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Pre and Post-emergence Herbicides for the Control of Resistant *Phalaris minor* in Wheat

Ghulam Sakhi Qazizada, Todar Mal, Sushil Kumar* and Pardeep Kumar
Department of Agronomy,
CCS Haryana Agricultural University, Hisar – 125004, Haryana, India.

(Corresponding author - Sushil Kumar)*
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ABSTRACT: Continuous use of herbicides with same mode of action resulted in the development of multiple herbicide resistance in *Phalaris minor* threatening the sustainability of rice-wheat system in northern India. In this context, field study was conducted in *rabi* season 2018 at CCS Haryana Agricultural University, Hisar in randomized block design with three replications and seventeen treatments having different combinations of pre and post emergence herbicides, their mixture and seed treatment with *Bacillus subtilis* strain SYB 101. The result showed that application of pendimethalin @ 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mix) @ 50 + 105 g ha^{-1} at 35 DAS resulted in minimum dry matter accumulation of *Phalaris minor* (11.0 g), highest grassy weed control efficiency (81.8 %) at 90 DAS, maximum numbers of effective tillers (92.0 m^{-1} row length), grains spike^{-1} (59.9), 1000 grains weight (42.7 g) and highest grain, straw and biological yield (5761 kg ha^{-1}, 8202 kg ha^{-1} and 13963 kg ha^{-1}, respectively). However, broadleaved weeds were effectively controlled with application of pendimethalin @ 1000 g ha^{-1} JAS *fb* sulfosulfuron + metribuzin as a tank mix @ 25 + 105 g ha^{-1} at 35 DAS with maximum weed control efficiency of 84.8 % at 90 DAS. It was concluded that sequential application of pre and post-emergence herbicides provide better control of *Phalaris minor* in comparison to their application alone.

Keywords: *Phalaris minor*, pre and post-emergence herbicides, wheat

INTRODUCTION

In India, wheat (*Triticum aestivum* L.) is a major cereal crop. Several grassy and broad-leaf weeds compete with the crop during its growth cycle, depending on the agronomic practices, soil types, subsurface water quality, weed management measures, and cropping scheme. *Phalaris minor* has emerged as the most dominant weed of wheat in the rice-wheat cropping system (RWCS) in the north-western region of Indo-Gangetic Plains of India. Following the emergence of resistance in *Phalaris minor* biotypes to isoproturon, many groups of herbicides with various modes of action have been identified and recommended. During 1999-1998, the herbicides clodinafop, sulfosulfuron, and fenoxaprop were advised to suppress the isoproturon resistant population of *Phalaris minor*.

These herbicides effectively controlled this weed until 2007 (Chhokar and Sharma 2008) and increased wheat productivity. However, as a result of the continual use of these herbicides, *Phalaris minor* developed resistance to them (Dhawan *et al*., 2009). Due to development of multiple resistance its control has become more and more difficult with recommended herbicides: clodinafop-propargyl, diclofop-methyl, fenoxaprop-p-ethyl, pinoxaden (ACCase); sulfosulfuron and pre-mix of mesosulfuron + iodosulfuron (ALS inhibitors); mediated by increased metabolism and target site mutation (Dhawan *et al*., 2012). The various herbicide-resistant populations of *Phalaris minor* in wheat in RWCS jeopardized wheat productivity and profitability. During surveys and meetings with farmers, it was revealed that herbicide resistance in weeds evolved as a result of non-compliance with herbicide rotation, as well as incorrect time and manner of herbicide administration. Farmers only replace the brand of herbicides when one stops working, not the entire herbicide group. This showed the necessity for herbicides with different modes of action to be used in rotation or sequential application to effectively manage weed flora in wheat. Using multiple herbicides in a tank-mix or pre-mix chemistries or the sequential application of pre-and post-emergence herbicides at different times shown better weed control (Baghestani *et al*., 2008). As a result, the current study was conducted to assess the efficacy of pre-and post-emergence herbicides, as well as their combination, against *Phalaris minor*, and on the yield and yield attributes of wheat.

MATERIAL AND METHODS

A field experiment was conducted at Agronomy Farm of CCS HAU, Hisar, Haryana (India) in the winter seasons of 2018-19 to evaluate the bio-efficacy of pre (PE) and post emergence (PoE) herbicides against resistant *Phalaris minor* in wheat. During the crop season 2018-19, the mean weekly maximum and lowest temperatures ranged from 40.7°C to 1.9°C, respectively.

The mean weekly relative humidity ranged from 56 to 99 % in the morning and 19 to 66 % in the evening (Fig. 1). The texture of the soil at the experimental site was judged to be sandy loam, with a slightly alkaline response (pH 8.3) and normal electrical conductivity (0.25 dS m^{-1}). Organic carbon (0.26 %), nitrogen (114.5 kg ha^{-1}), and phosphorus (12.6 kg ha^{-1}) were all determined to be low in the soil. The soil, on the other hand, has a high potassium content (226.4 kg ha^{-1}). The wheat variety WH 1105 was planted in rows 20 cm apart in a routinely tilled seed bed with 100 kg seed ha^{-1}. Wheat planting was done on 21st November, 2018. To effectively raise the crop, the state university's standard agronomic practices were followed.

The experiment was set up in Randomized Complete Block Design and was repeated three times. Herbicide treatments used to combat resistant *Phalaris minor* included, T_1: Clodinafop-propargyl 60 g ha^{-1} at 35 days after sowing (DAS), T_2: Pinoxaden 50 g ha^{-1} at 35 DAS, T_3: Sulfosulfuron 25 g ha^{-1} at 35 DAS, T_4: Clodinafop- propargyl + metribuzin (tank mixed) 60 + 105 g ha^{-1} at 35 DAS, T_5: Pinoxaden + metribuzin (tank mixed) 50 + 105 g ha^{-1} at 35 DAS, T_6: Sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS, T_7: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml kg^{-1} seed) and clodinafop-propargyl + metribuzin (tank mixed) 60 + 210 g ha^{-1} at 35 DAS, T_8: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml kg^{-1} seed) and pinoxaden + metribuzin (tank mixed) 50 + 210 g ha^{-1} at 35 DAS, T_9: Seed treatment with *Bacillus subtilis* strain SYB 101 (5.0 ml kg^{-1} seed) and sulfosulfuron + metribuzin (tank mixed) 25 + 210 g ha^{-1} at 35 DAS, T_{10}: Pendimethalin 1000 g ha^{-1} just after sowing (JAS) *fb* clodinafop-p-ethyl + metribuzin (tank mixed) 60 + 105 g ha^{-1} at 35 DAS, T_{11}: Pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mixed) 50 + 105 g ha^{-1} at 35 DAS, T_{12}: Pendimethalin 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS, T_{13}: Metribuzin 210 g ha^{-1} (JAS) *fb* clodinafop- propargyl 60 g ha^{-1}at 35 DAS, T_{14}: Mertibuzin 210 g ha^{-1} (JAS) *fb* pinoxaden 50 g ha^{-1} at 35 DAS, T_{15}: Metribuzin 210 g ha^{-1}(JAS) *fb* sulfosulfuron 25 g ha^{-1} at 35 DAS, T_{16}: Weedy check and T_{17}: Weed free check. PE herbicides were applied just after sowing in moist soil, while PoE herbicides were applied with a knapsack sprayer at 35 DAS.

The densities and dry weights of *Phalaris minor* and broad-leaf weeds were recorded at 90 DAS. A quadrat was used to collect weed samples from two randomly selected locations in each plot (0.5 × 0.5 m). Each weed sample was split into two categories: *Phalaris minor* and broad leaf weeds. The number of *Phalaris minor* and broadleaf weed plants in each sample was counted and the average of two quadrates was taken. Plants of *Phalaris minor* and broad-leaf weeds from each quadrat were sun-dried before being placed in an oven at 65°C to produce a constant weight. The dried weed samples were then weighed, and the weight was expressed as g m^{-2}. Weed control efficiency was calculated as a percentage reduction in weed dry weight under different treatments compared to weedy. The weed control efficiency (WCE) was calculated as recommended by Gupta (2015) at harvest by the formula:

$$\text{WCE (\%)} = \frac{\text{Dry weight of weeds in weedy plot} - \text{Dry weight of weeds in treatment plot}}{\text{Dry weight of weeds in weedy plot}} \times 100$$

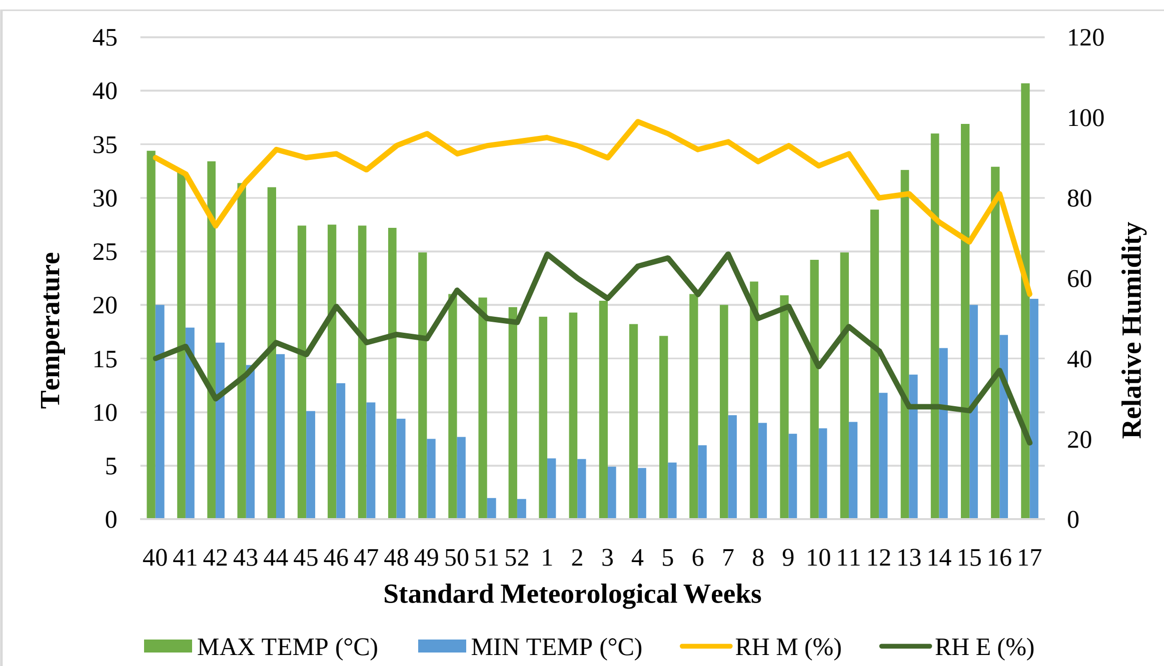


Fig. 1. Mean weekly meteorological data of Hisar district from November, 2018-April, 2019.

Before harvest, effective tillers were counted along a one-meter length of crop row in three locations per plot that had already been identified for all replications. The count was then translated to effective tillers m^{-2}. Five randomly selected spikes were collected from each plot, and the number of grains were calculated, normalized, and expressed as grains $spike^{-1}$. At the time of threshing, a random sample of grains was selected from each plot, and the weight of 1000 grains was recorded to get the test weight, which was expressed in grams. The harvested bundles from every net plot were weighed to determine the biological yield (kg $plot^{-1}$), which was then converted and represented as grain yield kg ha^{-1}. Straw yield was calculated for every plot by subtracting grain yield from biological yield and expressed as kg ha^{-1}. The data were statistically analyzed using the analysis of variance (ANOVA) approach to determine the significance of the treatment's effect. The F-test was used to determine whether or not a treatment had a significant effect at a 5% level of significance.

RESULTS AND DISCUSSION

A. Density of Grassy weeds

Pre-emergence application of pendimethalin @ 1000 g ha^{-1} *fb* sulfosulfuron + metribuzin as a tank mix @ 25 + 105 g ha^{-1} at 35 DAS resulted in a significantly minimum density of *Phalaris minor* at 90 DAS, as compared to other treatments and it was at par with seed treatment of wheat with *Bacillus subtilis* strain SYB 101 @ 5.0 ml kg^{-1} seed and a post-emergence (35 DAS) application of sulfosulfuron + metribuzin (tank mix) @ 50 + 210 g ha^{-1}, pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1}, and metribuzin 210 g ha^{-1} (JAS) *fb* pinoxaden 50 g ha^{-1} (Table 1). Due to application of pendimethalin (PRE) germinating weeds were killed at early stage and spray of post-emergence herbicides helped to control the weed growth at later stages. These results are in line with Kumar (2018) and Yadav *et al*. (2016).

B. Density of broadleaved weeds

At 90 DAS, significant lowest weed count of *Rumex dentatus*, *Chenopodium album, Anagalis arvensis and Melilotus indica* was reported with the pre-emergence application of pendimethalin @ 1000 g ha^{-1} just after sowing (JAS) *fb* sulfosulfuron + metribuzin as a tank mix @ 25 + 105 g ha^{-1} at 35 DAS than rest of the treatments and it was statistically comparable to pendimethalin @ 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mixed) @ 50 + 105 g/ha and pendimethalin @ 1000 g ha^{-1} as pre just after sowing (JAS) *fb* clodinafop-propargyl + metribuzin as a tank mix with an application rate of 60 + 105 g ha^{-1} at 35 DAS (Table 1).

However, in the case of *Coronopus didymus* significantly minimum density was recorded from treatment in which seed treatment of wheat was done with *Bacillus subtilis* strain SYB 101(5.0 ml kg^{-1} seed) *fb* tank mix application of sulfosulfuron + metribuzin @ 25 + 210 g ha^{-1} as PoE at 35 DAS in comparison to other treatments and it was statistically at par with pinoxaden + metribuzin (tank mix) @ 50 + 105 g/ha at 35 DAS, sulfosulfuron + metribuzin (tank mix) @ 25 + 105 g ha^{-1}, pendimethalin @ 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mix) @ 50 + 105 g ha^{-1} at 35 DAS and pendimethalin @ 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mix) @ 25 + 105 g ha^{-1} at 35 DAS. The combination of pendimethalin (PRE) and PoE herbicides provided effective control of weeds. These results are in conformity with Chopra and Chopra (2005) and Kumar *et al.* (2013).

C. Dry matter accumulation by weeds

Application of pendimethalin (PRE) @ 1000 g ha^{-1} just after sowing (JAS) *fb* pinoxaden + metribuzin (tank mix) @ 50 + 105 g ha^{-1} at 35 DAS reported significantly lower dry matter accumulation of grassy weed as compared to the rest of the treatments at 90 DAS (Table 2). While significant minimum dry matter accumulation by broad leaved weeds was recorded in the treatment with pre-emergence application of pendimethalin JAS @ 1000 g ha^{-1} *fb* sulfosulfuron + metribuzin (tank mix) @ 25 + 105 g ha^{-1} at 35 DAS followed by pendimethalin @ 1000 g ha^{-1} JAS *fb* pinoxaden + metribuzin (tank mix) @ 50 + 105 g ha^{-1} at 35 DAS in comparison to the weedy check. Weeds were effectively controlled due to sequential application of pendimethalin followed by post-emergence herbicides that resulted in lesser weed count which ultimately leads to lower dry matter accumulation. Similar results were reported by Sheoran *et al.* (2013) and Kumar (2018).

D. Weed control efficiency

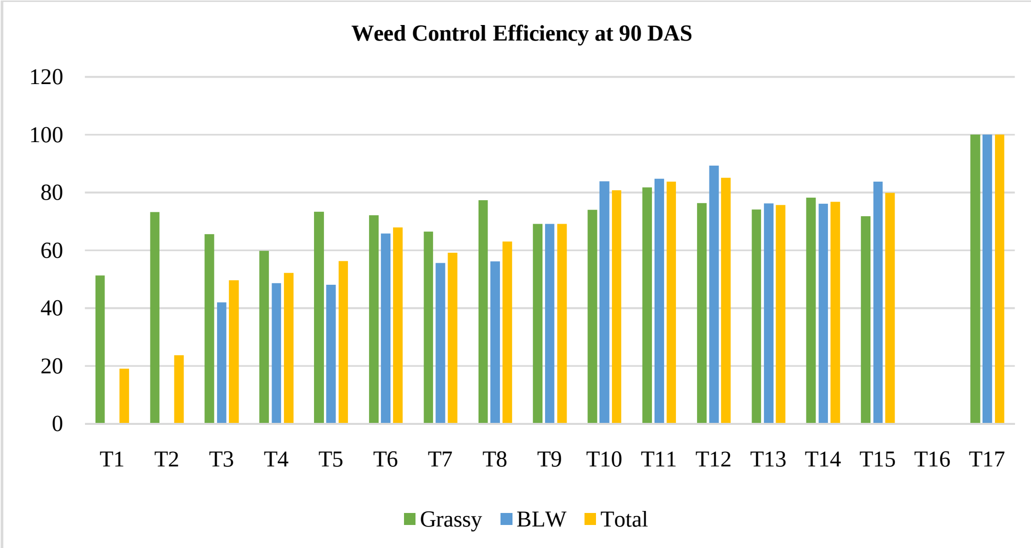
At 90 DAS, among the various herbicides, maximum weed control efficiency for grassy weeds was observed from the treatment with the application of pendimethalin @ 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mix) @ 50 + 105 g ha^{-1} followed by Metribuzin @ 210 g/ha (JAS) *fb* pinoxaden 50 g ha^{-1} at 35 DAS (Fig. 2). Although in the case of broadleaf weeds highest weed control efficiency of 89.3 % was observed with Pendimethalin 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mix) at the rate of 25 + 105 g ha^{-1} at 35 DAS followed by the treatment where Pendimethalin was applied @ 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mix) @ 50 + 105 g ha^{-1} (84.8 %) at 35 DAS. However, the overall highest weed control efficiency at 90 DAS was reported with Pendimethalin 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mix) 25 + 105 g ha^{-1} at 35 DAS. Minimum dry matter accumulation of weeds through sequential application of pre and post-emergence herbicides resulted in higher weed control efficiency as compared to weedy check. Similar results were reported by Kumar (2018) and Yadav *et al*. (2016).

Table 1: Effect of different herbicides treatment on density of weeds at 90 DAS in wheat.

Treatments	*Phalaris minor*	*Rumex dentatus*	*Chenopodium album*	*Anagallis arvensis*	*Melilotus indica*	*Coronopus didymus*
T1: Clodinafop-propargyl 60 g/ha at 35 days after sowing (DAS)	4.6 (20.7)	5.9(34.3)	5.1 (25.3)	3.3 (10.0)	4.0 (15.3)	4.9(23.3)
T2: Pinoxaden 50 g/ha at 35 DAS	3.2(9.3)	6.0(35.7)	4.9 (24.0)	3.6 (12.0)	3.9 (14.7)	4.9(23.3)
T3: Sulfosulfuron 25 g/ha at 35 DAS	3.5 (11.3)	5.3(27.3)	4.3 (17.3)	2.9(7.3)	3.0 (8.0)	3.7(12.7)
T4: Clodinafop-propargyl + metribuzin (tank mixed) 60 + 105 g/ha at 35 DAS	4.3 (17.3)	3.8(14.0)	3.5 (11.3)	3.2(9.0)	3.3 (10.0)	3.4(10.7)
T5: Pinoxaden + metribuzin (tank mixed) 50 + 105 g/ha at 35 DAS	2.9(7.3)	3.6(12.3)	3.5 (12.0)	3.3(9.7)	3.5 (11.3)	3.1(8.7)
T6: Sulfosulfuron + metribuzin (tank mixed) 25 + 105 g/ha at 35 DAS	3.2(9.3)	3.5(11.7)	2.9 (7.3)	2.6(6.0)	2.9 (7.3)	3.1(8.7)
T7: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and clodinafop-propargyl + metribuzin (tank mixed) 60 + 210 g/ha at 35 DAS	4.0 (14.7)	3.3(10.0)	3.7 (12.6)	2.7(6.7)	3.3 (10.0)	3.5(11.3)
T8: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and pinoxaden + metribuzin (tank mixed) 50 + 210 g/ha at 35 DAS	2.8(6.7)	3.7(13.0)	3.5 (11.3)	2.9(7.3)	3.4 (10.7)	3.4(10.7)
T9: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and sulfosulfuron + metribuzin (tank mixed) 25 + 210 g/ha at 35 DAS	2.7(6.7)	3.2(9.6)	2.8 (6.7)	2.5(5.3)	3.0 (8.0)	2.9(7.3)
T10: Pendimethalin 1000 g/ha just after sowing (JAS) *fb* clodinafop-propargyl+ metribuzin (tank mixed) 60 + 105 g/ha at 35 DAS	3.0(8.0)	1.5(1.3)	1.5 (1.3)	1.5(1.3)	2.0 (3.3)	3.6(12.0)
T11: Pendimethalin 1000 g/ha (JAS) *fb* pinoxaden + metribuzin (tank mixed) 50 + 105 g/ha at 35 DAS	2.4(4.7)	1.1(0.3)	1.5 (1.3)	2.1(3.3)	1.9 (2.7)	3.3(10.0)
T12: Pendimethalin 1000 g/ha (JAS) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g/ha at 35 DAS	2.7(6.7)	1.1(0.3)	1.0 (0.0)	1.7(2.0)	1.5 (1.3)	3.2(9.3)
T13: Metribuzin 210 g/ha (JAS) *fb* clodinafop-propargyl 60 g/ha at 35 DAS	3.3 (10.0)	2.4(4.7)	3.1 (8.6)	2.1(3.3)	3.0 (8.0)	3.8(13.3)
T14: Metribuzin 210 g/ha (JAS) *fb* pinoxaden 50 g/ha at 35 DAS	2.6(6.0)	2.3(4.7)	3.2 (9.3)	2.2(4.0)	3.0 (8.0)	4.0(14.7)
T15: Metribuzin 210 g/ha (JAS) *fb* sulfosulfuron 25 g/ha at 35 DAS	3.1(8.7)	2.2(4.0)	2.7 (6.7)	1.7(2.0)	2.5 (5.3)	3.3(10.0)
T16: Weedy check	7.8 (59.3)	6.2(38.0)	5.3 (27.0)	3.6 (12.0)	4.1 (16.7)	4.9(22.7)
T17: Weed free check	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0 (0.0)	1.0(0.0)
SEm (±)	0.2	0.1	0.2	0.1	0.2	0.2
CD at 5%	0.5	0.4	0.6	0.4	0.6	0.4

Original data given in parenthesis was subjected to square root($\sqrt{x+1}$) transformation before analysis

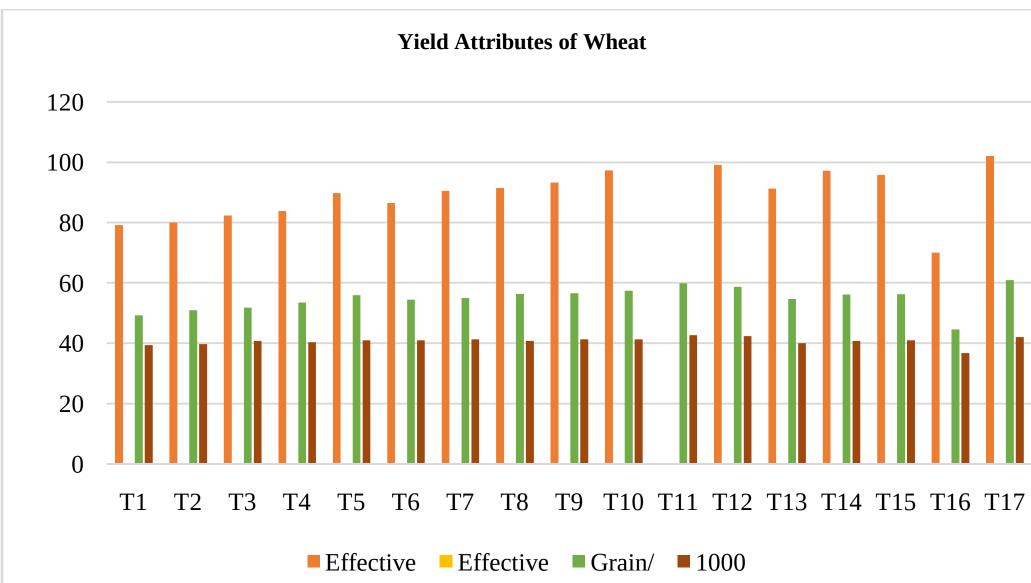
Application of pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS recorded significantly higher number of effective tillers. Statistically, similar results were obtained with pendimethalin 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS, pendimethalin 1000 g ha^{-1} just after sowing (JAS) *fb* clodinafop-propargyl + metribuzin (tank mixed) 60 + 105 g ha^{-1} at 35 DAS, metribuzin 210 g ha^{-1} (JAS) *fb* pinoxaden 50 g ha^{-1} at 35 DAS and metribuzin 210 g ha^{-1} (JAS) *fb* sulfosulfuron 25 gha^{-1} at 35 DAS (Fig. 3). Among the different treatments, treatment with pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS recorded maximum no. of grains spike^{-1} followed by Pendimethalin 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mix) 25 + 105 g ha^{-1} at 35 DAS.



*BLW – Broad Leaved Weeds; *Total: Grassy + BLW

T_1: Clodinafop-propargyl 60 g ha^{-1} at 35 days after sowing (DAS), T_2: Pinoxaden 50 g ha^{-1} at 35 DAS, T_3: Sulfosulfuron 25 gha^{-1} at 35 DAS, T_4: Clodinafop- propargyl + metribuzin (tank mixed) 60 + 105 g ha^{-1} at 35 DAS, T_5: Pinoxaden + metribuzin (tank mixed) 50 + 105 g ha^{-1} at 35 DAS, T_6: Sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS, T_7: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml kg^{-1} seed) and clodinafop- propargyl + metribuzin (tank mixed) 60 + 210 g ha^{-1} at 35 DAS, T_8: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml kg^{-1} seed) and pinoxaden + metribuzin (tank mixed) 50 + 210 g ha^{-1}at 35 DAS, T_9: Seed treatment with *Bacillus subtilis* strain SYB 101 (5.0 ml kg^{-1} seed) and sulfosulfuron + metribuzin (tank mixed) 25 + 210 g ha^{-1} at 35 DAS, T_{10}: Pendimethalin 1000 g ha^{-1} just after sowing (JAS) *fb* clodinafop-p-ethyl + metribuzin (tank mixed) 60 + 105 g ha^{-1} at 35 DAS, T_{11}: Pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mixed) 50 + 105 g ha^{-1} at 35 DAS, T_{12}: Pendimethalin 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS, T_{13}: Metribuzin 210 g ha^{-1} (JAS) *fb* clodinafop- propargyl 60 g ha^{-1} at 35 DAS, T_{14}: Mertibuzin 210 g ha^{-1} (JAS) *fb* pinoxaden 50 g ha^{-1} at 35 DAS, T_{15}: Metribuzin 210 g ha^{-1} (JAS) *fb* sulfosulfuron 25 g ha^{-1} at 35 DAS; T_{16}: Weedy check and T_{17}: Weed free check

Fig. 2. Weed control efficiency as influenced by different herbicidal treatment at 90 DAS Yield attributes of wheat.



T_1: Clodinafop-propargyl 60 g ha^{-1} at 35 days after sowing (DAS), T_2: Pinoxaden 50 g ha^{-1} at 35 DAS, T_3: Sulfosulfuron 25 g ha^{-1} at 35 DAS, T_4: Clodinafop- propargyl + metribuzin (tank mixed) 60 + 105 g ha^{-1} at 35 DAS, T_5: Pinoxaden + metribuzin (tank mixed) 50 + 105 g ha^{-1} at 35 DAS, T_6: Sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS, T_7: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml kg^{-1} seed) and clodinafop- propargyl + metribuzin (tank mixed) 60 + 210 g ha^{-1} at 35 DAS, T_8: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml kg^{-1} seed) and pinoxaden + metribuzin (tank mixed) 50 + 210 g ha^{-1} at 35 DAS, T_9: Seed treatment with *Bacillus subtilis* strain SYB 101 (5.0 ml kg^{-1} seed) and sulfosulfuron + metribuzin (tank mixed) 25 + 210 g ha^{-1} at 35 DAS, T_{10}: Pendimethalin 1000 g ha^{-1} just after sowing (JAS) *fb* clodinafop-p-ethyl + metribuzin (tank mixed) 60 + 105 g ha^{-1} at 35 DAS, T_{11}: Pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mixed) 50 + 105 g ha^{-1} at 35 DAS, T_{12}: Pendimethalin 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g ha^{-1} at 35 DAS, T_{13}: Metribuzin 210 g ha^{-1} (JAS) *fb* clodinafop- propargyl 60 g ha^{-1} at 35 DAS, T_{14}: Mertibuzin 210 g ha^{-1} (JAS) *fb* pinoxaden 50 g ha^{-1} at 35 DAS, T_{15}: Metribuzin 210 g ha^{-1} (JAS) *fb* sulfosulfuron 25 g ha^{-1} at 35 DAS,; T_{16}: Weedy check and T_{17}: Weed free check.

Fig. 3. Yield attributes of wheat as affected by various herbicide treatments.

Pre-emergence application of pendimethalin just after sowing (JAS) @ 1000 g ha^{-1} *fb* pinoxaden + metribuzin (tank mix) @ 50 + 105 g ha^{-1} at 35 DAS recorded maximum weight of 1000 grains and it was statistically comparable to other herbicidal combinations except clodinafop-propargyl 60 g ha^{-1} at 35 DAS, pinoxaden 50 g ha^{-1} at 35 DAS, clodinafop- propargyl + metribuzin (tank mix) 60 + 105 g ha^{-1} at 35 DAS and metribuzin 210 g ha^{-1} (JAS) *fb* clodinafop- propargyl 60 g ha^{-1} at 35 DAS. Reduction of weed density by pre and post-emergence herbicides helped in better utilization of available resources by crop plants thus producing greater number tillers, higher grains spike^{-1} and bold grains. These results are in line with Sheoran *et al.* (2013).

D. Grain, straw and biological yield

Application of pendimethalin (JAS) 1000 g ha^{-1} *fb* pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS, pendimethalin (JAS) 1000 g ha^{-1} *fb* sulfosulfuron + metribuzin (tank mix) 25 + 105 g ha^{-1} at 35 DAS, metribuzin (JAS) 210 g ha^{-1} *fb* pinoxaden 50 g ha^{-1} at 35 DAS, pendimethalin just after sowing (JAS) @ 1000 g ha^{-1}*fb* clodinafop-propargyl + metribuzin (tank mix) 60 + 105 g ha^{-1} at 35 DAS and metribuzin (JAS) @ 210 g ha^{-1}*fb* sulfosulfuron 25 g ha^{-1}at 35 DAS reported statistically similar grain yield as that of weed free (Table 2).

Among the different herbicidal treatments, application of pendimethalin (JAS) 1000 g ha^{-1} *fb* pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS recorded significantly higher straw and biological yield (8202 kg ha^{-1} and 13963 kg/ha) which was at par with pendimethalin 1000 g ha^{-1} (JAS) *fb* sulfosulfuron + metribuzin (tank mix) 25 + 105 g ha^{-1} at 35 DAS (8133 kg ha^{-1}and 13659 kg/ha), metribuzin 210 g ha^{-1} (JAS) *fb* sulfosulfuron 25 g ha^{-1} at 35 DAS (8104 kg ha^{-1} and 13500 kg/ha), metribuzin 210 g ha^{-1} (JAS) *fb* pinoxaden 50 g ha^{-1} at 35 DAS [7875 kg ha^{-1} (Straw yield)] and weed-free. The potential of pendimethalin followed by post-emergence herbicides in the management of resistance in *Phalaris minor* and the improvement of wheat productivity was previously reported in the literature (Chhokar and Sharma, 2008; Dhawan *et al.*, 2012).

Table 2: Effect of various herbicides combination on dry weight of grassy and broadleaved weeds at 90 DAS and grain, straw and biological yield of wheat.

Treatment	The dry weight of weeds at 90DAS		Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)
	Grassy	BLW			
T1: Clodinafop-propargyl 60 g/ha at 35 days after sowing (DAS)	32.2	132.4	4343	6842	11185
T2: Pinoxaden 50 g/ha at 35 DAS	17.7	137.6	4688	7225	11913
T3: Sulfosulfuron 25 g/ha at 35 DAS	22.7	79.8	4705	7439	12144
T4: Clodinafop- propargyl + metribuzin (tank mixed) 60 + 105 g/ha at 35 DAS	26.5	70.7	4777	7471	12248
T5: Pinoxaden + metribuzin (tank mixed) 50 + 105 g/ha at 35 DAS	17.6	71.4	4935	7609	12544
T6: Sulfosulfuron + metribuzin (tank mixed) 25 + 105 g/ha at 35 DAS	18.4	47.0	4811	7593	12404
T7: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and clodinafop- propargyl + metribuzin (tank mixed) 60 + 210 g/ha at 35 DAS	22.1	61.0	4969	7731	12700
T8: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and pinoxaden + metribuzin (tank mixed) 50 + 210 g/ha at 35 DAS	15.0	60.3	5176	7657	12833
T9: Seed treatment with *Bacillus subtilis* strain SYB 101(5.0 ml/kg seed) and sulfosulfuron + metribuzin (tank mixed) 25 + 210 g/ha at 35 DAS	20.3	42.3	5054	7446	12500
T10: Pendimethalin 1000 g/ha just after sowing (JAS) *fb* clodinafop-propargyl+ metribuzin (tank mixed) 60 + 105 g/ha at 35 DAS	17.1	22.2	5404	7819	13223
T11: Pendimethalin 1000 g/ha (JAS) *fb* pinoxaden + metribuzin (tank mixed) 50 + 105 g/ha at 35 DAS	11.0	20.9	5761	8202	13963
T12: Pendimethalin 1000 g/ha (JAS) *fb* sulfosulfuron + metribuzin (tank mixed) 25 + 105 g/ha at 35 DAS	15.6	14.7	5526	8133	13659
T13: Metribuzin 210 g/ha (JAS) *fb* clodinafop- propargyl 60 g/ha at 35 DAS	17.0	32.6	5121	7431	12552
T14: Metribuzin 210 g/ha (JAS) *fb* pinoxaden 50 g/ha at 35 DAS	14.4	32.8	5455	7875	13330
T15: Metribuzin 210 g/ha (JAS) *fb* sulfosulfuron 25 g/ha at 35 DAS	18.6	22.3	5396	8104	13500
T16: Weedy check	66.0	137.5	3602	6327	9929
T17: Weed-free check	0.0	0.0	5873	8408	14281
SEm (±)	1.6	2.8	171	199	270
CD at 5%	4.8	8.1	496	575	783

CONCLUSION

Based on the experiment it can be conclude that successive herbicide applications and herbicide combinations resulted in decreased weed density, weed dry weight, and higher weed control efficacy as compared to PoE herbicide application alone. Sequential application of pendimethalin 1000 g ha^{-1} (JAS) *fb* pinoxaden + metribuzin (tank mix) 50 + 105 g ha^{-1} at 35 DAS was found to be the most effective herbicidal treatment, yielding about 60% more grain than the weedy control.

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