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RESEARCH ARTICLE

Weed management in wheat under different sowing windows in new alluvial zone of West Bengal, India

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ABSTRACT

A field experiment was conducted at District Seed Farm (AB Block), Kalyani under Bidhan Chandra Krishi Viswavidyalaya during the winter season of 2019-20 and 2020-21 in upland situations to study the effect of different sowing windows and weed management measures on growth and yield of wheat. The experiment was carried out in a split plot design with three replications. Three sowing times (timely, late and very late) in the main plot and eight weed management options, viz. pendimethalin 750 g/ha *fb* metsulfuron g/ha, pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha, pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha, pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha, pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha, pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS, hand weeding thrice (at 20, 35 and 50 DAS) and weedy check in sub -plots. At 30 DAS, more weed density was observed with the timely sowing condition and reduced with the date of progress of wheat sowing. However, broad -leaf weed density was less with very late sown conditions and significantly superior to all other main plot treatments. With different subplot treatments, the lowest density of grasses was found with hand weeding thrice and was followed by pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha, and was statistically better to all other treatments except pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS. However, at 60 and 90 DAS, the lowest density of grassy, BLWs and sedges was observed with the timely sown condition and significantly better than other treatments. With various herbicidal treatments, the lowest density of grasses registered with the pendimethalin 750 g/ha *fb* one hand weeding and markedly better than all other treatments except hand weeding thrice. Total uptake of nutrients was lowest with the timely sown condition and was notably better than all other main plot treatments. Among herbicidal treatments, significantly lower uptake by weed was seen with pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha. Grain yield varies significantly with sowing windows and weed management measures. More grain yield was found with timely sown conditions and was statistically better than other main plot treatments. Timely sown conditions gain 97.6 and 45.86 % more grain yield over very late sown situations. Among various integrated weed management options more grain yield gain with hand weeding thrice and was at par with pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS, pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha, pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha. The study concluded that sequential/tank-mix application of pre- and or post-emergence herbicide could be adopted with appropriate sowing time for broad-spectrum control of weeds in wheat.

Keywords: Herbicide, IWM, Nutrient, Sowing Time, Weed, Wheat, Yield

INTRODUCTION

Wheat (*Triticum aestivum* L. emend. Fiori and Paol.) as an important source of calories and energy for humans and account for a prominent share in the consumption basket. This has been cultivated around 224.05 million hectare with output to the tune of 793.37 million tonnes ((ICAR-IIWBR, 2023). Wheat is the most important cereal crop because it is the staple food of the people of India. During the post-green revolution period, the productivity of wheat has increased tremendously but is still far below the potential yield (11.2 t/ha). In India this wheat is grown in 31.09 million hectares (23.78% of total crop acreage) contributing 34.34 % of the total foodgrains produced during 2022-23 as per 4th Advance Estimate, Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, India. In the current production season, the wheat output is pegged at 107.74 million tones with a national average of 3543 kg/ha. In West Bengal, wheat cultivated area is quite low 221 thousand ha with production of 657 thousand tons, with productivity only 2.9 t/ha (ICAR-IIWBR 2023), this might be due to late sowing and poor weed management options etc. In weather factors, temperature is the driving force of plant development; day length and vernalization effect. Consequently, different times of sowing with different genetic make-up mature at different rates but the difference is greater when sown early or variation in nutrient or proper weed management measures etc. Climate change influences crop productivity by altering plant growth etc. (Chetna *et*

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al. 2023). Therefore , proper time of sowing becomes another factor to optimize the appropriate weather for cultivation. In spite of cultivation of high-yielding varieties, improved cultural practices and plant-protection measures, favourable weather is a must for good harvests.

Weeds are regarded as most disdainful of crop production and account for about one third of total losses caused by all the pests. Of the several constraints to low productivity of wheat, weeds have been recognized as an important one which compete with crop plants for nutrients and other growth factors, and in absence of an effective control measure weeds remove considerable quantities of applied nutrients resulting in higher loss in yield. Weed infestation during the crop period causes more than 43.63% reduction in grain yield, depending on the weed densities and type of weed flora present (Mukherjee 2023). Achieving effective weed control in the later stages and maintaining optimal field conditions requires a comprehensive approach, where a single method, such as relying solely on herbicides or manual/mechanical weeding, may not be sufficient. Herbicides offer several advantages, including time and cost savings, enabling the coverage of larger areas in a shorter period and facilitating timely weed control. These benefits are particularly crucial for managing weed infestations in a timely manner.

In wheat growing regions, the challenge of dealing with both grassy and broadleaf weeds has become increasingly common, leading to significant yield losses and complicating weed control efforts (Mukherjee 2020). This complex situation necessitates a well-rounded weed management approach that combines various strategies to address the diverse weed species effectively. Recent research highlights that adopting appropriate sowing time and proper weed management technologies can lead to substantial additional food grain production. By employing integrated weed management practices that incorporate herbicides, manual, and mechanical weeding as appropriate, farmers can better control weed infestations, minimize yield losses, and significantly increase crop productivity. Such a comprehensive approach is key to meet the growing demand for food and ensure food security in the face of challenges posed by weed infestations (Debnath *et al.* 2021). By focusing on improving production through appropriate sowing time and effective technologies, suitable herbicides can play a pivotal role in timely and efficiently controlling weeds. Sowing windows significantly impact the composition of weeds present in a wheat field, with earlier sowing generally leading to less weed pressure and a different weed species composition compared to late sowing, as certain weed species thrive under specific temperature and light conditions that vary throughout the growing season; essentially, adjusting sowing time can be a tool to manage weed populations in wheat crops by favoring the growth of the wheat plant over specific weed species. As such, the use of herbicides has become a necessity to manage weeds effectively. Identifying appropriate herbicides that offer economical and safe weed control is of utmost importance in enhancing the productivity and sustainability of wheat production. Keeping in view these points, the present study was conducted with the objective of more wheat productivity via appropriate sowing time with different herbicide combinations for controlling different groups of weeds under the new alluvial zone of West Bengal.

MATERIALS AND METHODS

The field experiment was conducted at District Seed Farm (AB Block), Kalyani under Bidhan Chandra Krishi Viswavidyalaya during the winter season of 2019-20 and 2020-21 in upland conditions. The farm is situated at approximately 22° 56´ N latitude and 88° 32´ E longitude with an average altitude of 9.75 m above mean sea level (MSL). The soil was sandy loam in texture, low in organic carbon (0.43%), medium in available N (253.72 kg/ha), low in available P (8.04 kg/ha) and medium in available K (167.29 kg/ha) content with pH 7.2. The total rainfall recorded during crop growth period was 19.3 and 12.1 mm, minimum temperature ranges from 10.9 to 15.7 and 10.8 to 18.9, and maximum temperature 22.4 to 37.8 and 18.9 to 34.8^0 C during winter 2019-20 and 2020-21, respectively. The field experiment was conducted in split plot design with three replications, having twenty four treatment combinations including three sowing windows (timely, late and very late) in the main plot and eight weed management measures, viz. pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha, pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha, pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha, pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha, pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha, pendimethalin 750 g/ha *fb* one hand weeding at 35 days after sowing (DAS), hand weeding thrice (at 20, 35 and 50 DAS) and weedy check in subplots. The recommended fertilizer dose is 120:60:40 kg N, P and K per hectare, respectively. Wheat cultivar "*DBW 187*" was used for this experiment. The sowing of crop was done as per main plot treatments allotment (Timely: 5th November to 11th November; Late: 10th December to 16th December; Very late: 01st January to

7[th] January) with recommended seed rate of 125 kg/ha using 150 kg N, 26.2 kg P and 33.1 kg/ha. Pre-emergence application of pendimethalin was given 3 DAS and all post -emergence herbicides were applied 25 DAS, with the help of a knapsack sprayer fitted with flat fan nozzle at spray volume of 500 L/ha. Weed population and weed dry weight were recorded at 30, 60 and 90 DAS by placing a quadrate of 50 × 50 cm randomly at two spots in each plot. Data on weed count and weed dry weight were subjected to square root transformation before statistical analysis. The irrigation and other recommended packages of practice were adopted during the crop growth period in both the years. The five randomly selected plants from each plot were uprooted and later cleaned and observations like plant height and dry weight at peak growth stage *i.e.* 60 DAS were recorded and averaged. The yield attributes were recorded at harvest to assess the contribution of yield. The 1000 seed weights were counted from the lot, weighed and expressed as 1000 seed weight. The grain and biological yield were computed from the harvest of net plot and expressed in t/ha. Plant and soil samples were analyzed for uptake of nitrogen, phosphorus and potash as per standard laboratory procedures (Jackson, 1973). Available phosphorus was determined by Olsen's method as outlined by Jackson (1973), using a spectrophotometer (660 nm wavelength). Available potassium was extracted with neutral normal ammonium acetate and the content of K in the solution was estimated by flame photometer (Jackson, 1973). The experimental data were analyzed statistically by applying the technique of analysis of variance (ANOVA) prescribed for the design to test the significance of overall difference among treatments by the F test and conclusions were drawn at 5% probability level (Gomez and Gomez, 1984). The effect of treatments was evaluated on pooled analysis basis on growth, yield attributes and yields.

RESULTS AND DISCUSSION

Weed flora

The weed flora in the experimental field consisted of some grasses, sedges and broad-leaved weeds. Among the weeds, grasses were predominant weed species in both the seasons at all the stages of observations. Among the grasses, *Echinochloa colona, Panicum repens and Cynodon dactylon* were dominant species. The broad-leaved weeds constituted the major proportion of the weed flora accounting more in total weed density. Among the sedges, *Cyperus iria, Fimbristylis miliacea* were the dominant species and in broad leaved weeds, *Physalis minima*, *Chenopodium album*, *Anagallis arvensis*, *Circium arvense*, *Fumaria parviflora*, *Melilotus alba* and *Alternanthera philoxeroides* were the dominant weed species.

Weed dynamics at different stages

With different treatments, sowing time significantly influences the population of different classes of weeds. At 30 DAS, more weed density was observed with the timely sowing condition and reduced with the date of progress of wheat sowing. Lowest population was observed with late sown condition and was statistically better to other treatment and showed parity only with very late condition. However, less broad leaf weed density was observed with very late sown condition and significantly superior to all other main plot treatments. Among different classes of weeds, sedges failed to give any statistical difference with main plots, however the lowest value was found with the very late sown condition and was closely followed by timely sown condition. With different subplot treatments, lowest density of grasses found with hand weeding thrice and was followed by pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha, and was statistically better to all other treatments except pendimethalin 750 g/ha *fb* one HW at 35 DAS, where they were at par to each other. Among various weed management option lowest BLW population was observed with pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and was at par with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and significantly better to all other treatments except hand weeding thrice. Lowest sedges density was seen with hand weeding thrice and was followed by pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha, which showed parity with pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha, pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha, and statistically superior to all other treatments. Dry weight of weeds at 30 DAS was found less with the very late sowing condition for all categories of weeds and this showed parity only with late sowing for BLW and statistically better to all other treatments. Among weed management strategies, dry weight of grasses at 30 DAS, lowest with hand weeding thrice and was closely followed by pendimethalin 750 g/ha) *fb* clodinafop-propargyl 60 g/ha, which showed parity with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and notably better to all other treatments. Further, **table 1** revealed that, with different herbicide treatments, dry weight of BLW less establish with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and was at par only with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and significantly better to all other treatment except hand weeding thrice. Reduce dry matter of sedges was seen with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and was at par with pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS, pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha and pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and significantly better to all other treatments except hand weeding thrice which showed lowest dry weight of weed biomass. Apart from causing reductions in crop yield, weeds also deplete the soil of essential nutrients. The extent of nutrient removal by weeds is influenced by the level of weed infestation and the accumulation of weed biomass. Effective weed control measures have been observed to minimize nutrient losses attributed to weeds. At 30 DAS more nutrient uptake by weeds was observed with late sown condition, due to higher dry matter production. Among treatments, least NPK uptake by weed was observed with timely sowing of wheat and showed parity with very late sown condition and statistically better to all other treatments. With different herbicidal treatments, lowest nitrogen uptake resulted with pendimethalin 750 g/ha) *fb* clodinafop-propargyl 60 g/ha for nitrogen uptake and notable better to all other treatments except hand weeding thrice which gave lowest nitrogen uptake by weeds. Total uptake by weeds was observed lowest with hand weeding thrice and was significantly better to other treatments, this was followed by pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha, which showed parity with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and significantly better to other integrated weed management options.

At 60 DAS, lowest density of grassy weeds was observed with timely sown condition and significantly better than other treatments **(Table 2)**. BLWs density was lowest with timely sown condition and was at par only with very late condition, and notably better to other treatments. While the least number of sedges was seen with very late sown condition and showed parity with timely sown wheat and statistically superior to all other treatments. Among different subplot of various herbicidal treatments lowest density of grasses registered with the pendimethalin 750 g/ha *fb* one hand weeding and significantly better to all other treatments except hand weeding thrice. Density of broad leaf weeds and sedges, were seen lowest with hand weeding thrice and this was significantly better to all other treatments. This was followed by pendimethalin 750 g/ha *fb* one hand weeding. Lowest total weed density was seen with hand weeding thrice and statistically

Table 1. Effect of treatments on weed density, dry weight and nutrient uptake pattern of weed in wheat at 30 DAS (pooled value of two years)

Treatment	Weed population (at 30 DAS) (no./m^2)			Total weed population (no./m^2)	Dry weight (no./m^2)			Total dry weight (no./m^2)	Nutrient uptake by weeds (kg/ha)			Total uptake by weeds (kg/ha)
	Grasses	BLW	Sedges		Grasses	BLW	Sedges		N	P	K	
Sowing time												
Timely	3.22* (9.90) **	5.35 (28.09)	2.48 (5.64)	6.77 (45.37)	1.63 (2.15)	3.3 (10.41)	2.22 (4.45)	4.18 (17.01)	4.36	2.06	7.34	13.76
Late	2.47 (5.59)	5.43 (29.00)	2.81 (7.38)	6.38 (40.23)	2.11 (3.95)	3.29 (10.32)	2.06 (3.75)	4.3 (18.02)	5.74	2.18	8.41	16.33
Very late	2.74 (6.99)	4.88 (23.32)	2.38 (5.16)	6.00 (35.47)	1.66 (2.26)	3.13 (9.30)	1.6 (2.05)	3.76 (13.61)	4.32	1.98	6.78	13.08
LSD (p=0.05)	0.37	0.41	NS	0.38	0.17	0.26	0.22	0.32	0.49	0.26	0.66	0.96
Weed management												
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha	2.2 (4.35)	4.61 (20.73)	2.17 (4.20)	5.46 (29.28)	2.2 (4.36)	3.51 (11.79)	2.03 (3.64)	4.5 (19.79)	7.33	2.86	7.42	16.82
Pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha	3.03 (8.68)	5.23 (26.86)	2.34 (4.99)	6.41 (40.53)	1.99 (3.48)	3.33 (10.62)	1.69 (2.35)	4.12 (16.45)	5.39	2.10	6.30	15.55
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha	1.92 (3.20)	3.34 (10.64)	2.31 (4.84)	4.38 (18.68)	1.51 (1.78)	2.65 (6.50)	1.77 (2.62)	3.38 (10.90)	6.09	2.73	7.3	14.41
Pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha	2.47 (5.60)	3.58 (12.34)	2.26 (4.63)	4.8 (22.57)	1.51 (1.78)	2.37 (5.12)	1.93 (3.23)	3.26 (10.13)	5.71	2.41	6.77	12.93
Pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha	2.97 (8.30)	4.6 (20.66)	2.55 (6.00)	5.95 (34.96)	1.3 (1.2)	2.38 (5.18)	1.49 (1.71)	2.93 (8.09)	4.39	2.00	5.62	12.74
Pendimethalin 750 g/ha *fb* one hand weeding	2.22 (4.43)	5.9 (34.26)	2.59 (6.23)	6.74 (44.92)	1.75 (2.58)	3.21 (9.82)	1.55 (1.89)	3.85 (14.29)	5.64	1.19	6.21	14.82
Hand weeding at 20, 35 and 50 DAS	1.39 (1.44)	2.68 (6.67)	1.08 (0.66)	3.04 (8.77)	0.91 (0.32)	1.26 (1.10)	0.9 (0.31)	1.49 (1.73)	2.44	0.73	3.8	6.97
Weedy check	4.96 (24.06)	9.09 (82.09)	4.23 (17.41)	11.1 (123.56)	2.74 (7.00)	5.12 (25.69)	3.48 (11.63)	6.69 (44.32)	7.64	3.32	8.44	19.4
LSD p=0.05)	0.39	0.44	0.37	0.50	0.22	0.30	0.27	0.39	0.55	0.32	0.74	2.56

*Data analyzed after square root transformation $\sqrt{x+0.5}$; **Figures in parentheses are original values

better to other subplot treatments. This was closely followed by pendimethalin 750 g/ha *fb* one hand weeding and pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha. Dry matter of weeds showed significant differences with different classes of weeds. Lowest grass and sedges dry matter were seen with timely sown condition and statistically superior to all other treatments. Reduced dry matter of broad leaf weeds was observed with very late sown condition and it showed parity with timely sown only. Dry matter of grasses and sedges were found lowest with hand weeding thrice and notably better to all other treatments, this was followed by pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha **(Table 2).** Among different chemical treatments lowest dry matter of BLWs was found with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and was at par with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and statistically better to all other treatments except pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and hand weeding thrice. Further, table 2 revealed that, total dry matter of weeds was observed lowest with timely sown condition and statistically superior to all main plot treatments. With different subplot treatments, total dry matter of weed was found lowest with hand weeding thrice and significantly better than other treatments. This was followed by pendimethalin 750 g/ha *fb* one hand weeding and pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha. Highest total weed dry matter registered with weedy check and was followed by pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha. Nutrient uptake by weeds was seen lowest with timely sown condition and was statistically better to all other main plot treatments. Understanding and managing the impact of weeds on nutrient dynamics is crucial to ensure sustainable and productive agricultural systems. By implementing effective weed management strategies, farmers can mitigate the negative effects of weeds on crop productivity and nutrient availability in the soil. Total uptake of nutrient was lowest with timely sown condition and was notably better to all other main plot treatments **(Table 2).** This was followed by very late conditions. With different sub plot treatments highest uptake of nutrient by weeds seen with weedy check and was followed by pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha. Significant lower uptake by weed seen with hand weeding thrice and statistically superior to all other treatments. This was followed by pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha.

Table 2. Effect of treatments on weed density, dry weight and nutrient uptake pattern of weed in wheat at 60 DAS (pooled value of two years)

Treatment	Weed population (no./m^2)			Total weed population (no./m^2)	Dry weight (no./m^2)			Total dry weight (g/m^2)	Nutrient uptake by weeds (kg/ha)			Total uptake by weeds (kg/ha)
	Grasses	BLW	Sedges		Grasses	BLW	Sedges		N	P	K	
Sowing time												
Timely	4.51 (19.80)	8.04 (64.16)	4.07 (16.07)	10 .00 (100.03)	4.93 (23.82)	9.06 (81.65)	4.64 (21.02)	11.24 (124.22)	9.14	2.87	10.42	22.43
Late	5.09 (25.37)	8.39 (69.93)	4.86 (23.15)	10.9 (118.45)	5.67 (31.65)	10.3 (106.02)	5.47 (29.37)	12.91 (167.04)	14.13	3.06	15.14	32.33
Very late	4.96 (24.13)	8.34 (69.10)	3.99 (15.46)	10.4 (108.69)	5.3 (27.59)	8.94 (79.38)	5.44 (29.13)	11.8 2 (138.37)	12.09	3.17	13.38	28.64
LSD (p=0.05)	0.24	0.30	0.31	0.44	0.29	0.41	0.39	0.50	0.36	0.10	0.26	2.45
Weed management												
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha	3.87 (14.47)	8.42 (70.38)	5.84 (33.57)	10.9 (118.42)	4.98 (24.29)	9.95 (98.42)	6.52 (41.99)	12.93 (164.70)	13.44	2.86	14.63	30.93
Pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha	4.65 (21.11)	9.3 (85.97)	2.34 (4.99)	10.6 (112.07)	5.57 (30.55)	11.5 (131.06)	4.59 (20.58)	13.51 (182.19)	15.44	3.98	16.81	36.23
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha	5.11 (25.61)	7.97 (63.06)	4.76 (22.14)	10.1 (110.81)	5.31 (27.71)	10.7 (113.5)	5.52 (29.92)	13.18 (171.13)	13.89	2.97	14.97	31.83
Pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha	4.36 (18.53)	7.73 (59.28)	3.77 (13.73)	9.59 (91.54)	5.53 30.13)	9.24 (84.89)	5.7 (32.03)	12.11 (147.05)	13.01	3.31	13.98	30.3
Pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha	4.42 (19.02)	7.96 (62.84)	5.23 (26.86)	10.5 (108.72)	5.25 27.02)	9.52 (90.15)	5.00 (24.5)	11.98 (141.67)	12.69	3.28	13.23	29.2
Pendimethalin 750 g/ha *fb* one hand weeding	3.97 (15.30)	5.72 (32.26)	2.59 (6.23)	7.37 (53.79)	2.7 (6.78)	4.24 (17.49)	2.19 (4.28)	5.39 (28.55)	5.71	0.92	6.06	12.69
Hand weeding at 20, 35 and 50 DAS	1.68 (2.33)	3.44 (11.32)	1.08 (0.66)	3.85 (14.31)	1.47 (1.65)	2.08 (3.81)	0.78 (0.11)	2.46 (5.57)	1.61	0.57	2.18	4.36
Weedy check	8.29 (68.25)	12.5 (156.68)	6.17 (37.53)	16.2 (262.46)	8.63 74.01)	13.5 (183.1)	7.36 (53.72)	17.6 (310.83)	16.31	6.01	19.36	41.68
LSD (p=0.05)	0.31	0.41	0.35	0.69	0.36	0.47	0.41	0.43	0.31	0.08	0.20	2.67

*Data analyzed after square root transformation $\sqrt{x+0.5}$; **Figures in parentheses are original values

At 90 DAS, density of grasses failed to produce any significant response with various main plot treatments, however, lowest density of grasses seen with timely sown condition and was followed by very late sown condition **(Table 3).** Lowest density of BLWs was found with timely sown condition and showed parity only with very late sown situation and statistically superior to other treatments. Moreover, the least sedges population was seen with very late sown condition and was significantly better to other main plot treatments. With different subplot treatments, lowest value of grassy weeds population observed with hand weeding thrice and showed parity only with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and statistically superior to all other treatments. Among weed management strategies, density of broad leaf weeds was seen least with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and was at par with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and significantly better to all other treatment except hand weeding thrice, which showed lowest density of BLWs. However, lowest sedges density was observed with pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and was at par with hand weeding thrice, pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha and pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and significantly better to all other weed management options. Further observation revealed that total weed density was found lowest with timely sown condition and was closely followed by very late sown condition, they were at par to each other and notably better to other main plot treatments. Total density of weeds was found less with hand weeding thrice and was at par only with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and statistically superior to all other treatments. Biomass production significantly varies with different main and subplot treatments **(Table 3).** More value of dry matter of grassy weeds observed with late sown condition and statistically poor to rest of the main plot treatments. Less BLWs biomass production was observed with very late condition and was at par with timely sown condition. They were at par to each other and statistically superior to other treatments. Lowest sedges dry-matter production was seen with timely sown condition and was at par only with late sown condition and significantly better to other treatments. Dry matter of different classes of weeds significantly found lower with hand weeding thrice and statistically superior to all other treatments. Among weed management strategies, lowest dry matter production of different class of weeds resulted with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and showed parity only with grassy weeds with pendimethalin 750 g/ha *fb* one hand weeding and

Table 3. Effect of treatments on weed density, dry weight and nutrient uptake pattern of weed in wheat at 90 DAS (pooled value of two years)

Treatment	Weed population (no./m^2)			Total weed population (no./m^2)	Dry weight of weeds (g/m^2)			Total dry weight of weeds (g/m^2)	Nutrient uptake by total weeds (kg/ha)			Total uptake by weeds (kg/ha)
	Grasses	BLW	Sedges		Grasses	BLW	Sedges		N	P	K	
Sowing time												
Timely	3.35* (10.75)**	6.21 (38.13)	4.08 (16.21)	8.09 (65.0)	3.86 (14.42)	8.29 (68.33)	4.06 (16.02)	9.96 (98.7)	8.07	2.33	8.26	18.66
Late	3.74 (13.49)	6.99 (48.43)	4.83 (22.9)	9.23 (84.8)	4.81 (22.67)	8.71 (75.52)	4.26 (17.71)	10.7 (115.9)	11.51	2.87	13.14	28.16
Very late	3.37 (10.89)	6.48 (41.62)	3.67 (12.98)	8.12 (65.4)	4.26 (17.72)	8.24 (67.42)	4.80 (22.61)	10.4 (107.7)	10.56	2.36	11.67	24.09
LSD (p=0.05)	NS	0.42	0.38	0.77	0.29	0.31	0.24	0.39	1.64	NS	1.66	2.79
Weed management												
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha	2.57 (6.14)	7.60 (57.38)	4.70 (21.6)	9.25 (85.1)	4.08 (16.22)	7.94 (62.67)	4.92 (23.71)	10.15 (102.6)	10.32	2.84	10.01	23.17
Pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha	3.36 (10.84)	8.25 (67.68)	3.47 (11.59)	9.51 (90.1)	4.36 (18.56)	9.15 (83.37)	4.49 (19.72)	11.05 (121.6)	13.21	3.98	14.56	31.75
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha	3.85 (14.39)	5.60 (30.92)	3.23 (9.98)	7.47 (55.3)	4.63 (21.02)	8.86 (78.05)	3.63 (12.69)	10.59 (111.6)	13.09	1.39	13.17	27.65
Pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha	3.38 (10.98)	5.38 (28.48)	4.31 (18.61)	7.65 (58.0)	4.63 (21.01)	8.61 (73.8)	4.60 (20.68)	10.76 (115.4)	12.14	2.66	13.47	28.27
Pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha	3.17 (9.59)	4.93 (23.85)	3.36 (10.81)	6.68 (44.2)	3.40 (11.09)	5.99 (35.43)	3.08 (9.01)	7.4 (55.3)	4.34	1.24	5.98	11.56
Pendimethalin 750 g/ha *fb* one hand weeding	3.68 (13.07)	5.61 (31.04)	4.99 (24.46)	8.31 (68.5)	3.95 (15.13)	8.54 (72.47)	4.63 (21.01)	10.44 (108.61)	10.69	2.63	11.18	24.52
Hand weeding at 20, 35 and 50 DAS	2.86 (7.72)	3.96 (15.21)	3.24 (10.02)	5.78 (32.9)	2.00 (3.51)	3.31 (10.43)	1.36 (1.35)	3.9 (15.2)	2.35	0.78	3.01	6.14
Weedy check	4.61 (20.76)	9.34 (86.9)	5.75 (32.59)	11.86 (140.2)	6.42 (40.72)	12.53 (156.51)	6.72 (44.72)	15.5 (241.9)	14.19	4.63	15.96	34.78
LSD (p=0.05)	0.37	0.58	0.44	0.97	0.49	0.42	0.39	0.98	1.81	1.23	1.50	2.37

*Data analyzed after square root transformation $\sqrt{x+0.5}$; **Figures in parentheses are original values

significantly better to all other treatments except hand weeding thrice. Lowest dry matter of total weeds observed with timely sown condition and was statistically better to all other main plot treatments. Total weed dry matter significantly influenced by various subplot treatments and lowest value seen with hand weeding thrice, this was followed by pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha. Nutrient uptake by weeds showed significant response with various main plot treatments, lowest nutrient uptake by weeds observed with timely sown condition and statistically better to other date of sowing. Among weed management strategies, least uptake of nutrients by weeds resulted with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha, which was notably better to all other treatments except hand weeding thrice.

Crop growth parameters

Growth attributes such as plant height, dry matter production and CGR serve as indicators of effective resource utilization and play a significant role in achieving better crop production outcomes. Plant height, which can vary based on different varieties and field management practices, is influenced by the number and length of elongated internodes **(Table 4)**. Highest plant height observed with timely sown condition and was at par with late sown condition and significantly better to other main plot treatments. With different weed management options more plant height at maximum growth stage seen with pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha and was at par with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and hand weeding thrice. This might have resulted in reduced crop-weed competition for the growth factors such as light, space and nutrients which in turn might have helped in efficient photosynthetic activity resulting in taller plants. The findings of this study are consistent with the results reported by Mukherjee *et al.* (2022). Sowing dates and weed management practices had a considerable impact on the dry matter accumulation, and this parameter was found more with timely sown condition and was significantly better to all other treatments except late sown where they were at par to each other. Among different herbicidal treatments, more dry matter accumulation observed with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and was at par with three hand weeding and pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha. The weed control treatments had a significant impact on the physiological parameters such as crop growth rate. In the current study, CGR values were observed to be relatively higher at the flowering stage, gradually declining as the crop approached maturity. The variation in CGR is a critical physiological factor that directly influences crop yield potential. CGR of wheat increased with advancement of crop growth and the highest increase was recorded between 60 to 90 DAS **(Table 4)**. CGR of wheat was not significantly influenced by time of sowing techniques except at 60 and 90 DAS. At 60 and 90 DAS, significantly higher CGR was recorded under timely sowing and statistically better than all other treatments, due to more leaf growth, more dry matter accumulated by crop. At 60 and 90 DAS, very late observed lowest CGR over other dates, due to poor growth of crops. CGR was not significantly influenced by weed control treatments at all crop growth stages except at 60, 90 and 120 DAS. With different herbicidal treatments more CGR at 60 DAS was found with hand weeding and was at par only with pendimethalin

Table 4. Effect of treatments on various growth parameters of wheat (pooled data of two years)

Treatment	Plant height at 60 DAS (cm)	Dry matter accumulation at 60 DAS (g/m^2)	Crop growth rate (g/m^2/day) 60 DAS	90 DAS	120 DAS	At harvest	Days to 50% heading	Days to physiological maturity
Sowing time								
Timely	73.39	108.02	5.77	17.08	18.07	7.86	74.66	117.35
Late	70.25	90.24	5.51	16.98	17.53	7.38	68.33	112.4
Very late	68.44	79.21	4.59	16.28	17.78	7.34	62.31	105.44
LSD (P =0.05)	3.62	3.1	0.05	0.16	NS	NS	4.81	3.56
Weed management								
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha	72.25	78.25	5.64	15.48	18.33	7.65	72.66	110.43
Pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha	79.25	102.26	5.33	16.96	18.33	8.35	68.25	112.66
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha	63.25	87.25	4.03	16.64	17.15	6.92	70.43	112.36
Pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha	58.32	89.36	4.85	16.35	16.94	7.74	63.25	113.39
Pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha	76.10	105.36	6.01	17.56	17.03	6.36	65.65	110.31
Pendimethalin 750 g/ha *fb* one hand weeding	74.21	100.65	5.35	17.54	18.69	7.98	70.52	111.42
Hand weeding at 20, 35 and 50 DAS	75.25	104.36	6.03	17.48	18.74	7.35	68.83	113.32
Weedy check	67.36	74.23	4.63	15.68	16.5	7.18	67.66	110.25
LSD (p=0.05)	4.22	3.36	0.10	0.19	0.35	0.61	3.14	4.21

NS : Non-significant* Days after sowing

750 g/ha *fb* clodinafop-propargyl 60 g/ha and statistically better to all other treatments **(Table 4)**. At 90 DAS more CGR observed with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and showed parity with pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and hand weeding thrice. At 120 DAS, more CGR was observed with hand weeding thrice and was at par only with pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and statistically better to other treatments. Days to fifty percent heading was earlier with very late condition and was statistically less to other treatments. Days to 50% heading observed least with pendimethalin 750 g/ha *fb* one hand weeding and was at par with pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha and hand weeding thrice at 20, 35 and 50 DAS. Further, highest duration of physiological maturity took place by timely sown condition and statistically more to other main plot treatments. However, the least value found with very late sown condition. Various herbicidal treatments produced statistical difference and more time needed with pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and was followed by pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha, hand weeding thrice and significantly better to other treatments.

Yield attributes

Yield attributing characters and yield varies significantly with different treatments and showed quite distinct marks on crop yield **(Table 5)**. Ear head /m^2 observed more with timely sown condition and was statistically at par with late condition, and significantly superior to other main plot treatments. With different weed management options, more ear head per meter square were seen with hand weeding thrice and showed parity with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS, and significantly better to other treatments. Lowest number of ineffective tillers per meter square determined with timely sown condition and statistically better to all other treatments. With different subplot treatments, least ineffective tiller/m^2 observed with hand weeding thrice and was at par with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and statistically better to other treatments. Grain per spike and test weight of grain were observed highest with timely sown condition and was statistically better to other sowing time. This was followed by late and very late sowing of wheat. Grain/spike observed more with pendimethalin 750 g/ha *fb* one hand weeding and was notably better to all other treatments. Thousand grain weight more observed with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and was at par with hand weeding at 20, 35 and 50 DAS, pendimethalin 750 g/ha *fb* one hand weeding at 35 DAS and pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha. The final yield of a crop is the net result of growth and developmental activities in individual plants, which in turn would depend upon the genetic potential of the cultivars and the environmental condition to which it is exposed during the course of its life cycle. Biomass production showed significant variation with different sowing time under various weed control measures.

Grain and straw yield

Grain yield varies significantly with sowing windows and weed management measures. More grain yield was observed with timely sown condition and was statistically better to other main plot treatments during first (4.94 t/ha) and second year (4.6 t/ha) of data recording. Timely sown conditions gain 97.6 and 45.86 % more grain yield over very late sown situations **(Table 5)**. Delayed sowing of wheat, exposed to both the extremes of temperature (low temperature during early growth period) which restrict the vegetative phase and high temperature during post anthesis period which reduce the duration of grain development and consequently the grain yield drastically reduced under very late sown situation (Mukherjee and Mandal 2021). With various subplot treatments, during first year more grain yield was observed with pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha (4.63 t/ha) and was closely followed by hand weeding thrice, pendimethalin 750 g/ha *fb* one hand weeding, pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha and they were statistically at par with each other. However, during second year, more grain yield observed with hand weeding thrice (4.36 t/ha) and showed parity with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and pendimethalin 750 g/ha *fb* one hand weeding, and significantly better than other treatments. These treatments registered 76.71 and 20.93% more gain yield over the control plot respectively, during the first and second year of observation. More grain yield was recorded owing to effective control of weeds and higher growth and yield attribute of wheat. This corroborates with the finding of Kumar *et al.* (2014). The study concluded that sequential/tank-mix application of pre- and or post-emergence grass, sedges and broadleaf killers could be adopted for broad-spectrum control of weeds in wheat. The adoption of effective weed management practices resulted in reduced competition between wheat and weeds for essential resources like nutrients, moisture, light, and space. This facilitated better utilization of sunlight, increased carbohydrate synthesis, and improved allocation of

Table 5. Effect of various treatments on yield attributes (pooled data of two years) and yield of wheat

Treatment	Ear head /m² (no.)	No. of ineffective tiller/m²	Grain/spike (no.)	1000 grain weight (g)	Grain yield (t/ha)		Straw yield (t/ha)		Harvest index (%)	
					2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Sowing time										
Timely	313.16	41.98	52.67	45.01	4.94	4.61	6.73	7.81	42.33	37.11
Late	287.43	50.44	44.36	41.95	3.86	3.30	6.83	4.41	36.10	42.80
Very late	256.86	58.54	37.61	37.48	2.50	3.16	4.70	3.83	34.72	45.20
LSD (p=0.05)	27.09	1.24	4.23	2.21	0.32	0.43	0.58	0.61	2.17	1.98
Weed management										
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha	241.01	68.98	44.51	38.11	3.50	3.27	4.12	5.25	45.93	38.38
Pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha	279.15	47.41	39.54	39.68	3.02	3.96	5.10	5.71	37.19	40.95
Pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha + carfentrazone 20 g/ha	301.74	60.65	45.59	37.75	4.63	3.74	6.83	6.21	40.40	37.58
Pendimethalin 750 g/ha *fb* pinoxaden 50 g/ha	307.43	39.44	47.73	43.53	4.32	3.81	6.71	5.49	39.16	40.96
Pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha	337.84	35.36	45.26	45.93	4.40	4.01	7.22	6.84	37.86	36.95
Pendimethalin 750 g/ha *fb* one hand weeding	336.78	46.84	51.65	44.29	4.60	3.92	6.67	6.02	40.81	39.43
Hand weeding at 20, 35 and 50 DAS	341.66	33	42.49	45.76	4.62	4.36	6.93	6.28	40.01	40.97
Weedy check	137.42	74	39.73	37.32	2.62	1.41	3.93	2.51	40.13	35.86
LSD (p=0.05)	20.97	3.00	3.03	2.44	0.41	0.47	0.67	0.73	3.14	NS

NS : Non-significant

photosynthates towards grain formation, ultimately leading to higher straw yield. This parameter, significantly influenced by main plot treatment measures and found more with the timely sown and was significantly better to other sowing windows. This gave 75.4 and 31.08% more over the very late and late sown condition. The more grain yield and straw production were resulted with timely sowing accrued mainly because of more dry matter accumulation and increase in yield attributing traits. Among various weed management measures, more biological yield observed with pendimethalin 750 g/ha *fb* clodinafop-propargyl 60 g/ha and was at par with all the treatments except pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha, pendimethalin 750 g/ha *fb* carfentrazone 20 g/ha and weedy check. Harvest index failed to produce any statistical difference with various main plot treatments **(Table 5)**. More harvest index observed with timely sown condition during first year and in second year seen with very late sown condition and statistically better to other main plot treatments. With various subplot treatments, more harvest index was seen with pendimethalin 750 g/ha *fb* metsulfuron 4 g/ha during first year only and failed to give any statistical difference in second year of experiment. Overall, the effective management of weeds using suitable herbicidal combinations under different sowing periods proved beneficial for wheat crops, leading to increased growth, yield, and productivity.

The study concluded that sequential/tank-mix application of pre- and or post-emergence grass, sedges and broadleaf killers could be adopted with appropriate sowing time for broad-spectrum control of weeds in wheat.

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