded under the weedy check-W_3 (77.56, 8.15, 18.34 kg/ha and 14.59, 2.12, 97.24 kg/ha; respectively).

Interaction: N, P and K uptake by grain and straw showed non-significant variation under the interactions (DxM, MxW & DxMxW).

DxW: A significant interaction between sowing time and weed control treatments was found for N, P and K uptake by grain and straw. The significantly highest N, P and K uptake by grain and straw (149.58, 21.75, 48.93 kg/ha and 35.79, 4.00, 183.43 kg/ha; respectively) was recorded for the interaction of fourth week of November-D_2 with Clodinafop-propargyl 60 g ai/ha + Metsulfuron-methyl 4 g ai/ha-W_2 compared with the other interactions; these values were on a par with those for the interaction of fourth week of november-D_2 with Clodinafop-propargyl 54 g ai/ha + Metribuzin 120 g ai/ha-W_1 (144.60, 20.91, 47.05 kg/ha and 34.52, 3.89, 178.56 kg/ha; respectively).

Reduced weed population and dry weight, together with increased availability of N, P and K, enhanced nutrient content and uptake under fourth week of November-D_2, FIRB sowing at 15 cm-M_2 and Clodinafop-propargyl 60 g ai/ha + Metsulfuron-methyl 4 g ai/ha-W_2 treatments. Similar findings were reported by Kumar *et al.* (2022), Yadav *et al.* (2023a) and Pavan *et al.* (2025).

Table 3a. Effect of sowing time, crop establishment method and weed control practices on Nitrogen (N) Phosphorus (P) and Potassium (K) uptake by grain and straw (Pooled)

Wheat	Grain			Straw		
Nutrient uptake (kg/ha)	**N**	**P**	**K**	**N**	**P**	**K**
Sowing times						
D_1	105.29	13.83	31.11	23.44	2.92	134.07
D_2	124.77	17.28	38.89	28.80	3.38	155.13
D_3	98.93	10.61	23.88	18.31	2.47	113.04
SEm	1.42	0.12	0.27	0.20	0.03	1.36
CD (P=0.05)	4.09	0.35	0.77	0.58	0.08	3.92
Crop establishment methods						
M_1	109.98	13.96	31.41	23.60	2.93	134.48
M_2	117.42	15.25	34.31	25.58	3.10	142.28
M_3	101.59	12.51	28.15	21.37	2.74	125.48
SEm	1.42	0.12	0.27	0.20	0.03	1.36
CD (P=0.05)	4.09	0.35	0.77	0.58	0.08	3.92
Weed control treatments						
W_1	123.53	16.40	36.92	27.39	3.27	150.15
W_2	127.91	17.16	38.62	28.57	3.38	154.85
W_3	77.56	8.15	18.34	14.59	2.12	97.24
SEm	2.48	0.30	0.69	0.50	0.07	3.10
CD (P=0.05)	6.98	0.85	1.95	1.41	0.18	8.73
Interaction						
D*M	NS	NS	NS	NS	NS	NS
D*W	S	S	S	S	S	S
M*W	NS	NS	NS	NS	NS	NS
D*M*W	NS	NS	NS	NS	NS	NS

Table 3b. Interaction effect of sowing times and weed control treatments on NPK uptake by grain (pooled)

Nutrient uptake (kg/ha)	N			P			K		
Treatments	**Sowing times**			**Sowing times**			**Sowing times**		
Weed control treatments	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**
W_1	118.28	144.60	107.72	16.24	20.91	12.07	36.54	47.05	27.16
W_2	122.25	149.58	111.89	16.96	21.75	12.78	38.15	48.93	28.77
W_3	75.35	80.13	77.19	8.28	9.19	6.98	18.63	20.68	15.70
SEm	**4.04**			**0.46**			**1.05**		
CD (P=0.05)	**10.01**			**1.21**			**2.77**		

Table 3c. Interaction effect of sowing times and weed control treatments on NPK uptake by straw (pooled)

Nutrient uptake (kg/ha)	N			P			K		
Treatments	**Sowing times**			**Sowing times**			**Sowing times**		
Weed control treatments	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**
W_1	27.19	34.52	20.46	3.26	3.89	2.67	149.67	178.56	122.24
W_2	28.34	35.79	21.59	3.37	4.00	2.76	154.35	183.43	126.76
W_3	14.79	16.09	12.89	2.14	2.25	1.97	98.20	103.40	90.12
SEm	**0.76**			**0.10**			**4.78**		
CD (P=0.05)	**2.01**			**0.26**			**12.42**		

**D_1: 2nd Week of November, D_2: 4th Week of November, D_3: 2nd Week of December, M_1: Normal line sowing at 22.5 cm, M_2: FIRB sowing at 15 cm, M_3: Line sowing under zero tillage at 22.5 cm, W_1: Clodinafop-propergyl 54 g a.i./ha + Metribuzin 120 g a.i./ha, W_2: Clodinafop-propergyl 60 g a.i./ha + Metsulfuron-methyl 4 g a.i./ha, W_3: Weedy check*

3.4 Effect of Sowing Time, Crop Establishment Method and Weed Control Practices on Protein Content and Protein Yield of Wheat

Sowing time and weed control practices significantly influenced protein content, whereas crop establishment methods showed non-significant variation during both years of investigation, as shown in Table 4. The results are described on the basis of pooled data from the two years.

Protein yield was significantly influenced by sowing time, crop establishment method and weed control practices during both years of investigation, as shown in Table 4. The results are described on the basis of pooled data from the two years.

Effect of Sowing Time (D): A significantly lower grain protein content (%) was recorded for second week of November-D_1 (11.72%); whereas a higher value was recorded for second week of December-D_3 (12.63%) than for the other sowing dates. In the case of protein yield, the significantly highest value was recorded for fourth week of november-D_2 (711 kg/ha); whereas the lowest value was recorded for second week of december-D_3 (564 kg/ha) compared with the other sowing dates.

Effect of Crop Establishment Method (M): The line sowing under zero tillage at 22.5 cm-M_3 (12.01% and 579 kg/ha; respectively) showed significantly lower protein content and protein yield than the other crop establishment methods; whereas the highest values were reported for FIRB sowing at 15 cm-M_2 (12.48% and 669 kg/ha; respectively).

Effect of Weed Control (W): The Clodinafop-propargyl 60 g ai/ha + Metsulfuron-methyl 4 g ai/ha-W_2 (12.81% and 729 kg/ha; respectively) recorded significantly higher protein content and protein yield than the other treatments; these values were on a par with those under Clodinafop-propargyl 54 g ai/ha + Metribuzin 120 g ai/ha-W_1. The lowest values were recorded under the weedy check-W_3 (12.66% and 704 kg/ha; respectively).

Interaction: Protein content and protein yield showed non-significant variation under the interactions (DxM, MxW & DxMxW).

DxW: A significant interaction between sowing time and weed control treatments was found for protein content and protein yield. The significantly highest protein content and protein yield were recorded for the interaction of fourth week of November-D_2 with Clodinafop-propargyl 60 g ai/ha + Metsulfuron-methyl 4 g ai/ha-W_2 (13.24% and 853 kg/ha; respectively) compared with the other interactions; these values were on a par with those for the interaction of fourth week of november-D_2 with Clodinafop-propargyl 54 g ai/ha + Metribuzin 120 g ai/ha-W_1 (13.05% and 824 kg/ha; respectively). This indicates that protein content and protein yield in wheat are jointly regulated by the thermal/photoperiodic environment during crop growth and the efficacy of weed management practices.

Late-sown wheat undergoes forced maturity due to high temperatures during the grain-filling stage. The shortened grain-filling period curtails starch accumulation more severely than nitrogen translocation, resulting in a "concentration effect" that raises the protein content in grain.

Protein yield is a function of total grain yield multiplied by protein content. Late-sown wheat has a higher protein content but its total grain yield declines substantially due to heat stress and shorter growth period, leading to lower protein yield.

Table 4. Effect of sowing time, crop establishment method and weed control practices on protein content and protein yield of wheat grain

Quality parameters	Protein content (%)	Protein yield (kg/ha)
Sowing times		
D_1	11.72	600
D_2	12.40	711
D_3	12.63	564
SEm	0.14	8
CD (P=0.05)	0.39	23
Crop establishment methods		
M_1	12.26	627
M_2	12.48	669
M_3	12.01	579
SEm	0.14	8
CD (P=0.05)	NS	23
Weed control treatments		
W_1	12.66	704
W_2	12.81	729
W_3	11.28	442
SEm	0.14	14
CD (P=0.05)	0.41	40
Interaction		
D*M	NS	NS
D*W	S	S
M*W	NS	NS
D*M*W	NS	NS

Table 5. Interaction effect of sowing times and weed control treatments on quality parameters of wheat (pooled)

Yield (kg/ha)	Protein content (%)			Protein yield		
Treatments	**Sowing times**					
Weed control treatments	**D_1**	**D_2**	**D_3**	**D_1**	**D_2**	**D_3**
W_1	12.10	13.05	12.84	674	824	614
W_2	12.25	13.24	12.94	697	853	638
W_3	10.81	10.91	12.11	429	457	440
SEm	**0.28**			**23**		
CD (P=0.05)	**0.61**			**57**		

**D_1: 2nd Week of November, D_2: 4th Week of November, D_3: 2nd Week of December, M_1: Normal line sowing at 22.5 cm, M_2: FIRB sowing at 15 cm, M_3: Line sowing under zero tillage at 22.5 cm, W_1: Clodinafop-propergyl 54 g a.i./ha + Metribuzin 120 g a.i./ha, W_2: Clodinafop-propergyl 60 g a.i./ha + Metsulfuron-methyl 4 g a.i./ha, W_3: Weedy check*

The synergistic effect of sowing time, crop establishment method and weed control practices, which ensured continuous nutrient availability throughout the crop-growth period through reduced competition for all growth inputs, enhanced chlorophyll synthesis, increased enzymatic activity and improved nutrient uptake; thereby promoting assimilate translocation towards developing grains. Consequently, protein yield was enhanced. Similar results have been reported by Bagherikia *et al.* (2025).

4. Conclusion

The two-year pooled results indicate that sowing time, crop establishment method and weed control practices influenced nutrient content, nutrient uptake and grain quality in wheat under the study conditions. Sowing during the fourth week of November produced the highest grain and straw N, P and K uptake among the evaluated sowing dates and the greatest protein yield (711 kg/ha), although grain protein concentration was highest with sowing during the second week of December (12.63%). Among establishment methods, FIRB sowing at 15 cm recorded the highest grain N, P and K uptake and protein yield (669 kg/ha). Among weed control practices, the application of clodinafop-propargyl at 60 g a.i./ha with metsulfuron-methyl at 4 g a.i./ha produced the highest protein yield (729 kg/ha), while the weedy check recorded 442 kg/ha. A significant sowing-time × weed-control interaction was observed for nutrient uptake and grain protein parameters. These results support the importance of considering sowing time, establishment method and weed management jointly when managing wheat nutrient acquisition and protein yield. Interpretation should remain confined to the tested treatments and field conditions.

5. Limitations

The experiment was conducted at one research farm over two *rabi* seasons using a single wheat variety (DBW 187). Consequently, the findings primarily reflect the soil and management conditions represented by this study. The measured responses were nutrient content and uptake in grain and straw, alongside grain protein content and protein yield. Further field evaluation across locations, seasons and wheat varieties would help determine how consistently these treatment effects occur under other production environments.

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Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. ChatGPT, Claude and Perplexity were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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