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RESEARCH ARTICLE

Efficacy of pre-emergent herbicides on weed dynamics, productivity and profitability of wheat (*Triticum aestivum* L.) in Northwestern Himalayan region

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Abstract

Weed infestation is one of the major threats to crop productivity and ineffective management can exacerbate the issue. Under these circumstances, using highly effective broad-spectrum herbicides is the only viable way to supress weeds. With this aim, a field experiments were conducted at Research Farm of Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu during *rabi* season 2021-22 and 2022-23 with twelve treatments on sandy clay loam soil in Randomized Block Design (RBD), replicated thrice. The results revealed that weed free plot gave higher growth and yield attributes *viz.,* plant height (100.05 cm), dry matter accumulation (1309.22 g m^{-2}), effective tillers (459.64 m^{-2}), grain spike^{-1} (47.26), test weight (42.76 g), grain yield (5377.67 kg ha^{-1}) and straw yield (7842.68 kg ha^{-1}) *fb* pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix). The pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix) recorded significantly higher weed control efficiency (90.75 and 90.82 %), lower weed density (4.12 and 4.21 m^{-2}), weed biomass (2.59 and 4.97 g m^{-2}) at 30 and 60 DAS, respectively and lower weed index (10.35 %) as compared to weedy check plot. Maximum gross returns (147573.36 ₹ ha^{-1}) and net returns (107206.86 ₹ ha^{-1}) were recorded under weed free plot but highest B: C ratio (3.37) was achieved in pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix). Moreover, no phytotoxicity symptoms were seen in any of the treatment in the succeeding crop.

Keywords: economics; phytotoxicity; pre-emergence; weed control efficiency; wheat; yield

Introduction

In India, wheat (*Triticum aestivum* L.) is a staple food and hold second position after rice. It contributes about one third of the whole cereal production which plays an important role in ensuring food and nutritional security. The top wheat producing countries are China, India, United states, Russia, France and Australia. Globally, India ranks as the second largest wheat producer, contributing around 12 % to the world's total wheat production. Wheat is cultivated on an area about 220.60 million hectares with a total production of 789.50 million tonnes and an average yield of 3.58 tonnes ha^{-1} in the world (1). In India, wheat is grown on an area about 30.47 million hectares with a production of 106.84 million tonnes and an average productivity of 3.50 tonnes ha^{-1} (2).

In Northwestern Himalayan (NWH) region, weeds are the major menace for sustainable wheat production and causes huge losses ranging from 37 to 50 % due to their interference (3). In NWH, the primary grassy weeds associated with wheat crops include *Phalaris minor, Cynodon dactylon, Avena ludoviciana* and *Poa annua*. Whereas main broad-leaved weeds are *Chenopodium album, Coronopus didymus, Ranunculus arvensis* and *Canada thistle* and sedges consisted of *Cyperus rotundus*. These weeds typically compete with crop plants for nutrient, water, space and light. They extract plant nutrients more efficiently than the crops. If not controlled, weeds can grow taller than crop plants and hinder their growth based on the level of competition. This leads to a reduction in crop yield by 10-15 % (4).

Wheat crop is planted at narrow row spacing, which makes mechanical weed control challenging and increasing production costs. Therefore, using herbicides is the most effective weed control method for farmers. Over the year, the effectiveness of herbicides has decreased and there is a likelihood of development of crop resistance (5). To effectively manage the diverse and complex weed flora in wheat crop, it is essential to assess various herbicides to achieve broad-spectrum weed control. In such situation, using herbicides with different mode of action like pendimethalin (pre-emergence), pyroxasulfone (pre-emergence) and metribuzin (pre and post emergence), whether used individually or tank mix combinations, could be better options (6). This approach not only broadens weed management and control strategies but also helps to reduce selection pressure on resistant biotypes, thereby preventing the development of multiple resistance and sustaining wheat production. These herbicides absorbed through the leaves and shoots with no harmful effect on the wheat and succeeding crops.

Thus, an on-farm experiment was conducted to evaluate the effectiveness of various pre-emergence and early post emergence herbicides in controlling the diverse weed flora in wheat. This aimed to develop an alternative chemical weed management strategy to improve wheat productivity, profitability and resource use efficiency.

Materials and Methods

A field experiment was conducted during *rabi* season of 2021-22 and 2022-23 at the experimental farm of Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu (Fig. 1). Geographically, it is located between 32˚39’33” N to 74˚48’45” E longitude at an altitude of 293 m above mean sea level. This region falls under subtropical foothills of Shivalik Himalayas agro-climatic zone of Jammu & Kashmir. The soil at the experimental site was sandy clay loam in texture, with pH (7.2), electric conductivity (0.25 dS m^{-1}), low organic carbon (4.06 g kg^{-1}) and available nitrogen (223 kg ha^{-1}) but medium in phosphorus (12.14 kg ha^{-1}) and potassium (153.21 kg ha^{-1}). Weather data was attained from the meteorological observatory located close to the experimental site at Research Farm, SKUAST-Jammu. Mean daily minimum and maximum temperature varied between 4.95 to 18.08 °C and 16.18 to 37.88 °C, respectively in 2021-22, whereas in the year of 2022-23 these values were 5.13 to 15.95 °C and 16.60 to 32.66 °C during the growing season (November to April). The average daily relative humidity fluctuated between 92.28 to 19.75 % in 2021-22 and 94.51 to 32.18 % in 2022-23. During 2021-22 and 2022-23, the total rainfall received in the crop growing season was 273.40 mm and 231.30 mm, respectively (Table 1). Wheat variety ‘*DBW -222*’ was manually sown on 18 November 2021 and 20 November 2022, using seed rate of 100 kg ha^{-1}. The crop was sown in line 20 cm apart. There were twelve treatments used in the experiment, namely: T_1-Pre-emergence (PE) application of Pendimethalin @ 1000 g a.i. ha^{-1}; T_2-Pendimethalin @ 1500 g a.i. ha^{-1} (PE); T_3-Pyroxasulfone @ 127.5 g a.i. ha^{-1} (PE); T_4-Pendimethalin + Pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1} (PE tank mix); T_5-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (PE); T_6-Early Post emergence (EPOST) application of Pyroxasulfone @ 127.5 g a.i. ha^{-1}; T_7-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (EPOST); T_8-Metribuzin @ 300 g a.i. ha^{-1} (PE); T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix); T_{10}-Pyroxasulfone + metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix); T_{11}-Weedy check and T_{12}-Weed free. The experiment was laid out in RBD replicated thrice. Each treatment occupied a 14.40 m^2 plot (1.80 m × 7 m). The crop fertilized with recommended rate of fertilizer (100:50:25 kg N:P:K ha^{-1}). Nitrogen was applied in three splits, 1/3rd nitrogen and full dose of phosphorus and potassium were applied as basal at the time of sowing. Remaining nitrogen was applied as 1/3rd at first irrigation and 1/3rd at second irrigation. Herbicides were applied as per the treatment by using battery operated knapsack sprayer fitted with flat fan nozzle at a water volume of 500 L ha^{-1}. From each plot 5 plants were randomly selected and tagged for recording different observations and mean of these five values was determined. Quadrate (0.50 m^2) was randomly placed at five places in each of the plot to count density (m^2) and biomass (g m^{-2}) of weeds at periodic intervals of 30, 60 DAS (days after sowing). The data were transformed using $\sqrt{x}$ + 0.5 to make analysis of variance more effective.

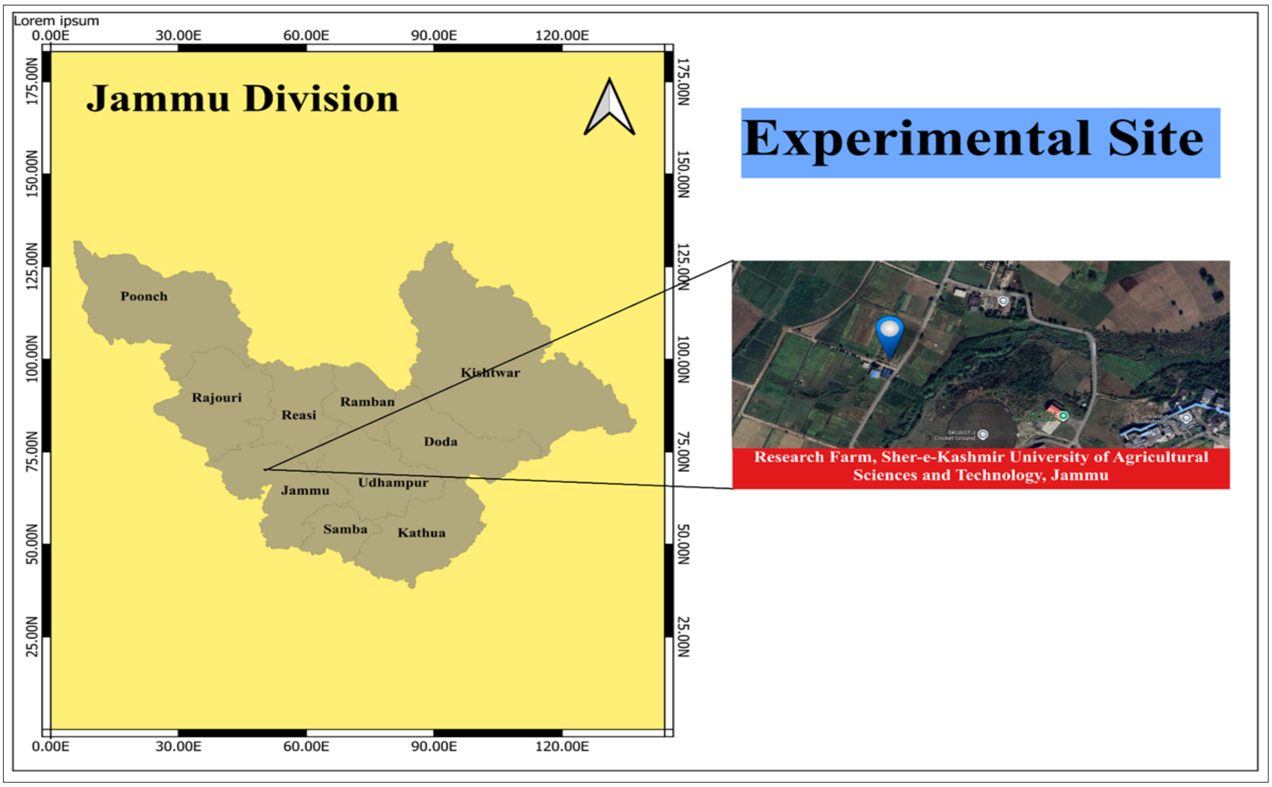

Fig. 1. Location map of the experimental site at Research Farm, SKUAST-Jammu (indicated as blue location sign).

Table 1. Weather data during the crop season

Month	2021-22					2022-23				
	Temperature (˚C)		Relative humidity (%)		Rainfall (mm)	Temperature (˚C)		Relative humidity (%)		Rainfall (mm)
	Max	Min	8 am	5 pm		Max	Min	8 am	5 pm	
November	25.53	7.57	91.33	37.67	0.00	24.77	8.03	93.13	46.23	10.60
December	20.95	4.95	91.75	47.50	0.00	20.93	5.55	92.95	51.90	9.60
January	16.18	7.42	92.28	72.96	191.80	16.60	5.13	94.51	70.17	51.80
February	21.14	6.70	91.30	55.12	40.80	24.28	8.46	88.71	51.23	32.80
March	29.92	12.66	82.38	43.88	36.20	26.86	12.49	91.03	51.23	96.20
April	37.88	18.08	53.23	19.75	4.60	32.66	15.95	77.07	32.18	30.30

Different weed indices were calculated by using following formulas:

Weed Control Efficiency (WCE)

It can be worked out taking into consideration the reduction in weed dry weight in treated plot over weed dry weight in unweeded plot (control). It is expressed in % (7).

$$\text{WCE (\%)} = \frac{\text{Wc - Wt}}{\text{Wc}} \text{ X 100} \qquad \text{(Eqn. 1)}$$

Whereas,

Wc= Weed dry weight in unweeded plot

Wt= Weed dry weight in treated plot

Weed Index (WI)

WI is the measure of the efficiency of a particular treatment when compared with a weed free treatment. WI is the percentage yield loss caused due to weeds as compared to unweeded (weedy check). Higher WI means greater yield loss. It is expressed in percentage (8).

$$\text{WI (\%)} = \frac{\text{Ywf - Yt}}{\text{Ywf}} \text{ X 100} \qquad \text{(Eqn. 2)}$$

Whereas,

Ywf= Yield from weed free plot

Yt= Yield from treated plot

Yield attributes and yield

After harvesting, various yield attributes were recorded and grain yield were recorded from the net plot area of 9.80 m^2 (1.40 m × 7 m) of every treatment. To evaluate the returns from each treatment, an economics analysis was carried out. Net returns were calculated by deducting the total cultivation expenses from the gross income derived from wheat grain and straw yield. The costs of urea, single superphosphate, muriate of potash and all herbicides were included in the calculations. In addition, various production expenses such as land preparation, sowing, weeding, fertilizer application, spraying and harvesting were considered.

Statistical analysis

The experimental data, collected from several observations, were subjected to statistical analysis using the Analysis of Variance (ANOVA) method. Pooled mean values derived from three replications per year were analysed (9). The Least Significance Difference (LSD) was calculated to compare treatments, whenever the variance ratio (F-test) showed significance at the 5 % probability level.

Results and Discussion

Weed studies

The most dominant weed species found in the experimental site during the crop growing period consisted of grassy weeds (20.89 %) *viz., Phalaris minor* and *Cynodon dactylon*. Similarly, broad-leaved weeds like *Chenopodium album, Coronopus didymus, Ranunculus arvensis* and *Canada thistle* consisted (30.04 %) and the weed amongst sedges was found to be *Cyperus rotundus* contributed (10.52 %) of the total weed flora (Fig. 2). Data presented in Fig. 2 showed that experimental field was mostly infested with broad-leaved population followed by grasses and sedges under all the treatments. The lowest relative weed density of broad leaved, grasses and sedges were recorded under treatment T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix) (20.57, 15.32 and 5.13 %, respectively), whereas the highest relative weed density was found under weedy check treatment. Data further revealed that on pooled basis in Table 2, among the herbicide application significantly lowest weed density (4.12 m^{-2}), weed biomass (2.59 g m^{-2}) and higher WCE (90.75 %) were recorded in T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix) which was statistically at par with T_{10}-Pyroxasulfone + metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix) and T_4-Pendimethalin + Pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1} (PE tank mix) at 30 DAS. Similarly, at 60 DAS, significantly minimum weed density (4.21 m^{-2}), weed biomass (4.97 g m^{-2}) and higher weed control efficiency (90.82 %) were recorded in T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix) than all the other treatments but remained at par with T_{10}-Pyroxasulfone + metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix) and T_4-Pendimethalin + pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1} (PE tank mix). Furthermore, the WI followed the similar trend. Whereas significantly highest weed density (9.10 and 11.78 m^{-2}), weed biomass (8.23 and 16.34 g m^{-2}) at 30 and 60 DAS, respectively and WI (56.97 %) were recorded under the weed check (T_{11}) treatment. A significant negative correlation (r = -0.95) was observed between weed biomass and grain yield (Fig. 3). Sole application of a single herbicide is often less effective in managing weed populations as compared to tank mix herbicide applications. This can be attributes to fact that different herbicides target specific types of weeds and using only one may not sufficiently address the diversity of weeds present in a field. The inadequate control can lead to the potential resurgence of weeds that the single herbicide does not affect, further complicating weed management strategies.

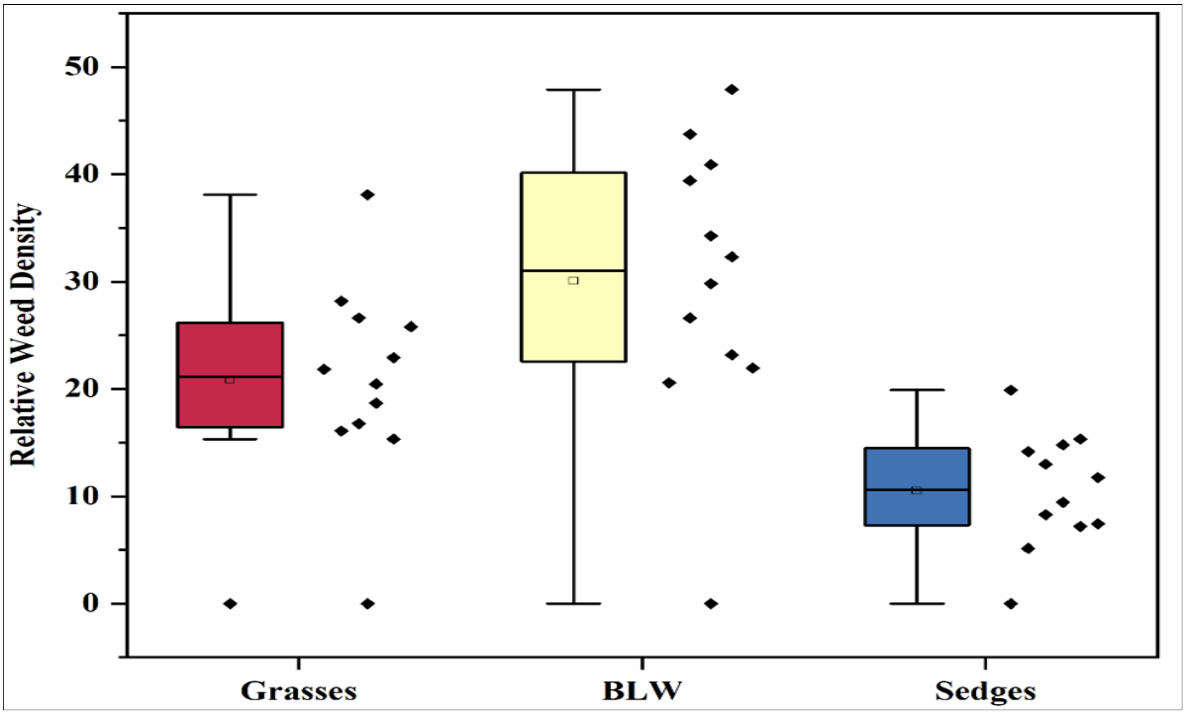

Fig. 2. Box plot of Relative Weed Density (%) as influenced by pre and early pre-emergence tank mix herbicide application.

The application of tank mixtures combining broad-leaf and grassy weed herbicides has been shown to enhance weed control effectiveness compared to single herbicide applications. Such combinations not only reduce weed density but also effectively manage WI. This combination exhibits properties of both foliar and soil activity that inhibits cell division in shoots and roots by inhibiting elongation of Very-Long-Chain Fatty Acids (VLCFA) that are crucial for the formation of cell membrane, leading to the failure of essential cellular structures in germinating weed seeds. In addition, it inhibits photosynthesis by binding to the D1 protein in the Photosystem II reaction centre. This binding blocks the electron transport chain that is essential for the production of ATP (adenosine triphosphate) and NADPH (nicotinamide adenine dinucleotide phosphate hydrogen), both of which are critical energy molecules for photosynthesis. Without the generation of these energy molecules, the plant is unable to convert light energy into chemical energy leading to energy depletion, oxidative damage and ultimately, cell death. The individual application of either herbicide alone proved ineffective in managing all types of weeds throughout the entire crop season (10, 11).

Growth attributes

Plant height and dry matter accumulation of wheat as influenced by various weed management practices is illustrated in Table 3. Significantly highest plant height and dry matter accumulation of wheat (100.05 cm and 1309.22 g m^{-2}, respectively) were recorded under the weed free (T_{12}) treatment in contrary to all the treatment. The next best treatment was T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix) (100.03 cm and 1149.79 g m^{-2}, respectively) was statistically similar to T_{10}-Pyroxasulfone + Metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix) and T_4-Pendimethalin + Pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1}

Table 2. Weed Density (WD), Weed Biomass (WB), WCE and WI at different growth stages of wheat as influenced by different weed management practices (pooled data of two years)

Treatments	WD (m^{-2})		WB (g m^{-2})		WCE (%)		WI (%)
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	
T_1	6.10(36.68)	5.11(25.66)	4.00(15.55)	7.22(51.75)	76.66	80.55	22.64
T_2	4.90(23.52)	4.95(24.10)	3.26(10.18)	6.20(37.99)	84.91	85.72	21.58
T_3	6.60(43.19)	6.14(37.22)	4.34(18.36)	8.21(66.90)	72.62	74.87	24.77
T_4	4.57(20.43)	4.61(20.72)	2.88(7.81)	5.43(29.03)	88.30	89.09	18.66
T_5	6.37(40.21)	6.00(35.49)	4.04(15.85)	8.01(63.65)	76.23	76.09	23.47
T_6	7.02(48.82)	6.95(47.82)	4.59(20.59)	8.53(72.24)	69.40	72.87	25.22
T_7	6.42(40.79)	6.07(36.41)	4.25(17.57)	8.19(66.70)	73.72	74.94	23.97
T_8	6.24(38.52)	5.86(33.83)	4.01(15.57)	7.97(63.17)	76.68	76.34	23.37
T_9	4.12(16.45)	4.21(17.38)	2.59(6.20)	4.97(24.39)	90.75	90.82	10.35
T_{10}	4.56(20.27)	4.57(20.44)	2.75(7.11)	5.39(28.59)	89.46	89.27	15.49
T_{11}	9.10(82.37)	11.78(138.35)	8.23(67.35)	16.34(266.72)	0.00	0.00	56.97
T_{12}	0.71 (0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	100.00	100.00	0.00
LSD (p=0.05)	**0.47**	**0.44**	**0.34**	**0.51**	**3.49**	**2.49**	**8.51**

T_1-Pre-emergence (PE) application of Pendimethalin @ 1000 g a.i. ha^{-1}; T_2-Pendimethalin @ 1500 g a.i. ha^{-1} (PE); T_3-Pyroxasulfone @ 127.5 g a.i. ha^{-1} (PE); T_4-Pendimethalin + Pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1} (PE tank mix); T_5-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (PE); T_6-Early Post emergence (EPOST) application of Pyroxasulfone @ 127.5 g a.i. ha^{-1}; T_7-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (EPOST); T_8-Metribuzin @ 300 g a.i. ha^{-1} (PE); T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix); T_{10}-Pyroxasulfone + metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix); T_{11}-Weedy check and T_{12}-Weed free. Where, the original values enclosed in parentheses underwent a square root transformation ($\sqrt{X + 0.5}$) prior to being subjected to statistical analysis.

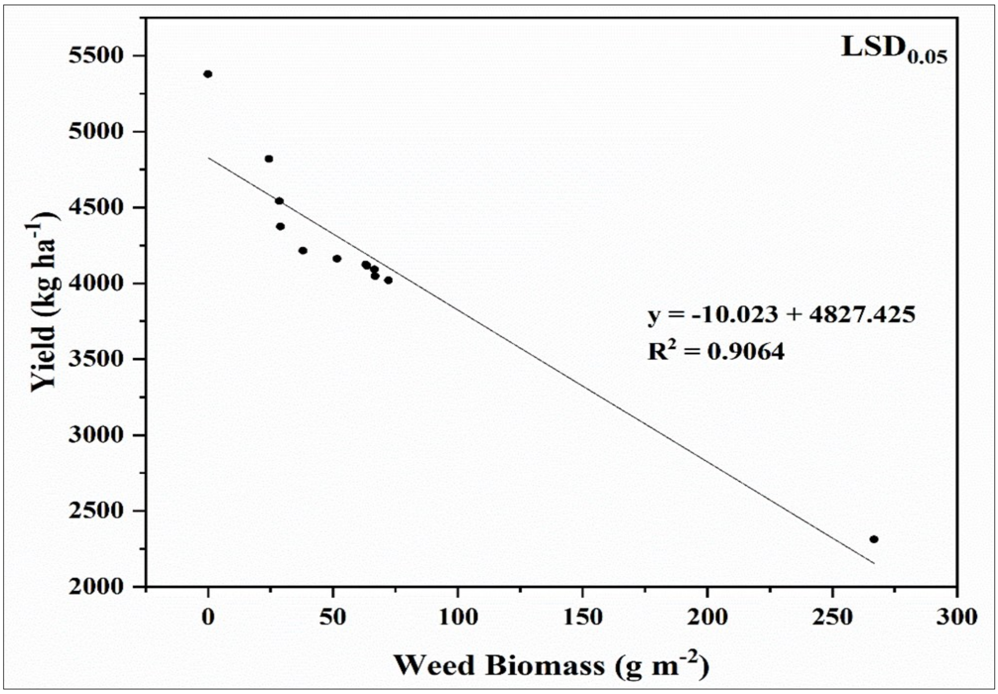

Fig. 3. Linear regression analysis between weed biomass (g m^{-2}) and grain yield (kg ha^{-1}).

(PE tank mix). The weedy check (T_{11}) recorded significantly lower plant height and dry matter accumulation (76.77 cm and 728.54 g m^{-2}, respectively). The use of pyroxasulfone and metribuzin herbicide tank mix can be attributed to the synergistic effects of effective weed management. These two herbicides work together to provide comprehensive control of weeds than single herbicide application, which reduced competition for critical resources such as light, nutrients, water and space. By effectively controlling both grass and broadleaf weeds, crop can maximize their physiological processes, including photosynthesis and nutrient uptake, leading to increased biomass production and improved plant height (12-14).

Yield attributes and yield

The yield attributes of wheat such as effective tillers, grains spike^{-1} and test weight were influenced significantly due to different weed management practices is presented in Table 3. Significantly higher effective tillers and grains spike^{-1} were recorded under T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix) (452.12 m^{-2} and 45.18, respectively) than rest of treatments but was found statistically at par with T_{10}-Pyroxasulfone + Metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix) and T_4-Pendimethalin + pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1} (PE tank mix). The test weight showed non-significant result. This can be attributed to a substantial reduction in crop weed competition, which allowed the crop to make optimal use of nutrient, water, light and space. This improved resource availability positively impacted growth parameters, ultimately enhancing yield attributing traits (15, 16). The significantly highest grain and straw yield of wheat (5377.67 and 7842.68 kg ha^{-1}) were observed in weed free (T_{12}) than all rest of the treatments. However, among herbicide treatments significantly higher grain and straw yield were recorded under T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix) (4820 and 7169.07 kg ha^{-1}, respectively) which was statistically similar to T_{10}-Pyroxasulfone + metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix) (4542 and 6781.74 kg ha^{-1}, respectively) and T_4-Pendimethalin + pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1} (PE tank mix) (4374.33 and 6430.73 kg ha^{-1}, respectively). The grain yield increased by 52.01, 49.07 and 47.12 % after the application of T_9-Pendimethalin + metribuzin

Table 3. Growth and yield attributes of wheat as influenced by different weed management practices (pooled data of two years)

Treatments	Plant height (cm)	Dry biomass (g m^{-2})	Effective Tillers (m^{-2})	Grains spike^{-1}	Test weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1	89.38	993.38	388.52	39.87	38.35	4161.00	6295.80
T_2	89.99	1002.38	393.21	40.01	39.10	4215.00	6365.80
T_3	86.56	953.42	366.25	38.23	36.79	4046.00	5718.73
T_4	97.86	1045.40	429.70	42.19	40.16	4374.33	6430.73
T_5	88.30	969.78	379.34	39.14	37.85	4114.33	5830.11
T_6	86.12	952.40	361.59	37.92	36.60	4020.00	5564.06
T_7	87.77	966.02	370.46	38.76	37.14	4092.00	5762.14
T_8	89.20	968.56	384.00	39.44	38.21	4124.33	6173.37
T_9	100.03	1149.79	452.12	45.85	41.81	4820.00	7169.07
T_{10}	98.72	1048.42	434.20	43.26	40.75	4542.00	6781.74
T_{11}	76.77	728.54	293.01	22.30	34.94	2313.00	3724.33
T_{12}	100.05	1309.22	459.64	47.26	42.76	5377.67	7842.68
LSD (p=0.05)	**7.70**	**135.17**	**56.90**	**4.28**	**NS**	**457.13**	**760.75**

T_1-Pre-emergence (PE) application of Pendimethalin @ 1000 g a.i. ha^{-1}; T_2-Pendimethalin @ 1500 g a.i. ha^{-1} (PE); T_3-Pyroxasulfone @ 127.5 g a.i. ha^{-1} (PE); T_4-Pendimethalin + Pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1} (PE tank mix); T_5-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (PE); T_6-Early Post emergence (EPOST) application of Pyroxasulfone @ 127.5 g a.i. ha^{-1}; T_7-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (EPOST); T_8-Metribuzin @ 300 g a.i. ha^{-1} (PE); T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix); T_{10}-Pyroxasulfone + metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix); T_{11}-Weedy check and T_{12}-Weed free.

@ 1250 + 280 g a.i. ha^{-1} (PE tank mix) followed by T_{10}-Pyroxasulfone + metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix) and T_4-Pendimethalin + pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1} (PE tank mix), respectively over weedy check due to higher weed control efficiency (Fig. 4). This might be due to fact that the accumulation of photosynthates in different plant parts promotes tissue growth and expansion, resulting in a steady increase in dry matter. This process contributes to the development of more effective tillers, an increased number of grains spike-1 and higher test weight, all of which collectively enhance grain yield (17, 18).

Economics

It was observed that cost of cultivation for wheat was more in case of weed free treatment (₹ 40366.5 ha^{-1}). Among the herbicide treatments maximum gross returns, net returns and B: C ratio was recorded under T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix) (₹ 132968.28 ha^{-1}, ₹ 102549.28 ha^{-1} and 3.37, respectively). Whereas, weedy check (T_{11}) treatment recorded minimum gross returns, net return and B: C ratio (₹ 65228.60 ha^{-1}, ₹ 37862.10 ha^{-1} and 1.38, respectively) (Table 4). The higher economics returns in the aforementioned treatments can be attributed to the higher yield achieved in those treatments. The higher yield was primarily due to improved growth parameters and yield contributing factors. These improvements were a direct result of effective weed management in the treated plots, which minimized competition for nutrient, water, space and light. Consequently, the crop exhibited enhanced physiological performance, leading to higher quality produce ultimately generating greater returns (19).

Correlation and regression studies

The correlation matrix (Fig. 5) demonstrated the linear

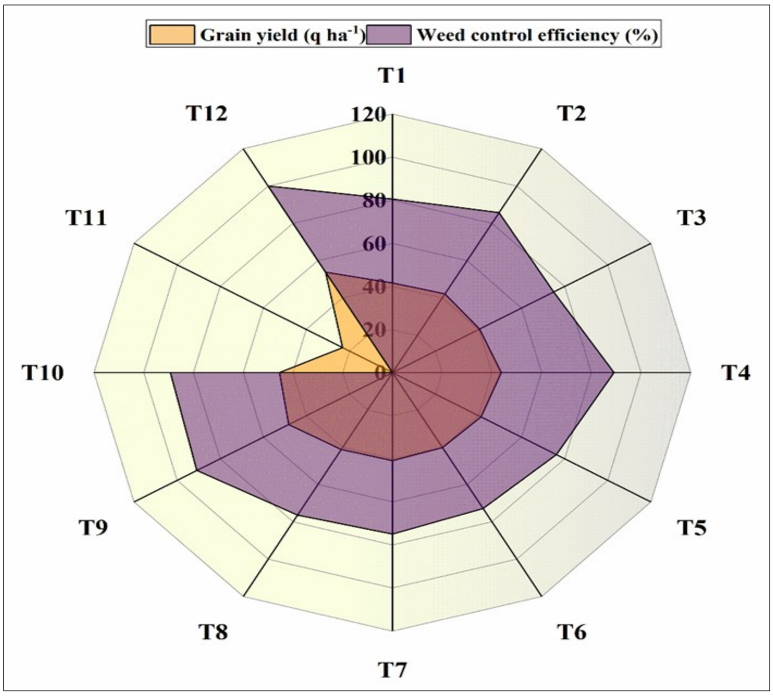

Fig. 4. Comparative radar chart of grain yield (q ha^{-1}) and WCE (%). T_1-Pre-emergence (PE) application of Pendimethalin @ 1000 g a.i. ha^{-1}; T_2-Pendimethalin @ 1500 g a.i. ha^{-1} (PE); T_3-Pyroxasulfone @ 127.5 g a.i. ha^{-1} (PE); T_4-Pendimethalin + Pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1} (PE tank mix); T_5-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (PE); T_6-Early Post emergence (EPOST) application of Pyroxasulfone @ 127.5 g a.i. ha^{-1}; T_7-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (EPOST); T_8-Metribuzin @ 300 g a.i. ha^{-1} (PE); T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix); T_{10}-Pyroxasulfone + metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix); T_{11}-Weedy check and T_{12}-Weed free.

Table 4. Relative economics of wheat as influenced by different weed management practices (pooled data of two years)

Treatments	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B: C ratio
T_1	29041.49	115323.14	86281.65	2.97
T_2	29716.50	116761.25	87044.75	2.93
T_3	30691.50	110120.55	79429.05	2.59
T_4	32379.00	120296.47	87917.47	2.72
T_5	30941.50	112054.29	81112.79	2.62
T_6	30691.50	108823.32	78131.82	2.55
T_7	30941.50	111264.51	80323.01	2.60
T_8	28805.86	113972.11	85166.25	2.96
T_9	30419.00	132968.28	102549.28	3.37
T_{10}	31731.50	125429.92	93698.42	2.95
T_{11}	27366.50	65228.60	37862.10	1.38
T_{12}	40366.5	147573.36	107206.86	2.66

T_1-Pre-emergence (PE) application of Pendimethalin @ 1000 g a.i. ha^{-1}; T_2-Pendimethalin @ 1500 g a.i. ha^{-1} (PE); T_3-Pyroxasulfone @ 127.5 g a.i. ha^{-1} (PE); T_4-Pendimethalin + Pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1} (PE tank mix); T_5-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (PE); T_6-Early Post emergence (EPOST) application of Pyroxasulfone @ 127.5 g a.i. ha^{-1}; T_7-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (EPOST); T_8-Metribuzin @ 300 g a.i. ha^{-1} (PE); T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix); T_{10}-Pyroxasulfone + metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix); T_{11}-Weedy check and T_{12}-Weed free

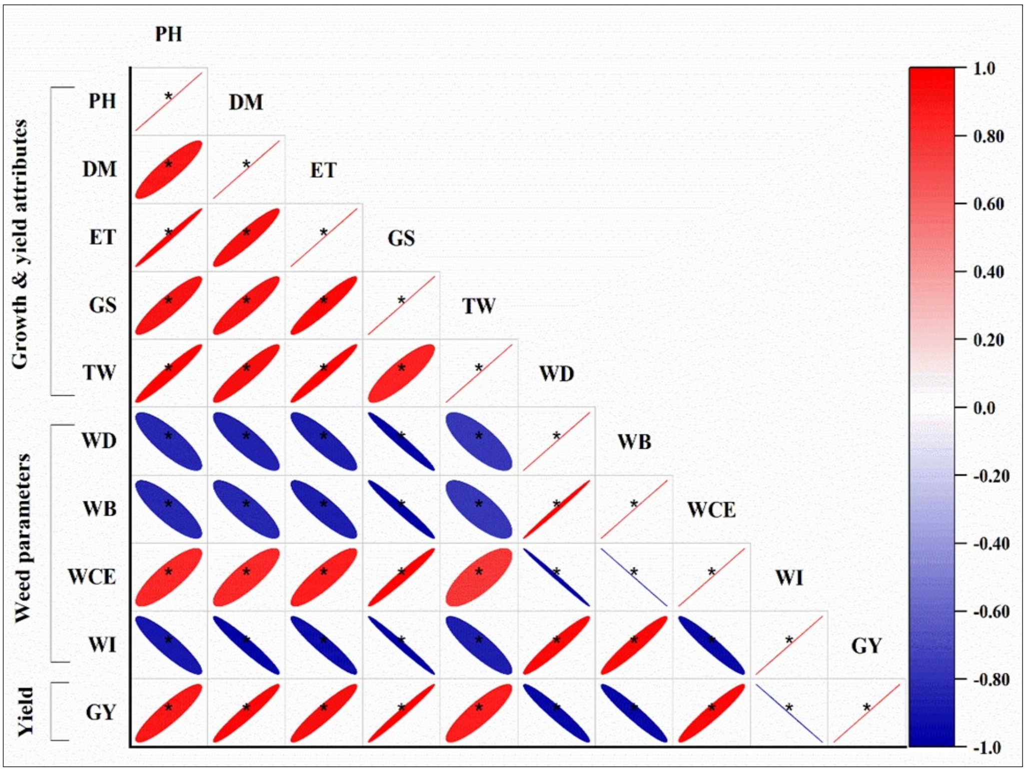

Fig. 5. Pearson's correlation among weed parameters, growth and yield attributes and yield of wheat. WD: Weed Density; WB: Weed Biomass; WCE: Weed Control Efficiency; WI: Weed Index; PH: Plant Height; DM: Dry Matter accumulation; ET: Effective Tillers; GS: Grains Spike^{-1}; TW: Test Weight; GY: Grain Yield.

relationship among various parameters, highlighting that individual parameter such as PH, DM, ET, GS, TW, WD, WB, WI and WCE has a significant (p = 0.05) influenced GY of wheat under different weed management practices. The matrix clearly indicated that grain yield had strong positive relation with PH (r= 0.90), DM (r = 0.96), ET (r = 0.94), GS (r = 0.99), TW (r = 0.87) and WCE (r = 0.95), whereas negative correlation was exhibited with WD (r = -0.96), WB (r = -0.95) and WI (r = -0.99). The degree of goodness of the fitted regression model for wheat grain yield on PH (R^2= 0.81), DM (R^2= 0.92), ET (R^2= 0.88), GS (R^2= 0.98), TW (R^2= 0.75), WD (R^2= -0.92), WB (R^2= -0.90), WI (R^2= -0.98) and WCE (R^2= 0.90) illustrated the strong dependence of wheat grain yield on these parameters under different weed management practices.

Phytotoxicity study on succeeding crop of mungbean

All the herbicide treatments did not cause any phytotoxic effect on mungbean. After planting no visible phytotoxicity symptoms on the germination of the succeeding crop of mungbean (Fig. 6).

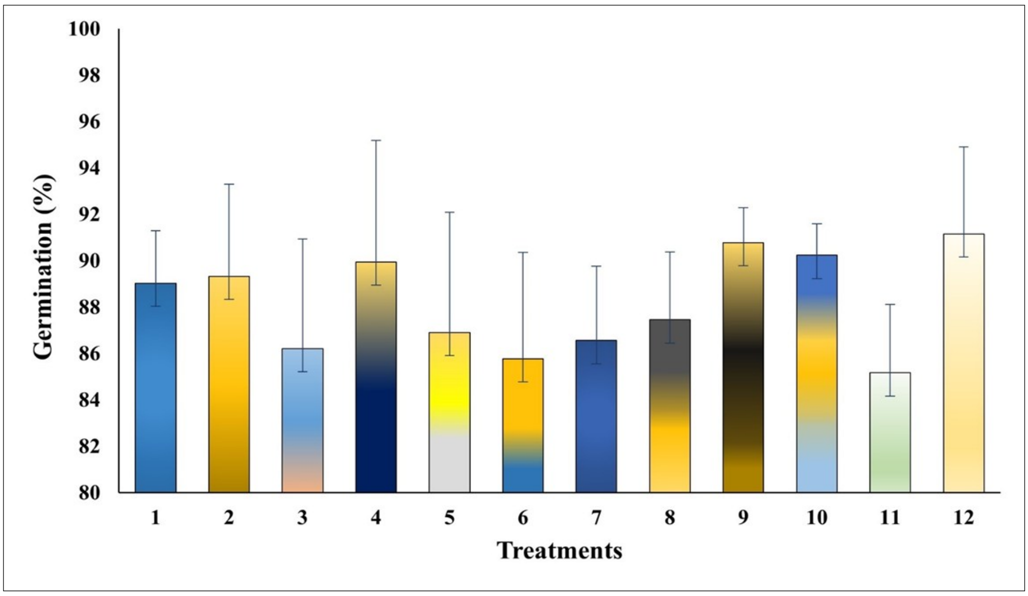

Fig. 6. Phytotoxicity effect on germination (%) of succeeding crop of mungbean. T_1-Pre-emergence (PE) application of Pendimethalin @ 1000 g a.i. ha^{-1}; T_2-Pendimethalin @ 1500 g a.i. ha^{-1} (PE); T_3-Pyroxasulfone @ 127.5 g a.i. ha^{-1} (PE); T_4-Pendimethalin + Pyroxasulfone @ 1250 + 127.5 g a.i. ha^{-1} (PE tank mix); T_5-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (PE); T_6-Early Post emergence (EPOST) application of Pyroxasulfone @ 127.5 g a.i. ha^{-1}; T_7-Pyroxasulfone + metsulfuron @ 127.5 + 4 g a.i. ha^{-1} (EPOST); T_8-Metribuzin @ 300 g a.i. ha^{-1} (PE); T_9-Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix); T_{10}-Pyroxasulfone + metribuzin @ 127.5 + 280 g a.i. ha^{-1} (PE tank mix); T_{11}-Weedy check and T_{12}-Weed free.

Conclusion

Based on two years of experimentation it may be concluded that pre-emergence tank mix application of Pendimethalin + metribuzin @ 1250 + 280 g a.i. ha^{-1} (PE tank mix) was found most effective for diverse weed flora and can be safely used for weed control in wheat crop without any phytotoxicity effect on succeeding crop of mungbean.

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Authors' contributions

RK and MCD designed the experiment and carried out experiment. MG and VB wrote the manuscript. B performed the statistical analysis. NS and RP reviewed the manuscript. SJ and FF participated in the sequence alignment. 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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