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Herbicide combinations for management of resistance in *Phalaris minor*

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ABSTRACT

Littleseed canarygrass (*Phalaris minor* Retz.) is a problematic weed of wheat under irrigated rice-wheat cropping system of Indo-Gangetic plains (IGP) of India. Due to its morphological similarity with wheat, herbicides are the best-suited method for its control. However, continuous use of same herbicide along with monocropping leads to development of multiple-herbicide resistance. To tackle this problem, an experiment was conducted at CCS Haryana Agricultural University, Hisar during 2016-17 and 2019-20 to find out the suitable herbicide combinations for management of resistance *Phalaris minor*, its regression and correlation studies with wheat. The finding revealed that increase in weed density and dry weight displayed a strong negative linear relationship with grain yield. Linear regression equation represented that increase in every one unit of density and dry weight of *P. minor* led to reduction in wheat yield by 0.027 and 0.0102 times, respectively. Among the herbicidal treatments, sequential application of pendimethalin + pyroxasulfone (tank-mix, TM) *fb* mesosulfuron + iodosulfuron (ready-mix, RM) (1500 + 102 g/ha) pre-emergence, (PE) *fb* 14.4 g/ha post-emergence, (PoE) or pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 g/ha PoE led to significantly control of *P. minor*, broad-leaved weeds (BLWs) and total weeds. This resulted in better crop growth, higher yield attributes, 37.6-51.9% higher grain yield and 80-81% higher net return as compared to unweeded control. However, PE or PoE herbicide applied alone recorded poor efficacy towards *P. minor* and other weeds and resulted in poor yield. Correlation studies indicated strong positive association of grain yield with visual weed control, crop dry weight and its height and negative association with weed density and dry weight. Therefore, for effective management of resistant *P. minor* along with other weed flora, herbicide combination with its sequential application is of prime importance for optimum yield in wheat.

INTRODUCTION

The resistance of weeds towards herbicides is increasing day by day and upto year 2020 nearly 512 unique cases (species × site of action) of herbicide resistance have been recorded. Total 262 weed species (152 dicots and 110 monocots) having resistance to 23 of the 26 known herbicide sites of action was observed (Heap 2020). In India, the problem of herbicide resistance in weeds is increasing drastically. This is primarily due to the indiscriminate use of herbicides coupled with monocropping of rice-wheat system, that develops the selection pressure and ultimately resulting in resistant weed population. Littleseed canarygrass (*Phalaris minor* Retz.) is a mimic weed of wheat, predominant in the irrigated rice-wheat cropping system and severely infests wheat fields in the north-western Indo-Gangetic plains of India including Haryana (Kaur *et al.* 2016). If left uncontrolled, it may lead to 15-40% or more yield loss along with lowering the quality (Chhokar *et al.* 2008). To control this weed, application of herbicide is most appropriate tool. However, repeated application of same herbicide resulted in the development of herbicide resistance in *P. minor*. Herbicide resistance in this weed started from isoproturon to clodinafop, fenoxaprop and sulfosulfuron. Also, some of the biotypes developed resistance to some new herbicides, *viz*., pinoxaden and mesosulfuron + iodosulfuron. As of now, multiple herbicide resistance has evolved in *P. minor* (Dhawan *et al*. 2012, Rasool *et al*. 2017). It is estimated that *P. minor* invades about 50% (15 million ha) of the cultivated wheat area in India, out of that multiple herbicide-resistant *P. minor* affected area is about 3.0 m ha (Chhokar *et al.* 2019).

Phalaris minor has superior growth traits and competitive advantage over wheat. Cultivation of semi-dwarf wheat varieties require frequent irrigation along with high fertilizer doses, modifies the agro-ecological conditions, provides conducive micro-climate for growth and development of *P. minor* that helps to compete vigorously with wheat (Singh *et al.* 1995). The heavy infestation of *P. minor* (2000-3000 plants/m^2) results in complete crop failure (Malik and Singh 1995). Targeting the resistant *P. minor* along with other weed flora within a field by using different herbicides with different modes of action, herbicide combinations and/or their compatible mixture is the best possible option. They offer broad-spectrum action, enhanced herbicide efficacy through synergistic or additive effect, requirement in lesser quantity, arrest weed shifts, prevent herbicide resistance in weeds and reduced the selection pressure (Powles and Shaner 2001). The herbicide-resistant weeds in wheat were found susceptible to pre-emergence herbicides such as pendimethalin, metribuzin and pyroxasulfone (Dhawan *et al.* 2012). The use of pre-emergence herbicides offers an alternate mode of action to most of post-emergence herbicides, reduce selection pressure on subsequent post-emergence herbicide applications and remove much of the early season weed competitive pressure on the crop (Singh 2015). However, only pre-emergence herbicide application is not enough to control all weeds and its cohorts. Therefore, pre-emergence herbicides require a mixing partner for improved and broad-spectrum control of weeds. The practice of herbicide mixtures is now endorsed worldwide as a part of a proactive herbicide-resistant weed management program. One way to improve crop safety is to reduce the rate of the herbicides in combination with reduced dose of other herbicides, which will also broaden the spectrum of weed control and delay the evolution of resistance. Therefore, keeping this in view, the present study has been planned to manage herbicide resistance in *P. minor* Retz. through sequential application of pre- and post-emergence herbicides in wheat.

MATERIALS AND METHODS

A field experiment was conducted at Agronomy Research Farm, CCS Haryana Agricultural University, Hisar (Haryana) (29°8’56.62"N latitude and 75°41’4.24"E longitude) in winter season 2016-17 and 2019-20 with a history of poor control of *P. minor* with clodinafop (Abdullrasheed, 2019). Seasonal weather was quite different during both cropping seasons (**Figure 1**).

The wheat *cv ‘HD 2967’* was sown on 20th November and 4th December using seed rate of 100 kg/ha in solid rows 20 cm apart; and harvested on 16th April and 27th April during 2016-17 and 2019-20, respectively. Sixteen treatments: pendimethalin (1500 g/ha) pre-emergence (PE), metribuzin (210 g/ha) PE, pendimethalin + metribuzin [tank mix (TM)] (1500 + 175 g/ha) PE, pendimethalin + metribuzin (TM) *fb* pinoxaden (1000 +175 g/ha) PE *fb* 60 g/ha post-emergence (PoE), pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron [ready mix (RM)] (1000 + 175 g/ha) PE *fb* 14.4 g/ha PoE, pendimethalin + pyroxasulfone (TM) (1500 + 102

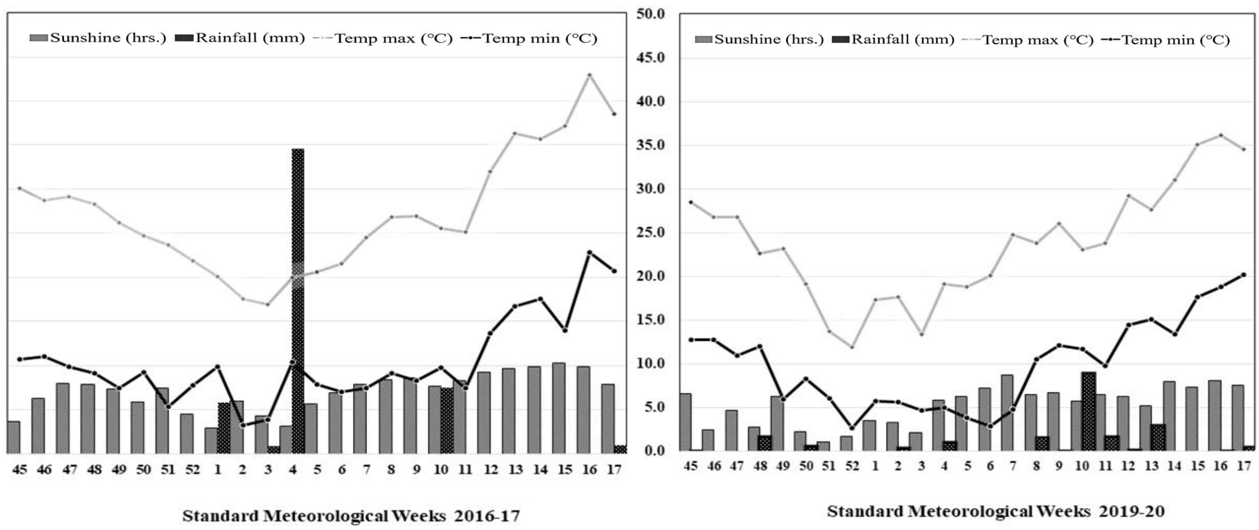


Figure 1. Weekly mean weather during crop season (2016-17 and 2019-20)

g/ha) PE, pendimethalin + pyroxasulfone (TM) *fb* pinoxaden (1500 + 102 g/ha) PE *fb* 60 g/ha PoE, pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ ha) PE *fb* 14.4 g/ha PoE, pendimethalin + metribuzin (TM) *fb* pinoxaden (1500 + 175 g/ha) before sowing *fb* 60 g/ha PoE, sulfosulfuron *fb* pinoxaden [25 g/ha before irrigation (BI) *fb* 60 g/ha PoE], pinoxaden (60 g/ha) PoE, pinoxaden + metribuzin (TM) (50+120 g/ ha) PoE, pinoxaden + metribuzin (TM) (50 + 150 g/ ha) PoE, mesosulfuron + iodosulfuron (RM) (14.4 g/ ha) PoE, weed-free check, unweeded control, were evaluated in a randomized block design with three replication having plot size 6 × 6 m. Herbicides were applied as per treatment using knapsack sprayer fitted with a flat fan nozzle using spray fluid at 500 l/ha immediately after sowing and 35 days after sowing. Hand weeding was done in weed-free treatment whenever it is required in crop season and no weed management was done in unweeded control. All other management practices were done as per recommendation given by CCS Haryana Agricultural University, Hisar. Crop growth and weed parameters were recorded at 60 DAS; yield attributes and yield were recorded at harvest, while economics was calculated based on prevailing market price. Statistically analysed by using OPSTAT software (Sheoran *et al.* 1998) with the following link http:// 14.139.232.166/opstat/default.asp. The response of different treatments was similar during both the years and followed the homogeneity test; data was pooled for statistical analysis. Wherever the treatment differences were found significant (F test), least significant difference (LSD) was tested at 5% level of significance.

RESULTS AND DISCUSSION

Weed studies

The experimental field was dominated by *P. minor* under grassy and *Melilotus indica, Rumex dentatus*, *Chenopodium album* under broad-leaved weeds (BLWs) in both the year. The relative composition of *P. minor* and BLWs at 60 DAS was 49.4 and 49.5%, respectively (pooled data of two years).

Wheat grain yield followed the strong negative linear relationship with weed density and dry weight (**Figure 2**). Coefficient of determination (R^2) was 0.78 and 0.77 for *P. minor* density and dry weight, respectively that indicate 78 and 77% variation in wheat yield was due to *P. minor* density and dry weight, respectively. Whereas, one unit increase in *P. minor* density and its dry weight led to reduction in yield by 0.027 and 0.0102 times, respectively (**Figure 2a** and **2b)**. Under BLWs, 77 and 73% variation in wheat yield was predicted due to BLWs density and dry weight, respectively. A unit increase in BLWs density and dry weight may lead to reduction in wheat yield by 0.0227 and 0.0043 times, respectively (**Figure 2c** and **2d)**. Whereas, total weed density and dry weight resulted in 91 and 86% variation in wheat yield, respectively. The unit increase in total weed density and dry weight may lead to reduction in wheat yield by 0.05 and 0.0145 times, respectively (**Figure 2e** and **2f)**.

This could be due to heavy weed infestation that robbed the crop's of common essential resources from early-stage onwards. Hence, crop was deprived of resources and could not grow to its full potential that ultimately reduced grain yield (Choudhary 2019).

The weed control treatment studies at 60 DAS showed that significantly minimum density and dry weight of all types of weeds were recorded in weed-free check and maximum in unweeded control (**Table 1**). Among the herbicide treated plot, significantly higher reduction in total weed density, dry weight, *P. minor* density and dry weight, and BLWs density and dry weight was observed in sequentially applied pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ ha) PE *fb* 14.4 g/ha PoE followed by pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 g/ha PoE. However, *P. minor* density and dry weight was also found least in pendimethalin + pyroxasulfone (TM) *fb* pinoxaden (1500 + 102 g/ha) PE *fb* 60 g/ha PoE. Whereas, significantly higher density and dry weight of all types of weed was observed under PE metribuzin followed by PE pendimethalin. Visual control of weed (*P. minor* and BLWs) was recorded at 60 DAS on 0-100 scale (**Table 1**). Unweeded control was taken as reference (zero per cent control), while weed-free provided complete control. Under *P. minor,* application of PE pendimethalin + metribuzin resulted in 75% control (pooled of two years) and its sequential application *fb* PoE pinoxaden or mesosulfuron + iodosulfuron resulted in 93 and 98% control level of *P. minor*, respectively. Similarly, PE pendimethalin + pyroxasulfone caused 88% control and its sequential application *fb* PoE pinoxaden or mesosulfuron + iodosulfuron resulted in similar level of control (≈100%). Whereas PE metribuzin (52%) and pendimethalin (60%) showed poor efficacy compared to other herbicide treatments.

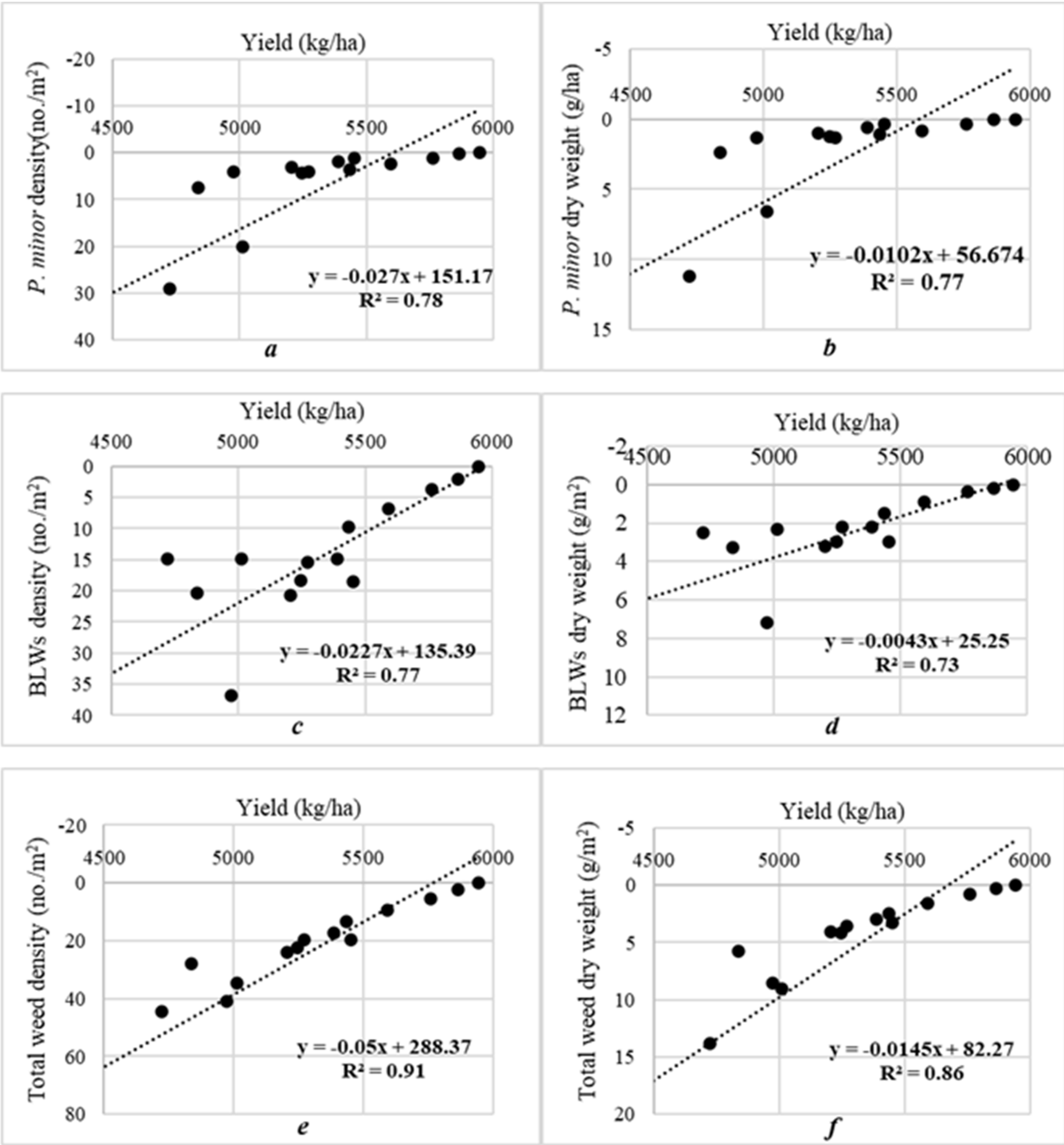


Figure 2. Relationship between wheat grain yield and weed density and dry weight (pooled data of two years) a: *P. minor* density, b: *P. minor* dry weight, c: BLWs density, d: BLWs dry weight, e: Total weed density and f: Total weed dry weight

Under BLWs, application of PE pendimethalin + metribuzin (TM) provided nearly similar control level as its sequential application with PoE pinoxaden. Similarly, PE pendimethalin + pyroxasulfone (TM) showed comparable efficacy as its sequential application with PoE pinoxaden. Whereas, PE pendimethalin + metribuzin *fb* PoE mesosulfuron + iodosulfuron and PE pendimethalin + pyroxasulfone *fb* PoE mesosulfuron + iodosulfuron caused similar efficacy towards BLWs (≈100%). While PE metribuzin (57%) shows poor control of BLWs in comparison with other herbicide treatments. This might be due to broad-spectrum control of *P. minor* and BLWs by sequential application of pre-emergence tank-mixed herbicide followed by post-emergence herbicide. Pinoxaden provides 90-100% control of *P. minor* and its resistant population (Singh *et al*. 2010, Soni *et al*. 2020) and pyroxasulfone best suited against grassy weed including resistant grassy weeds, however both these herbicides were noneffective against BLWs (Punia *et al*. 2020). Punia *et al*. (2018) reported that pre-emergence pendimethalin or metribuzin provided <35% control of *P. minor*, while, pendimethalin + metribuzin provided sufficient control of *P. minor* and other BLWs. However, it did not control weeds of second and further flushes of weeds.

Crop growth, yield attributes and grain yield

Among the crop growth parameters (60 DAS), dry weight per plant was recorded highest in weed-free check (3.3 g) that was statistically at par with sequentially applied pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) or pinoxaden. Leaf area index (LAI) was significantly higher in weed-free check (3.39) at par with pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM), and mesosulfuron + iodosulfuron (RM) alone. Similarly, yield attributes (at harvest) like grains per spike was significantly higher in weed-free check (56 no.) at par with sequentially applied pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) or pinoxaden and pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM). While across the treatments spike length remains non-significant (**Table 2**).

Weed growing throughout the crop duration significantly reduced the wheat grain yield to the extent of 34.6 and 29.9% in 2016-17 and 2019-20, respectively compared to weed-free check. All the weed control treatments produced significantly higher grain yield as compared to unweeded control. Significantly higher grain yield was recorded in weed-free check with 6.32 t/ha and 5.57 t/ha in 2016-17 and 2019-20, respectively and it was statistically at par with pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha) PE *fb* 14.4 g/ha; pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 g/ha PoE, and mesosulfuron + iodosulfuron (RM) (14.4 g/ha) PoE in both year. While significantly lower grain yield was obtained in unweeded check with 34.6% in 2016-17 and 32.4% in 2019-20 lower grain yield as compared to weed-free check (**Figure 3**). This could be due to effective reduction in weed density and dry weight by sequential application of herbicide that controlled most of weed cohorts and helped crop to get sufficient nutrients, moisture, light and optimum space. This ultimately helped in more photosynthesis, produced more dry weight, productive tillers, higher yield attributes and hence increased grain yield. However, relatively less grains yield was recorded with alone application of either pre- or post-emergence herbicides. This could be due to resistant *P. minor* and other weeds which were not efficiently controlled by alone pre- or post-emergence

Table 1. Weeds density (no./m^2), dry matter (g/m^2) and visual control at 60 DAS as influenced by different weed control treatments (pooled data of two years)

Treatment	Total weed		*P. minor*		BLWs		Visual control	
	Density	Dry weight	Density	Dry weight	Density	Dry weight	*P. minor*	BLWs
Pendimethalin (1500 g/ha) PE	6.7(44.3)	3.9(13.8)	5.5(29.0)	3.5(11.2)	4.0(14.8)	1.9(2.5)	60	83
Metribuzin (210 g/ha) PE	8.5(71.0)	4.5(19.1)	6.4(40.3)	3.9(13.9)	5.6(30.7)	2.5(5.2)	52	57
Pendimethalin + metribuzin (TM) (1500 + 175 g/ha) PE	6.0(34.8)	3.2(9.0)	4.6(20.0)	2.8(6.6)	3.9(14.8)	1.8(2.3)	75	88
Pendimethalin + metribuzin (TM) *fb* pinoxaden (1000 +175 g/ha) PE *fb* 60 PoE	4.8(22.5)	2.3(4.2)	2.3(4.3)	1.5(1.2)	4.4(18.3)	2.0(3.0)	93	80
Pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 PoE	2.5(5.3)	1.3(0.8)	1.4(1.2)	1.1(0.3)	2.1(3.7)	1.2(0.4)	98	97
Pendimethalin + pyroxasulfone (TM) (1500 + 102 g/ha) PE	5.4(27.8)	2.6(5.8)	2.9(7.5)	1.8(2.4)	4.6(20.3)	2.1(3.3)	88	55
Pendimethalin + pyroxasulfone (TM) *fb* pinoxaden (1500 + 102 g/ha) *fb* 60 PE *fb* PoE	4.5(19.7)	2.1(3.3)	1.4(1.2)	1.1(0.3)	4.4(18.5)	2.0(3.0)	99	67
Pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha) *fb* 14.4 PE *fb* PoE	1.7(2.2)	1.1(0.3)	1.1(0.2)	1.0(0.0)	1.6(2.0)	1.1(0.2)	99	98
Pendimethalin + metribuzin (TM) *fb* pinoxaden (1500 + 175 g/ha) *fb* 60 g/ha before sowing *fb* PoE	5.0(23.9)	2.3(4.1)	2.0(3.2)	1.4(1.0)	4.6(20.8)	2.0(3.2)	92	85
Sulfosulfuron *fb* pinoxaden (25 *fb* 60 g/ha) BI *fb* PoE	4.3(17.3)	2.0(3.0)	1.7(2.0)	1.3(0.6)	4.0(14.8)	1.8(2.2)	80	89
Pinoxaden (60 g/ha) PoE	6.5(40.8)	3.1(8.5)	2.2(4.0)	1.5(1.3)	6.1(36.8)	2.9(7.2)	72	15
Pinoxaden + metribuzin (TM) (50+120 g/ha) PoE	4.5(19.7)	2.1(3.6)	2.3(4.2)	1.5(1.3)	4.0(15.5)	1.8(2.2)	83	70
Pinoxaden + metribuzin (TM) (50+150 g/ha) PoE	3.7(13.3)	1.9(2.5)	2.1(3.5)	1.4(1.1)	3.3(9.8)	1.6(1.5)	86	87
Mesosulfuron + iodosulfuron (RM) (14.4 g/ha) PoE	3.1(9.2)	1.6(1.6)	1.8(2.3)	1.3(0.8)	2.7(6.8)	1.4(0.9)	86	96
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)	100	100
Unweeded control	10.3(105.7)	5.6(30.5)	7.3(52.2)	4.6(20.4)	7.3(52.3)	3.3(9.9)	0	0
LSD (p=0.05)	0.5	0.2	0.5	0.3	0.5	0.2	-	-

Data given in parentheses are original values, and outside are square-root transformed value herbicides, therefore weeds grow continue with crop and competing with limited available resources resulting in suppressed crop growth and finally lower grains yield. The beneficial effect of herbicide mixture and its sequential application for management of resistant *P. minor* and higher grain yield comparable to weed-free was reported by Yadav *et al.* (2016) and Kaur *et al.* (2019).

Economics

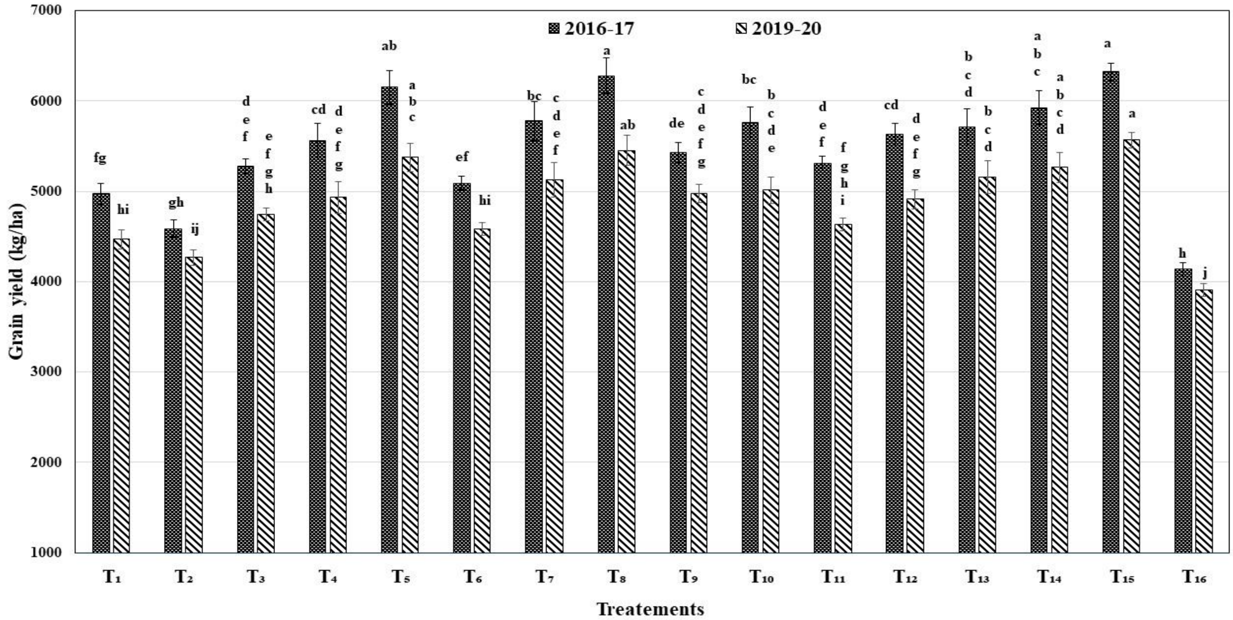
Economics of different treatments was recorded in the form of net return and BC ratio. The highest net return (71,213 ₹/ha) was observed in pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha) PE *fb* 14.4 g/ha PoE followed by pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 g/ha PoE. Whereas, highest BC ratio (2.31) was recorded in sole applied mesosulfuron + iodosulfuron (RM) (14.4 g/ha) PoE followed by sequentially applied pendimethalin + metribuzin (TM) or pendimethalin + pyroxasulfone (TM) *fb* PoE mesosulfuron + iodosulfuron. Whereas, least net return (39,297 ₹/ha) and BC ratio (1.76) was recorded in unweeded control (**Table 2**). This was due to higher yield in sequentially applied herbicides with comparatively lower cost of cultivation as compared to weed-free treatment.

Correlation studies

Plant dry weight, visual control of *P. minor* and BLWs had significant positive correlation with grain yield while density and dry weight of total weed, *P. minor* and BLWs were negatively correlated with grain yield during both the years (**Table 3**). Plant height had non-significant positive correlation with grain yield, visual control of *P. minor* and BLWs, respectively. It has non-significant negative correlated with density and dry weight of total weed and *P. minor,* respectively during both the years. Weed density and dry weight were negatively correlated with its visual control through different weed control treatments and crop growth parameters and vice-versa. In most of the cases, the correlations were highly significant (at 1% probability level). Among the parameters studied, the highest degree of positive association was observed between weed density and dry weight of *P. minor* followed by total weed, and BLWs (r=0.990 to 0.997**). Whereas, the highest negative association was recorded between visual control of *P. minor* with total weed dry weight (r=-0.967**) followed by visual control of BLWs with its dry weight (r= -0.958**). Wheat grain yield had positive relationship with visual control of *P. minor* (r= 0.875**), visual control of BLWs (r= 0.767**), plant dry weight (r= 0.794**) and plant height (0.261^{NS}). Negative correlation coefficient was

Table 2. Plant dry weight (g), leaf area index (LAI) at 60 DAS; grains per spike (no.), spike length (cm) at harvest stage, and economics of different weed control treatments (pooled data of two years)

Treatment	Plant dry weight	LAI	Grains per spike	Spike length	Net return (₹/ha)	B:C ratio
Pendimethalin (1500 g/ha) PE	2.8	2.98	46	10.3	51,258	1.95
Metribuzin (210 g/ha) PE	2.7	2.89	44	10.1	46,697	1.88
Pendimethalin + metribuzin (TM) (1500 + 175 g/ha) PE	3.0	3.05	47	10.4	57,206	2.05
Pendimethalin + metribuzin (TM) *fb* pinoxaden (1000 +175 g/ha) PE *fb* 60 PoE	3.0	3.13	51	10.7	60,216	2.07
Pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 PoE	2.8	3.26	53	10.8	70,730	2.27
Pendimethalin + pyroxasulfone (TM) (1500 + 102 g/ha) PE	2.9	3.02	49	10.7	51,200	1.92
Pendimethalin + pyroxasulfone (TM) *fb* pinoxaden (1500 + 102 g/ha) *fb* 60 PE *fb* PoE	3.1	3.12	52	10.8	62,447	2.08
Pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha) *fb* 14.4 PE *fb* PoE	3.2	3.35	55	11.1	71,213	2.24
Pendimethalin + metribuzin (TM) *fb* pinoxaden (1500 + 175 g/ha) *fb* 60 g/ha before sowing *fb* PoE	2.8	3.07	49	10.5	58,371	2.03
Sulfosulfuron *fb* pinoxaden (25 *fb* 60 g/ha) BI *fb* PoE	2.9	3.17	50	10.8	63,470	2.15
Pinoxaden (60 g/ha) PoE	2.8	2.99	46	10.6	56,021	2.04
Pinoxaden + metribuzin (TM) (50+120 g/ha) PoE	2.9	3.13	48	10.8	63,369	2.17
Pinoxaden + metribuzin (TM) (50+150 g/ha) PoE	3.0	3.13	50	10.8	66,625	2.23
Mesosulfuron + iodosulfuron (RM) (14.4 g/ha) PoE	3.0	3.22	50	10.8	70,202	2.31
Weed-free check	3.3	3.39	56	11.1	55,739	1.75
Unweeded control	2.6	2.76	42	9.8	39,297	1.76
LSD (p=0.05)	0.3	0.22	4	0.9	-	-



T_1:pendimethalin (1500 g/ha) PE, T_2: metribuzin (210 g/ha) PE, T_3: pendimethalin + metribuzin (TM) (1500 + 175 g/ha) PE, T_4: pendimethalin + metribuzin (TM) *fb* pinoxaden (1000 +175 g/ha) PE *fb* 60 g/ha PoE, T_5: pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 g/ha PoE, T_6: pendimethalin + pyroxasulfone (TM) (1500 + 102 g/ha) PE, T_7: pendimethalin + pyroxasulfone (TM) *fb* pinoxaden (1500 + 102 g/ha) PE *fb* 60 g/ha PoE, T_8: pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha)PE *fb* 14.4 g/ha PoE, T_9: pendimethalin + metribuzin (TM) *fb* pinoxaden (1500 + 175 g/ha) before sowing *fb* 60 g/ha PoE, T_{10}: sulfosulfuron *fb* pinoxaden (25 g/ha BI *fb* 60 g/ha PoE), T_{11}: pinoxaden (60 g/ha) PoE, T_{12}: pinoxaden + metribuzin (TM) (50 + 120 g/ha) PoE, T_{13}: pinoxaden + metribuzin (TM) (50 + 150 g/ha) PoE, T_{14}: mesosulfuron + iodosulfuron (RM) (14.4 g/ha) PoE, T_{15}: weed-free check and T_{16}: unweeded control

Figure 3. Wheat grain yield influenced by different weed control treatments (error bars indicate ±S.E. of mean of 3 replicates)

Table 3. Correlation coefficient (*r*) between weeds, different crop growth and yield of wheat (pooled data of two years)

Parameter	Yield	Total weed density	Total weed dry weight	*P. minor* density	*P. minor* dry weight	BLWs density	BLWs dry weight	Visual control *P. minor*	Visual control BLWs	Plant height	Plant dry weight
Yield	1										
Total weed density	-0.953^{**}	1									
Total weed dry weight	-0.930^{**}	0.990^{**}	1								
P. minor density	-0.881^{**}	0.935^{**}	0.969^{**}	1							
P. minor dry weight	-0.875^{**}	0.936^{**}	0.973^{**}	0.997^{**}	1						
BLWs density	-0.879^{**}	0.906^{**}	0.845^{**}	0.698^{**}	0.702^{**}	1					
BLWs dry weight	-0.856^{**}	0.900^{**}	0.844^{**}	0.691^{**}	0.699^{**}	0.995^{**}	1				
Visual control *P. minor*	0.875^{**}	-0.951^{**}	-0.967^{**}	-0.924^{**}	-0.938^{**}	-0.816^{**}	-0.823^{**}	1			
Visual control BLWs	0.767^{**}	-0.804^{**}	-0.747^{**}	-0.574^{*}	-0.586^{*}	-0.940^{**}	-0.958^{**}	0.735^{**}	1		
Plant height	0.261^{NS}	-0.337^{NS}	-0.279^{NS}	-0.132^{NS}	-0.160^{NS}	-0.519^{*}	-0.502^{*}	0.370^{NS}	0.437^{NS}	1	
Plant dry weight	0.794^{**}	-0.759^{**}	-0.724^{**}	-0.660^{**}	-0.659^{**}	-0.745^{**}	-0.718^{**}	0.721^{**}	0.624^{**}	0.561^{*}	1

**Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed); NS non-significant

found between grain yield with total weed density (r= -0.953**), total weed dry weight (r= -0.930**), *P. minor* density (r= -0.881^{**}), *P. minor* dry weight (r= -0.875**), BLWs density (r= -0.879^{**}) and BLWs dry weight (-0.856^{**}). The correlation study with grain yield of wheat was found significantly positively with WCE, crop growth parameters and negatively with the weed density and dry weight (Singh *et al.* 2007; Kaur and Singh 2019).

Conclusion

Phalaris minor is a potential threat for the sustainability of wheat in irrigated rice-wheat cropping system. Development of herbicide resistance in *P. minor* lead to poor herbicidal efficacy that resulted in higher *P. minor* density and finally lesser grain yield. The finding of the present study indicate that the coefficient of determination value was much higher in *P. minor* and become a major factor for yield reduction with higher negative correlation than other types of weeds. Among the treatment effect, solely applied either pre- or post-emergence herbicide remains ineffective for control of resistant *P. minor* or other weeds cohorts resulted in poor crop growth, yield attributes and grain yield. Therefore, herbicide combination with its sequential application with pre-emergence tank-mixed pendimethalin + pyroxasulfone (or) pendimethalin + metribuzin followed by post-emergence application of mesosulfuron + iodosulfuron provide effective control of resistance *P. minor* with broad-spectrum weed control resulted in better crop performance, higher yield and net returns.

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