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Bio-efficacy of pre- and post-emergence herbicides alone and in combination against herbicide resistant Phalaris minor in wheat (Triticum aestivum L.)

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Abstract

Herbicide resistance in littleseed canary grass (*Phalaris minor* Retz.) in wheat is a major concern along with crop residue management, which puts the question mark on sustainable growth of rice-wheat (R-W) system in north-western Indo-Gangetic Plains in long path. Crop rotation with integrated weed management is the best way to address or avert the herbicide resistance issues but due to cereal economics, cost and time bound obligations in dealing with weeds, farmers are still continuing with mono-cropping and relying on chemical weed control. Researchers were forced to think about herbicide rotation, by adopting the sequential or tank-mix applications of pre- and post-emergence herbicides. To evaluate the bio-efficacy of pre- and post-emergence herbicides alone and in combination against *Phalaris minor* in wheat, a field experiment with 18 treatments was conducted on CCSHAU Regional Research Station, Karnal during the *rabi* seasons of 2016-17 and 2017-18. Total seven herbicides three as pre-emergnce (pendimethalin, metribuzin and pyroxasulfone) and four as post-emergence (clodinafop, sulfosulfuron, pinoxaden and mesosulfuron + iodosulfuron RM) along with hand weeding were evaluated as alone or in combination as sequential or tank mix. Contrary to farmers' fields, recommended herbicides are still providing good control of *P. minor* at Research Farm, however their efficacy is also getting down. Yield loss could be restored by using already recommended herbicides in combination with pre-emergence herbicide pendimethalin or metribuzin. Overall, metribuzin (PRE) followed by sulfosulfuron (POE) (175 *fb* 25 g ha^{-1}) was found to be the best treatment in terms of weed control efficiency (WCE), grain yield, gross return, net return and B-C ratio. Mesosulfuron + iodosulfuron (ready-mix) alone and in combination with pre-emergence herbicides (metribuzin) also performed well against weeds (*P. minor* as well as broadleaf) but its consistency was poor. Pyroxasulfone was best herbicide against *P. minor* with complete control, but was not found that effective against broadleaf weeds mainly *Melilotus* spp. and also caused crop phyto-toxicity at 128 g ha^{-1} but not that much pronounced at 105 g ha^{-1}.

INTRODUCTION

Every year Indian agriculture sets a new record in wheat production, as per 2nd advance estimate by Ministry of Agriculture India will produce record 112.2 in 2022-23, which is higher by 4.5 million tonnes as compared to wheat production of 107.7 million tonnes achieved during 2021-22. India has 29.58 million ha area under wheat (13.65% at world level) and it contributes 13.57% of total wheat production at global level with average productivity of 3371 kg ha^{-1} (Ramadas et al., 2019). Haryana one of the major wheat producing state with 2.55 million ha area (8.65% at national level), 12.57 million tonnes of production (12.39% share in production at national level) with average productivity of 4925 kg ha^{-1} (1554 kg ha^{-1} higher than national average) (Statistical Abstract of Haryana 2020-21). But every achievement comes with some sacrifices or hidden sustainability issues, herbicide resistance in *P. minor* and crop residue management in Indo Gangetic Plain (IGP) one of them (Singh et al 2021; Singh et al 2021a).

Development of herbicide resistance in *P. minor* is not a one day phenomena rather it is a long process. With the introduction of high yielding dwarf varieties which are resistant to lodging under irrigation and high input use, definitely increased the wheat yield but also favored the grassy weeds. To deal with weeds isoproturon was brought in recommendation in 1977-78. Application of isoproturon at 1 kg ha^{-1} on 2–3 tiller stages after first irrigation was found very effective against *P. minor, Avena ludoviciana, Poa annua* and some broad-leaf weeds (Gill *et al*., 1978). Continuous use of single herbicides (isoproturon) for 10–15 years on large scale with mono-cropping triggered the evolution of resistance. That's why in 1997-98, recommendation of isoproturon was withdrawn and it was replaced with alternate herbicides (clodinafop, fenoxaprop and sulfosulfuron) (Yadav *et al*., 2006). Once again the wheat yield in resistance affected areas was restored at previous level (34.5 q ha^{-1} in 1994-95 to 43.5 q ha^{-1} in 1999–2000) with the use of these alternate herbicides (Yadav and Malik, 2005). Alternate herbicides were found very effective against isoprturon resistant *P. minor* (Malik and Yadav, 1997; Chhokar and Malik, 2002). But from 2008 onwards failure of one or more of these herbicides against *P. Minor* and increase in GR_{50} values (dose require to achieve 50% growth reduction) was reported by researchers (Dhawan et al., 2009; Yadav et al., 2016; Soni et al., 2023). Further, more alternative herbicides should be used in rotation or tank mix application, as rotation with herbicides having different modes of action (MOAs) has a strong effect in delaying the appearance of resistance, as shown by

simulation modelling (Cavan et al., 2000). Few scientists reported that tank mix applications of herbicides are more effective in delaying evolution of herbicide resistance than annual or sequential rotation as it allow very few progeny to succeed by putting multiple selection pressure concurrently (Powel *et al*., 1997; Digge *et al*., 2003; Beckie and Rebound, 2009)

For effective implementation of herbicide rotation, it is necessary that a large number of herbicides with different modes and mechanisms of action should be available and screened. No doubt that crop diversification and integrated weed control suggested by agriculture experts are also effective but farmers prefer chemical weed control over the other management strategies because of cost and time bound obligations. At present, farmers in IGP are mainly relying on pendimethalin, metribuzin, clodinafop, sulfosulfuron, pinoxaden and mesosulfuron + iodosulfuron (RM). All of the above herbicides (pre and post combinations) with different dose level are being tested in the present study, along with one new herbicide pyroxasulfone.

MATERIALS AND METHODS

To evaluate the bio-efficacy of pre- and post-emergence herbicides alone and in combination against *Phalaris minor* in wheat, a field experiment was conducted on CCSHAU Regional Research Station, Karnal during the *rabi* seasons of 2016-17 and 2017-18. Total 18 treatments were evaluated in the study which included pre-emergence (PRE) application of pendimethalin (1500 g ha^{-1}), metribuzin (210 g ha^{-1}), pyroxasulfone (105 or 128 g ha^{-1}), pendimethalin + metribuzin (1500 + 175 g ha^{-1} or 1000 + 175 g ha^{-1}) as tank mix, pendimethalin (1500 g ha^{-1}) + metribuzin (210 g ha^{-1}) as PRE followed by (*fb*) hand weeding at 35 DAS, post-emergence (POE) application of clodinafop (60 g ha^{-1}), sulfosulfuron (25 g ha^{-1}), pinoxaden (50 g ha^{-1}), mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) and sequential application of metribuzin (175 g ha^{-1}) as PRE *fb* clodinafop (60 g ha^{-1}), sulfosulfuron (25 g ha^{-1}), pinoxaden (50 g ha^{-1}) or mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) as POE, along with weed-free and weedy checks details given in Table 1. The experiment was laid out in completely randomized block design with three replications. Soil of the experimental field was clay loam in texture and slightly alkaline in pH. It was low in organic carbon (0.36%), low in available nitrogen (192 kg ha^{-1}), medium in available phosphorus (11 kg ha^{-1}) and high in potassium (294 kg ha^{-1}). Wheat (cv. HD 2967) was seeded on 20th November, 2016 and 17th November, 2017 using seed rate of 100 kg ha^{-1}, in 20 cm spaced rows. Sowing was done by the seed-cum-ferti-drill, after that layout was done keeping plot size 6 m x 2.2m (13.2 m^{-2}). All the herbicides were sprayed using knapsack sprayer fitted with a flat fan nozzle which was calibrated to deliver 500 litres water ha^{-1}. PRE herbicides were applied at 0 day after sowing (DAS), and POE herbicides at 35 DAS. In the weed free treatment, *P. minor* was removed manually whenever it appeared in the season. Crop was managed as per CCSHAU recommendation. **(Insert** Table 1 **Here)**

Table 1
Treatment details including dose and time of application of herbicides

Sr No	Treatment	Abbreviation	Dose (g/ha)	Type of treatment	Time (DAS)
T1	Pendimethalin	PMN	1500	PRE	JAS***
T2	Metribuzin	MBZ	210	PRE	JAS
T3	Clodinafop	CDF	60	POE	35
T4	Sulfosulfuron	SSN	25	POE	35
T5	Pinoxaden	PDN	50	POE	35
T6	Mesosulfuron + iodosulfuron (RM)*	MSN + ISN (RM)	14.4	POE	35
T7	Metribuzin *fb* clodinafop	MBZ *fb* CDF	175 *fb* 60	PRE *fb* POE	JAS/35
T8	Metribuzin *fb* sulfosulfuron	MBZ *fb* SSN	175 *fb* 25	PRE *fb* POE	JAS/35
T9	Metribuzin *fb* pinoxaden	MBZ *fb* PDN	175 *fb* 50	PRE *fb* POE	JAS/35
T10	Metribuzin *fb* Mesosulfuron + iodosulfuron (RM)	MBZ *fb* MSN + ISN (RM)	175 *fb* 14.4	PRE *fb* P POE	JAS/35
T11	Pendimethalin + Metribuzin (TM)**	PMN + MBZ (TM)	1500 + 175	PRE	JAS
T12	Pendimethalin + Metribuzin (TM)**	PMN + MBZ (TM)	1000 + 175	PRE	JAS
T13	Pyroxasulfone	PSF	105	PRE	JAS
T14	Pyroxasulfone	PSF	128	PRE	JAS
T15	Pendimethalin *fb* hand weeding	PMN *fb* HW	1500	PRE *fb* POE	JAS/35
T16	Metribuzin *fb* hand weeding	MBZ *fb* HW	210	PRE *fb* POE	JAS/35
T17	Weed Free	WF			
T18	Weedy Check	WC			
*RM- Ready Mix; **TM-Tank Mix; ***JAS- Just after sowing					

Weeds were recorded species wise at 30, 75 and 120 days after sowing using quadrat of 50 cm x 50 cm at two places in each plot. The count was expressed as number of weeds m^{-2}. The entire weed species falling within the quadrat (50 cm x 50 cm) were cut close to the ground, and were separated group wise (grassy and broad leaf weeds). These were sun dried followed by drying in a hot air oven maintained at 70^0C till constant dry weight and then weighed. The biomass was expressed as g m^{-2}. Tillers were counted from one meter length of crop row at two spots in each plot at 75 DAS and at harvest (effective tillers). The count was then expressed as tillers m^{-2}. Ten randomly selected spikes were taken at harvest from each plot and the number of grains was counted, averaged and expressed as number of grains per spike. The crop was harvested manually on 20th April 2017 and 18th April 2018. It was done from a net plot size of 5 m x 1.8 m with leaving one border row on each side and 0.5 m on edges. Phytotoxicity of herbicides was recorded visually on a scale of 0-100 (where 0 = no mortality and 100 = complete mortality) at 10 and 20 days after herbicide application, and was expressed as per cent. Effect of herbicides on wheat tillers also recorded.

Common cost of production was calculated and the additional cost of weed management treatments was added to calculate the cost of cultivation of each treatment. Benefit-cost ratio was calculated to assess the economics of wheat under various

treatments. Grain price was taken at minimum support price approved by government of India (GOI) as INR 1625 per q in 2017 and INR 1735 per q in 2018. Straw price was taken as INR 300 per q in 2017 and INR 350 per q in 2018. The data on different characters were analyzed by using analysis of variance (ANOVA) technique for Randomized Block Design (RBD) as suggested by Gomez and Gomez (1984). Standard error of mean difference at 5% level of probability was calculated for significant effects. Weed population were analyzed after doing log square-root transformation ($\sqrt{x} + 1$) and weed control efficiency were subjected to angular transformation ($Sin^{-1}\sqrt{X}$).

RESULTS AND DISCUSSION

1 Studies on weeds

In experimental field, the problem of weeds (grassy as well as broadleaf) was more in 2017-18 than 2016-17. Farmers also reported that in 2017-18, they faced more problems. Sowing time weather significantly differed in the second year which recorded very low sunshine hours consequently other parameter also turned in the favour to maintain cool and humid weather in second year. This played a major role for higher infestation of weeds and under such situations; the farmers are forced to go for wet seeding or delayed wheat sowing (Chaba and Jagga, 2017; Singh, 2019). Residue burning, an ill-practice prevailing in IGP is also one of the major key factor for unfavorable weather conditions at the onset of winter in north India (Nibber, 2015; Acharya et al., 2016; Singh et al., 2019). Due to this reason during second year, the performance of all herbicidal treatments against grassy as well as broadleaf was also poor than first year.

Weed density was counted at 30, 75 and 120 DAS and given in detail (Tables 2–3). At 30 DAS, only the effect of pre-emergence herbicides (pendimethalin metribuzin and pyroxasulfone) was visible (post-emergence not applied yet) and found that pendimethalin + metribuzin (1500 + 175 g ha^{-1}) and (1000 + 175 g ha^{-1}) were most effective against *P. minor* in both years and recorded lowest density (approximate 90 and 80% reduction in 2016-17 and 2017-18, respectively) followed by pyroxasulfone (105 and 128 g ha^{-1}) and pendimethalin (1500 g ha^{-1}) (Table 2). At 30 das performance of pyroxasulfone recorded little bit poor than tank mix application of (pendimethalin + metribuzin) but it gaves complete control of *P. minor* at later stage. Because it comes under K3 group herbicides those mode of action is Very-long-chain fatty acid elongase (VLCFAE), they allow weed seed to germinate but inhibit further shoot elongation and kill the weeds (Tanetani et al., 2009). Metribuzin (175 and 210 g ha^{-1}) also found effective but reflected little bit poor performance than pendimethalin and pyroxasulfone. First year performance of the all herbicides against *P. minor* was far better than second year. In case of broadleaf weeds during both years, pendimethalin (1500 g ha^{-1}) was not found effective but metribuzin (175 and 210 g ha^{-1}) and pyroxasulfone (105 and 128 g ha^{-1}) reduced broadleaf weeds significantly. However, during second year their performance was little bit poor and did not reduce the broadleaf population satisfactorily. During second year, none of the herbicides alone and in combination reduced the broadleaf weeds significantly at 30 DAS.

Performance of pre-emergence application of pendimethalin (1500 g ha^{-1}) or metribuzin (210 g ha^{-1}) and POE application clodinafop (60 g ha^{-1}) or sulfosulfuron (25 g ha^{-1}) was not much effective against resistant population of *P .minor* which was clearly evident with only 52–78% control in first year and 33–65% in second year at 75 DAS (Table 3). Tank mix application of pendimethalin + metribuzin (1500 + 175 or 1000 + 175 g ha^{-1}) increased the *P. minor* control (79–87% in first year and 66–81% in second year). Punia et al. (2018) conducted experiment in 2017-18 at CCSHAU, Hisar and reported similar results that alone application of pendimethalin or metribuzin was not that effective against resistant population of *P. minor* with only 33–35% control. Post-emergence application of pinoxaden (50 g ha^{-1}) or mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) found very effective in first year with 93–95% control, but during second year the performance was poor (only 45–55% control was recorded). Similar results were reported earlier by Punia et al. (2017) indicating that clodinafop (60 g ha^{-1}) and sulfosulfuron (25 g ha^{-1}) did not provide satisfactory control of *P. minor*, however, mesosulfuron + iodosulfuron 14.4 g ha^{-1}provided better control (85–90%). Pinoxaden (50 g ha^{-1}) resulted in 80% control of *P. minor* during first year but it provided only 55% control during second year at farmers' fields at Kheri Raiwali in Kaithal district of Haryana. *P. minor*

showed high level of resistance to fenoxaprop, isoproturon and clodinafop (resistance factor 1.92–3.89), low level to pinoxaden, sulfosulfuron and mesosulfuron + iodosulfuron (RF 1.06–1.34) (Rasool, 2016).

Pyroxasulfone (105 and 128 g ha^{-1}) provided 100% control of *P .minor* in first year and 85–94% in second year. Pyroxasulfone has also been reported very effective against *P. minor* earlier also (Singh, 2015; Punia et al., 2018). Sequential application of metribuzin (175 g ha^{-1}) followed by clodinafop (60 g ha^{-1}), sulfosulfuron (25 g ha^{-1}), pinoxaden (50 g ha^{-1}) and mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) gave upto 89 to 95% control of *P. minor* in first year and 82–86% in second year. Advantage of sequential application of pre- and post-emergence herbicides against *P. minor* was already reported (Yadav et al., 2016). Pendimethalin (1500 g ha^{-1}) and metribuzin (210 g ha^{-1}) followed by one hand weeding at 35 DAS was also found effective against *P. minor* in both years. Pre-emergence application of pendimethalin or metribuzin reduced *P. minor* population but it was not sufficient to control second flush of weeds which appeared after first irrigation (Punia et al., 2018), and hand weeding at 35 DAS helped to remove such weeds which emerged after first irrigation.

With regard to broadleaf weeds during both years, mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) alone and sequential application of metribuzin (175 g ha^{-1}) followed by sulfosulfuron (25 g ha^{-1}) and mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) gave almost complete control (98–100% in 2016-17 and 93 to 97% in 2017-18) at 75 DAS. Sulfosulfuron (25 g ha^{-1}) alone was also found as good as above mentioned treatments, but it was unable to control *Rumex dentatus*. Herbicide resistance or poor efficacy in *Rumex dentatus* against ALS inhibitors already reported in IGP by researchers (Chhokar et al., 2017). In the absence of other weeds, *Rumex dentatus* grew vigorously in sulfosulfuron treated plots. Pre-emergence herbicides pendimethalin (1500 g ha^{-1}), metribuzin (210 g ha^{-1}), pyroxasulfone (105 and 128 g ha^{-1}) were not found effective against broadleaf weeds in first year (36 to 59% control) and almost no control in second year (20 to 43%). Pendimethalin (1500 g ha^{-1} *fb* HW), metribuzin (210 g ha^{-1} *fb* HW), and pendimethalin + metribuzin (1500 + 175 and 1000 + 175 g ha^{-1}) provided satisfactory control of broadleaf weeds (75 to 83%) in first year. But in second year, the performance was not up to mark and recorded only 44 to 65% control.

Within pendimethalin (1500 g ha^{-1}) and metribuzin (210 g ha^{-1}), performance of pendimethalin was poor in both years as it was unable to control *Melilotus* spp (*alba/indica*). This comes at later stage of crop growth and grows profusely in the absence of other weeds (Das, 2011). However, pendimethalin (1500 g ha^{-1}) was found very effective against *Rumex dentatus* and gave complete control in both years. Kaur et al 2017 also reported that application of pendimethalin alone and tank-mix recorded 98–100% control of *Rumex dentatus.* So it is alternate option in those areas which are facing problem of herbicide resistance in *Rumex dentatus* against ALS inhibitors herbicides. Pyroxasulfone (105 and 128 g ha^{-1}) also behaved like pendimethalin and was unable to control *Melilotus* spp (*alba/indica*) in both years but gave complete control of *Rumex dentatus*. Clodinafop (60 g ha^{-1}) and pinoxaden (50 g ha^{-1}) did not provide any control of broadleaf weeds and were at par with weedy plot in both years. Sequential application of metribuzin (175 g ha^{-1}) followed by clodinafop (60 g ha^{-1}) and pinoxaden (50 g ha^{-1}) reduced the broadleaf weeds and their effect was synergetic with metribuzin against broadleaf. Clodinafop and pinoxaden did not control broadleaf weed and continuous use of grass killing herbicides, besides resulting into resistance development, also led to a shift in the weed flora (Chancellor, 1979; Chhoker *et al*., 2012; Yadav et al., 2016). Weed density in all treatments also followed similar trend at 120 DAS, but there was sharp reduction in broadleaf weeds density as their population was 2.80 and 3.05 times at 75 DAS in 2016-17 and 2017-18, respectively. *P. minor* was only 1.0 and 1.22 times (Table 3). Broadleaf weeds are less aggressive in nature and pose fewer problems than grassy weeds (Chhoker *et al*., 2012). **(Insert** Table 2 & 3 **Here)**

Table 2

Effect of different weed control treatments on weed density (No. m^{-2}) at 30 DAS

Treatment	Dose (g ha^{-1})	*P. minor*		Broadleaf weeds	
		2016-17	2017-18	2016-17	2017-18
PMN, PRE	1500	2.7(8.0)	4.6(24.0)	5.2(26.0)	8.5(71.3)
MBZ, PRE	210	4.6(20.0)	5.5(29.3)	4.4(18.7)	7.2(54)
CDF, POE	60	8.1(65.3)	8.3(68.7)	5.7(32.0)	8.7(74.7)
SSN, POE	25	8.0(63.3)	8.3(67.3)	5.9(33.3)	8.8(76.7)
PDN, POE	50	8.4(70.0)	8.2(66.0)	5.9(34.0)	8.6(73.3)
MSN + ISN, POE	14.4	8.3(68.0)	8.1(65.3)	6.0(34.7)	8.5(72.0)
MBZ *fb* CDF, PRE-POE	175 *fb* 60	4.9(22.7)	5.7(32.0)	3.6(12.0)	7.6(58.0)
MBZ *fb* SSN, PRE-POE	175 *fb* 25	5.0(24.7)	5.7(32.7)	3.8(13.3)	7.1(50.7)
MBZ *fb* PDN, PRE-POE	175 *fb* 50	4.9(23.3)	5.8(33.3)	4.5(19.3)	7.9(62.7)
MBZ *fb* MSN + ISN, PRE-POE	175 *fb* 14.4	6.0(37.3)	5.8(32.7)	4.3(17.3)	6.8(46.0)
PMN + MBZ, PRE	1500 + 175	2.2(5.3)	3.8(15.3)	3.8(14.0)	6.1(38.0)
PMN + MBZ, PRE	1000 + 175	2.8(7.3)	3.9(16.7)	4.2(17.3)	6.6(44.0)
PSF, PRE	105	4.2(16.7)	4.2(16.7)	3.9(15.3)	7.9(66.7)
PSF, PRE	128	3.6(12.0)	4.2(18.0)	4.2(17.3)	6.2(40.7)
PMN *fb* HW, PRE-POE	1500	3.0(8.7)	4.8(22.0)	5.0(24.7)	8.5(76.0)
MBZ *fb* HW, PRE-POE	210	4.7(21.3)	5.6(30.7)	4.0(15.3)	7.1(53.3)
WF		1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)
WC		8.2(70.7)	8.5(71.3)	6.2(37.3)	8.5(76.7)
SEm±		0.6	0.6	0.4	0.9
LSD (p = 0.05)		1.8	1.6	1.2	2.7

Original values in parenthesis were subjected to square root transformation ($\sqrt{x} + 1$) before statistical analysis

PMN, pendimethalin; MBZ, metribuzin; CDF, clodinafop; SSN, sulfosulfuron; PDN, pinoxaden; MSN + ISN, mesosulfuron + iodosulfuron (ready mix), PSF- pyroxasulfone, WF-weed free, WC-weedy check, PRE-pre-emergence, POE-post-emergence

Table 3

Effect of different weed control treatments on weed density (No. m^{-2}) at 75 and 120 DAS

Treatment	Dose (g ha^{-1})	75 DAS				120 DAS			
		P. minor		Broadleaf weeds		*P. minor*		Broadleaf weeds	
		2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
PMN, PRE	1500	3.4(10.3)	4.5(19.3)	7.5(55.3)	9.6(92.7)	3.1(8.7)	3.8(14.0)	5.1(24.7)	6.1(37.3)
MBZ, PRE	210	4.3(17.7)	6.6(42.7)	6.2(38.0)	8.9(79.3)	3.4(10.7)	4.9(24.7)	3.4(10.7)	5.2(26.7)
CDF, POE	60	4.0(15.3)	6.2(37.3)	9.1(82.7)	9.9(98.0)	3.3(10.0)	4.3(18.0)	5.1(25.3)	6.2(38.0)
SSN, POE	25	3.9(14.0)	5.0(24.7)	4.0(14.7)	4.5(20.7)	3.2(9.7)	4.3(17.3)	3.0(10.0)	4.3(18.0)
PDN, POE	50	1.7(2.0)	6.0(35.3)	8.6(74.6)	8.8(76.7)	2.5(5.3)	4.6(20.7)	4.8(22.0)	5.5(30.3)
MSN + ISN, POE	14.4	1.7(2.6)	5.6(30.7)	1.0(0.0)	2.8(7.3)	2.4(4.7)	4.3(17.3)	1.0(0.0)	2.4(7.3)
MBZ *fb* CDF, PRE-POE	175 *fb* 60	1.7(2.0)	3.1(8.7)	5.4(28.0)	8.7(76.0)	1.5(1.3)	3.3(10.0)	3.6(12.0)	5.1(25.3)
MBZ *fb* SSN, PRE-POE	175 *fb* 25	2.1(4.0)	3.2(9.3)	1.5(1.3)	3.0(8.0)	1.7(2.0)	2.8(6.7)	2.1(4.0)	1.4(1.3)
MBZ *fb* PDN, PRE-POE	175 *fb* 50	1.7(2.0)	3.0(8.0)	5.5(30.0)	7.7(59.3)	1.7(2.0)	2.2(4.0)	3.8(14.0)	4.9(24.7)
MBZ *fb* MSN + ISN, PRE-POE	175 *fb* 14.4	2.2(4.0)	3.2(9.7)	1.4(1.3)	2.0(3.3)	1.9(2.7)	2.4(4.7)	1.5(1.3)	1.5(2.0)
PMN + MBZ, PRE	1500 + 175	2.4(4.7)	3.4(10.7)	4.0(15.3)	7.2(50.7)	1.7(2.0)	2.4(5.3)	3.0(8.0)	4.7(22.0)
PMN + MBZ, PRE	1000 + 175	2.9(7.7)	4.4(18.7)	4.7(21.3)	8.0(64.7)	2.4(4.7)	3.5(12.0)	3.2(9.3)	5.2(28.0)
PSF, PRE	105	1(0.0)	2.9(8.0)	6.3(38.7)	8.7(75.3)	1(0.0)	2.0(4.0)	4.1(16.7)	5.5(30.0)
PSF, PRE	128	1(0.0)	1.9(3.3)	6.0(35.3)	8.1(66.0)	1(0.0)	1.7(2.7)	3.6(12.0)	5.2(28.0)
PMN *fb* HW, PRE-POE	1500	1.7(2.0)	3.7(12.7)	4.7(21.3)	7.6(61.3)	2.5(5.3)	2.9(7.3)	2.4(6.0)	4.5(22.0)
MBZ *fb* HW, PRE-POE	210	2.0(3.4)	4.2(16.7)	3.8(14.7)	6.2(40.7)	2.8(7.3)	2.9(8.0)	1.7(2.7)	4.1(16.0)
WF		1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1(0.0)	1(0.0)	1.0(0.0)	1.0(0.0)
WC		6.1(36.7)	7.4(55.3)	9.3(86.0)	10.8(116.0)	6.1(36.7)	6.8(45.3)	5.6(30.7)	6.3(38.0)
SEm±		0.3	0.4	0.5	0.7	0.2	0.4	0.4	0.6

Original values in parenthesis were subjected to square root transformation ($\sqrt{x+1}$) before statistical analysis

PMN, pendimethalin; MBZ, metribuzin; CDF, clodinafop; SSN, sulfosulfuron; PDN, pinoxaden; MSN + ISN, mesosulfuron + iodosulfuron (ready mix), PSF- pyroxasulfone, WF-weed free, WC-weedy check, PRE-pre-emergence, POE-post-emergence

Treatment	Dose (g ha^{-1})	75 DAS				120 DAS			
		P. minor		Broadleaf weeds		*P. minor*		Broadleaf weeds	
		2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
LSD (p = 0.05)		0.9	1.2	1.3	1.9	0.6	1.1	1.2	1.8
Original values in parenthesis were subjected to square root transformation ($\sqrt{x}+1$) before statistical analysis									
PMN, pendimethalin; MBZ, metribuzin; CDF, clodinafop; SSN, sulfosulfuron; PDN, pinoxaden; MSN + ISN, mesosulfuron + iodosulfuron (ready mix), PSF- pyroxasulfone, WF-weed free, WC-weedy check, PRE-pre-emergence, POE-post-emergence									

In 2016-17 at 75 DAS, *P. minor* biomass was nil in pyroxasulfone (105 and 128 g ha^{-1}) treated plots as no *P. minor* recorded (Table 4). Except pendimethalin (1500 g ha^{-1}), metribuzin (210 g ha^{-1}), clodinafop (60 g ha^{-1}) and sulfosulfuron (25 g ha^{-1}), all other treatments were found quite good with 83 to 98% biomass reduction. During second year, pyroxasulfone (128 g ha^{-1}) caused highest *P. minor* biomass reduction (97%) which was at par with weed free plot. Pyroxasulfone (105 g ha^{-1}) and sequential application of metribuzin (175 g ha^{-1}) followed by clodinafop (60 g ha^{-1}), sulfosulfuron (25 g ha^{-1}), pinoxaden (50 g ha^{-1}) and mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) gave up to 90 to 95% reduction of *P. minor* biomass. Pendimethalin + metribuzin (1500 + 175 g ha^{-1}), pendimethalin + metribuzin (1000 + 175 g ha^{-1}), pendimethalin (1500 g ha^{-1} *fb* HW), metribuzin (210 g ha^{-1} *fb* HW), sulfosulfuron (25 g ha^{-1}), pinoxaden (50 g ha^{-1}) and mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) reduced *P. minor* biomass significantly but efficacy was little bit lower (77 to 87%). Pendimethalin (1500 g ha^{-1}), metribuzin (210 g ha^{-1}) and clodinafop (60 g ha^{-1}) were not found so effective in second year also and recorded only 66 to 71% reduction in *P. minor* biomass.

In case of broadleaf weeds during both years, mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) alone and sequential application of metribuzin (175 g ha^{-1}) followed by sulfosulfuron (25 g ha^{-1}) and mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) gave best results which were as good as weed free treatment and recorded broadleaf weeds biomass reduction to the tunes of 94–100% in 2016-17 and 90 to 98% in 2017-18 at 75 DAS. Except pendimethalin (1500 g ha^{-1}), metribuzin (210 g ha^{-1}), clodinafop (60 g ha^{-1}), pinoxaden (50 g ha^{-1}) and pyroxasulfone (105 and 128 g ha^{-1}), all other treatments were found quite good against broadleaf weeds and provided 66 to 82% biomass reduction in first year. But in second year, only sulfosulfuron (25 g ha^{-1}) was found effective and all other treatments did not perform so well and provided only 33 to 63% reduction. Similar trend was observed at 120 DAS. In general, combination of herbicides resulted into better control of complex weed flora. **(Insert table** Figs. 1 & 4 **Here)**

Table 4

Effect of different weed control treatments on dry matter of weeds (group wise) (g m^{-2}) at 75 and 120 DAS

Treatment	Dose (g ha^{-1})	75 DAS				120 DAS			
		P. minor		Broadleaf weeds		*P. minor*		Broadleaf weeds	
		2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
PMN, PRE	1500	8.73	8.99	8.99	9.99	39.53	47.47	64.07	80.40
MBZ, PRE	210	10.03	12.84	6.17	7.95	50.20	127.20	34.00	61.53
CDF, POE	60	7.47	8.82	9.67	9.91	41.27	47.73	60.00	73.13
SSN, POE	25	7.41	6.59	3.29	2.86	33.13	50.60	17.20	18.67
PDN, POE	50	1.73	5.89	7.59	7.33	10.33	53.13	31.67	38.00
MSN + ISN, POE	14.4	0.98	5.03	0.0	1.27	10.13	44.20	0.00	3.60
MBZ *fb* CDF, PRE-POE	175 *fb* 60	1.84	1.41	3.63	9.20	4.40	34.87	52.93	56.67
MBZ *fb* SSN, PRE-POE	175 *fb* 25	2.01	1.69	0.34	0.28	5.40	19.47	2.73	0.13
MBZ *fb* PDN, PRE-POE	175 *fb* 50	1.41	2.79	3.78	6.91	4.47	25.20	27.80	44.87
MBZ *fb* MSN + ISN, PRE-POE	175 *fb* 14.4	0.60	1.72	0.71	0.42	5.67	17.80	2.40	4.27
PMN + MBZ, PRE	1500 + 175	3.58	3.81	3.11	5.14	6.13	25.67	30.27	44.47
PMN + MBZ, PRE	1000 + 175	4.26	4.95	2.55	7.39	11.73	40.87	42.20	51.80
PSF, PRE	105	0.00	1.64	6.71	8.01	0.00	2.93	56.00	66.40
PSF, PRE	128	0.00	0.88	5.67	7.05	0.00	2.87	38.53	56.07
PMN *fb* HW, PRE-POE	1500	1.18	6.29	2.87	6.49	22.27	28.60	26.20	43.07
MBZ *fb* HW, PRE-POE	210	1.73	6.46	2.01	4.85	32.47	35.00	6.73	19.67
WF		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WC		25.44	29.21	11.08	12.99	217.53	240.40	86.27	113.07
SEm±		0.46	0.58	0.57	0.75	4.16	6.44	3.83	3.29
LSD (p = 0.05)		1.32	1.65	1.63	2.2	11.96	18.51	11.01	9.46

PMN, pendimethalin; MBZ, metribuzin; CDF, clodinafop; SSN, sulfosulfuron; PDN, pinoxaden; MSN + ISN, mesosulfuron + iodosulfuron (ready mix), PSF- pyroxasulfone, WF-weed free, WC-weedy check, PRE-pre-emergence, POE-post-emergence

2. Visual crop phytotoxcity (%)

Visual crop phytotoxicity was recorded on 0-100 scale (where 0 = no mortality and 100 = complete mortality). In 2016-17 after first irrigation at 30 DAS, visual phytotoxicity (4.7 to 8.3%) was observed in all treatment which was having metribuzin as a component (Table 5). But it was recovered at later crop stages. Plants show slight phytotoxicity but later on it may be recovered depending upon level of sensitivity of cultivar. Wheat (HD-2329) was completely damaged by metribuzin in pot culture but in field conditions there was no issue (Das, 2011). In second year, no phytotoxicity was observed at 30 DAS. At the time of effective tillers counting, it was observed that some herbicidal treatments suppressed the wheat tillering and it was recorded at same scale considering it as phytotoxcity effect of herbicides which were reducing the tillering. In first year, sequential application of metribuzin (175 g ha^{-1}) followed by sulfosulfuron (25 g ha^{-1}) and mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) and pyroxasulfone (105 and 128 g ha^{-1}) caused 5 to 7.7% reduction in wheat tillers but in second year only pyroxasulfone (128 g ha^{-1}) caused 6.7% reduction but other treatments did not show any reduction (Table 6). Previous study also reported about injury through pyroxasulfone on wheat crop. Soft red winter wheat injured in the form of stunting ranging 11 to 20% at 120 and 160 g ha^{-1} application of pyroxasulfone as PRE (Grey *et al*. 2017). Hulting et al. (2012) noted 0–8% winter wheat injury and 3% at the end of the season from pyroxasulfone mainly associated with 150 g ha^{-1}. **(Insert** Table 5 **Here)**

Table 5
Crop phytotoxicity caused by different weed control treatments

Treatment	Dose (g ha^{-1})	2016-17		2017-18	
		30 DAS	120 DAS	30 DAS	120 DAS
PNM, PRE	1500	1.0(0.0)	1.0(0.0)	0.0(0.0)	1.0(0.0)
MBZ, PRE	210	3.0(8.3)	1.0(0.0)	0.0(0.0)	1.0(0.0)
CDF, POE	60	1.0(0.0)	1.0(0.0)	0.0(0.0)	1.0(0.0)
SFS, POE	25	1.0(0.0)	1.0(0.0)	0.0(0.0)	1.0(0.0)
PXD, POE	50	1.0(0.0)	1.0(0.0)	0.0(0.0)	1.0(0.0)
MS + IS, POE	14.4	1.0(0.0)	1.0(0.0)	0.0(0.0)	1.0(0.0)
MBZ *fb* CDF, PRE-POE	175 *fb* 60	2.5(6.7)	1.0(0.0)	0.0(0.0)	1.0(0.0)
MBZ *fb* SFS, PRE-POE	175 *fb* 25	2.8(7.3)	2.6(6.0)	0.0(0.0)	1.0(0.0)
MBZ *fb* PXD, PRE-POE	175 *fb* 50	2.5(5.7)	1.0(0.0)	0.0(0.0)	1.0(0.0)
MBZ *fb* MS + IS, PRE-POE	175 *fb* 14.4	3.0(8.3)	2.9(6.3)	0.0(0.0)	1.0(0.0)
PNM + MBZ, PRE	1500 + 175	2.3(4.7)	1.0(0.0)	0.0(0.0)	1.0(0.0)
PNM + MBZ, PRE	1000 + 175	2.4(5.0)	1.0(0.0)	0.0(0.0)	1.0(0.0)
PSF, PRE	105	1.0(0.0)	2.4(5.0)	0.0(0.0)	1.0(0.0)
PSF, PRE	128	1.0(0.0)	2.9(7.7)	0.0(0.0)	2.8(6.7)
PNM *fb* HW, PRE-POE	1500	1.0(0.0)	1.0(0.0)	0.0(0.0)	1.0(0.0)
MBZ *fb* HW, PRE-POE	210	2.3(7.0)	1.0(0.0)	0.0(0.0)	1.0(0.0)
WF		1.0(0.0)	1.0(0.0)	0.0(0.0)	1.0(0.0)
WC		1.0(0.0)	1.0(0.0)	0.0(0.0)	1.0(0.0)
SEm±		0.3	0.1	NA	0.04
LSD (p = 0.05)		0.8	0.25	NA	0.11
Original value in parenthesis were subjected to square root transformation ($\sqrt{x+1}$) before statistical analysis					
PMN, pendimethalin; MBZ, metribuzin; CDF, clodinafop; SSN, sulfosulfuron; PDN, pinoxaden; MSN + ISN, mesosulfuron + iodosulfuron (ready mix), PSF- pyroxasulfone, WF-weed free, WC-weedy check, PRE-pre-emergence, POE-post-emergence					

3. Studies on wheat crop

In all herbicidal treatments, higher grain yield was recorded during first year than in second year (Table 7). Overall in Haryana in 2017-18, anticipated wheat productivity was recorded 4.5% lower than 2016-17 (Anonymous, 2018). Farmers also reported during survey that they faced more problems in 2017-18 than previous years. Sowing time in the experimental field for both the year was almost same (20th November in 2016-17 and 17th November in 2017-18). During crop period weather parameters were almost similar but sowing time weather significantly deferred in second year which has been already described in detail. In 2017-18 throughout growing season, more infestation of weeds (grassy as well as broadleaf) was recorded than in 2016-17 in all treatments. During first year, average number of tillers in all treatments was 441 m^{-2} at 75 DAS and 395 m^{-2} at harvest. But in second year 371 m^{-2} (70 m^{-2} down) at 75 DAS and 354 m^{-2} (40 m^{-2} down) at harvest.

Difference in tillers was too high (70 m^{-2} at 75 DAS and only 40 m^{-2} at harvest). Number of grain per spike was also recorded lower in second year (49) than first in year (53) (Table 6). Other growth parameter and yield attributing characters like plant height, 1000-grain weight and spike length were not affected by treatments or years and these were non-significant in both years. All treatments recorded significantly higher grain yield in both years than weedy plot, excluding metribuzin (210 g ha^{-1}) in second year (Table 7). Mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}), alone metribuzin (210 g ha^{-1} *fb* HW) and sequential application of metribuzin (175 g ha^{-1}) followed by sulfosulfuron (25 g ha^{-1}), pinoxaden (50 g ha^{-1}) and mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) recorded equally good grain yield and were statistically at par with weed free treatment in both years. During first year, mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) alone recorded highest grain yield and during second year, it was due to sequential application of metribuzin (175 g ha^{-1}) followed by mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}). Pre-emergence application of pendimethalin (1500 g ha^{-1}), metribuzin (210 g ha^{-1}), pyroxasulfone (128 g ha^{-1}), pendimethalin + metribuzin (1000 + 175 g ha^{-1}) and POE application clodinafop (60) or sulfosulfuron (25 g ha^{-1}) also provided good grain yield but were not at par with weed free. Performance of pinoxaden (50 g ha^{-1}), pendimethalin (1500 g ha^{-1} *fb* HW) and pendimethalin + metribuzin (1500 + 175 g ha^{-1}) during first year was good and they were at par with weed free in terms of grain yield but during second year did not give up to mark results and in case of pyroxasulfone (105 g ha^{-1}), it has reverse trend in second year as it was at par with weed free but not so in first year. Overall, grain yield was ultimately decided by the combined effect of how a particular treatment is able to control *P. minor* and broadleaf weeds and there phytotoxicity on crop. During first year, sequential application of metribuzin (175 g ha^{-1}) followed by sulfosulfuron (25 g ha^{-1}) and mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) and pyroxasulfone (105 and 128 g ha^{-1}) attained relatively higher weed control efficiency. But it was not reflected in terms of grain yield because these treatments caused crop phytotoxicity and suppressed tillering. During second year, only pyroxasulfone (128 g ha^{-1}) caused phytotoxicity and did not attain expected yield. Pooled analysis revealed that overall mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) and sequential application of metribuzin (175 g ha^{-1}) followed by sulfosulfuron (25 g ha^{-1}) and mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) were adjudged best treatments which were at par with weed free treatments. Higher grain and biological yield by sequential application of PRE and POE herbicides in wheat has been reported earlier also (Yadav et al., 2016; Kaur, 2017; Kumar, 2017; Punia et al., 2018). **(Insert** Table 6 **Here)**

Table 6

Effect of different weed control treatments on No. of grain/spike, number of tillers (No. m^{-2}) at 75 DAS and effective tillers

Treatment	Dose (g ha^{-1})	No. of grain/spike		Tillers No. m^{-2} at 75 DAS		Effective tillers No. m^{-2}	
		2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
PNM, PRE	1500	49.3	43.3	414	335	367	312
MBZ, PRE	210	51.0	41.6	432	314	391	280
CDF, POE	60	50.4	45.3	419	348	370	325
SFS, POE	25	52.0	49.2	423	379	385	360
PXD, POE	50	54.0	49.1	453	374	407	353
MS + IS, POE	14.4	58.3	51.3	486	393	443	386
MBZ *fb* CDF, PRE-POE	175 *fb* 60	54.3	49.3	453	374	409	355
MBZ *fb* SFS, PRE-POE	175 *fb* 25	56.0	53.4	467	413	419	408
MBZ *fb* PXD, PRE-POE	175 *fb* 50	54.3	50.4	452	385	407	382
MBZ *fb* MS + IS, PRE-POE	175 *fb* 14.4	54.4	53.8	459	412	410	400
PNM + MBZ, PRE	1500 + 175	53.6	48.3	448	362	398	338
PNM + MBZ, PRE	1000 + 175	53.0	48.0	431	355	375	335
PSF, PRE	105	54.6	53.0	448	403	400	390
PSF, PRE	128	50.0	49.6	412	379	363	362
PNM *fb* HW, PRE-POE	1500	53.7	50.0	452	364	390	347
MBZ *fb* HW, PRE-POE	210	55.7	51.6	448	386	403	360
WF		58.4	53.9	488	418	447	411
WC		42.3	40.3	358	291	320	288
SEm±		1.9	1.5	18.1	16.3	12.6	10.7
LSD (p = 0.05)		5.6	4.4	52.0	46.9	36.3	30.8

PMN, pendimethalin; MBZ, metribuzin; CDF, clodinafop; SSN, sulfosulfuron; PDN, pinoxaden; MSN + ISN, mesosulfuron + iodosulfuron (ready mix), PSF- pyroxasulfone, WF-weed free, WC-weedy check, PRE-pre-emergence, POE-post-emergence

4. Economics

All treatments recorded higher gross return, net return and benefit cost ratio than weedy plot. Among different herbicidal treatments in 2016-17, highest gross return (Rs 1,17,275), net return (Rs 31,437 ha^{-1}) and benefit cost ratio (1.37) were recorded by mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) alone. In 2017-18, sequential application of metribuzin (175 g ha^{-1}) followed by mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) recorded highest gross return (Rs 1,10,117 ha^{-1}) but due higher cost of production, it was second best in net return (Rs 18,765 ha^{-1}). During both years, metribuzin (175 g ha^{-1}) followed by sulfosulfuron (25 g ha^{-1}) was the second best treatment in gross return (Rs 111,338 – 109,644 ha^{-1}) but due low cost of production, it was best treatment in second year in terms of net return with (Rs 19,105 ha^{-1}). Average gross return (Rs

110,491 ha^{-1}), net return (Rs 22,328 ha^{-1}) and B-C ratio (1.25) also indicated that metribuzin (175 g ha^{-1}) followed by sulfosulfuron (25 g ha^{-1}) was the best treatment, followed by mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}) alone and metribuzin (175 g ha^{-1}) followed by mesosulfuron + iodosulfuron (12 + 2.4 g ha^{-1}). Pyroxasulfone (128 g ha^{-1}) and sequential application of metribuzin (175 g ha^{-1}) followed by clodinafop (60 g ha^{-1}) and pinoxaden (50 g ha^{-1}) also attained average B-C ratio higher than weed free treatment. But in rest of the treatments, the average B-C ratio recorded lower than weed free treatment and these can't be recommended to farmers (Table 7). Increase in net return and B-C ratio due to sequential application of PRE and POE herbicides in wheat were also reported earlier (Yadav et al., 2016; Kaur, 2017; Kumar, 2017). **(Insert** Table 7 **Here)**

Table 7
Effect of different weed control treatments on grain yield, net return and B-C ratio

Treatment	Dose (g ha^{-1})	Grain yield (q ha^{-1})			Net Returns (Rs ha^{-1})			B-C ratio		
		2016-17	2017-18	Pooled	2016-17	2017-18	Avg.	2016-17	2017-18	Avg.
PNM, PRE	1500	50.45	41.82	46.14	14,687	-852	6,917	1.17	0.99	1.08
MBZ, PRE	210	52.47	39.35	45.91	19,513	-5738	6,887	1.23	0.94	1.08
CDF, POE	60	51.04	42.76	46.90	16,407	1,798	9,102	1.19	1.02	1.10
SFS, POE	25	51.77	47.76	49.76	18,537	9,632	14,085	1.22	1.11	1.16
PXD, POE	50	55.26	47.37	51.31	24,229	7,856	16,043	1.28	1.09	1.18
MS + IS, POE	14.4	60.08	49.55	54.81	31,437	12,902	22,169	1.37	1.14	1.25
MBZ *fb* CDF, PRE-POE	175 *fb* 60	55.61	47.62	51.61	24,527	9,087	16,807	1.29	1.10	1.19
MBZ *fb* SFS, PRE-POE	175 *fb* 25	56.39	52.98	54.69	25,551	19,105	22,328	1.30	1.21	1.25
MBZ *fb* PXD, PRE-POE	175 *fb* 50	55.33	49.84	52.58	23,673	11,767	17,720	1.27	1.13	1.20
MBZ *fb* MS + IS, PRE-POE	175 *fb* 14.4	55.43	53.18	54.30	22,720	18,765	20,743	1.26	1.21	1.23
PNM + MBZ, PRE	1500 + 175	54.85	45.50	50.18	21,247	5,172	13,210	1.25	1.06	1.15
PNM + MBZ, PRE	1000 + 175	52.50	45.18	48.84	18,931	4,852	11,892	1.22	1.05	1.13
PSF, PRE	105	54.42	52.22	53.32	19,804	17,589	18,696	1.23	1.19	1.21
PSF, PRE	128	50.08	48.47	49.27	13,209	9,781	11,495	1.15	1.11	1.13
PNM *fb* HW, PRE-POE	1500	55.93	46.38	51.16	18,745	2,882	10,813	1.21	1.03	1.12
MBZ *fb* HW, PRE-POE	210	56.05	49.18	52.61	21,731	8,680	15,206	1.24	1.09	1.17
WF		60.60	53.27	56.93	23,945	11,703	17,824	1.25	1.12	1.18
WC		43.43	37.08	40.26	2,535	-9,092	-3,278	1.03	0.90	0.96
SEm±		2.0	1.58	1.24						
LSD (p = 0.05)		5.8	4.55	3.50						

PMN, pendimethalin; MBZ, metribuzin; CDF, clodinafop; SSN, sulfosulfuron; PDN, pinoxaden; MSN + ISN, mesosulfuron + iodosulfuron (ready mix), PSF- pyroxasulfone, WF-weed free, WC-weedy check, PRE-pre-emergence, POE-post-emergence

CONCLUSIONS

Contrary to farmers' fields, alternate herbicides were still providing good control of *P. minor* at Research Farm, however, there efficacy is also getting down. Poor spray technique at farmers field is a big reason behind performance gaps of herbicides. Alternate herbicides (clodinafop, sulfosulfuron, pinoxaden and mesosulfuron + iodosulfuron) in combination with pre-emergence herbicide metribuzin or pendimethalin were found quite effective against *P. minor*. Overall, metribuzin followed by sulfosulfuron (175 fb 25 g ha-1) was found be the best treatment in terms of weed control efficiency (WCE), grain yield, gross

return, net return and B-C ratio. Mesosulfuron + iodosulfuron (ready-mix) alone and in combination with pre-emergence herbicides performed well against weeds (*P. minor* as well as broadleaf) but their consistency was poor. Pyroxasulfone was the most effective herbicide against *P. minor* which gave complete control, but it was not found so effective against broadleaf weeds mainly *Melilotus* spp. and also caused crop phyto-toxicity at 128 g ha^{-1} but not that much pronounced at 105 g ha^{-1}. Therefore, further research is required to evaluate pyroxasulfone at lower doses as PRE followed by some broadleaf weed killing herbicides as POE to achieve total weed control in wheat. Viable options are to use already recommended herbicide (sulfosulfuron and mesosulfuron + iodosulfuron) in combination with PRE herbicide metribuzin or pendimethalin to achieve satisfactory control of mixed weed flora in wheat.

Declarations

Disclosure of conflict of interest

The authors declared that they have no conflict of interest

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Figures

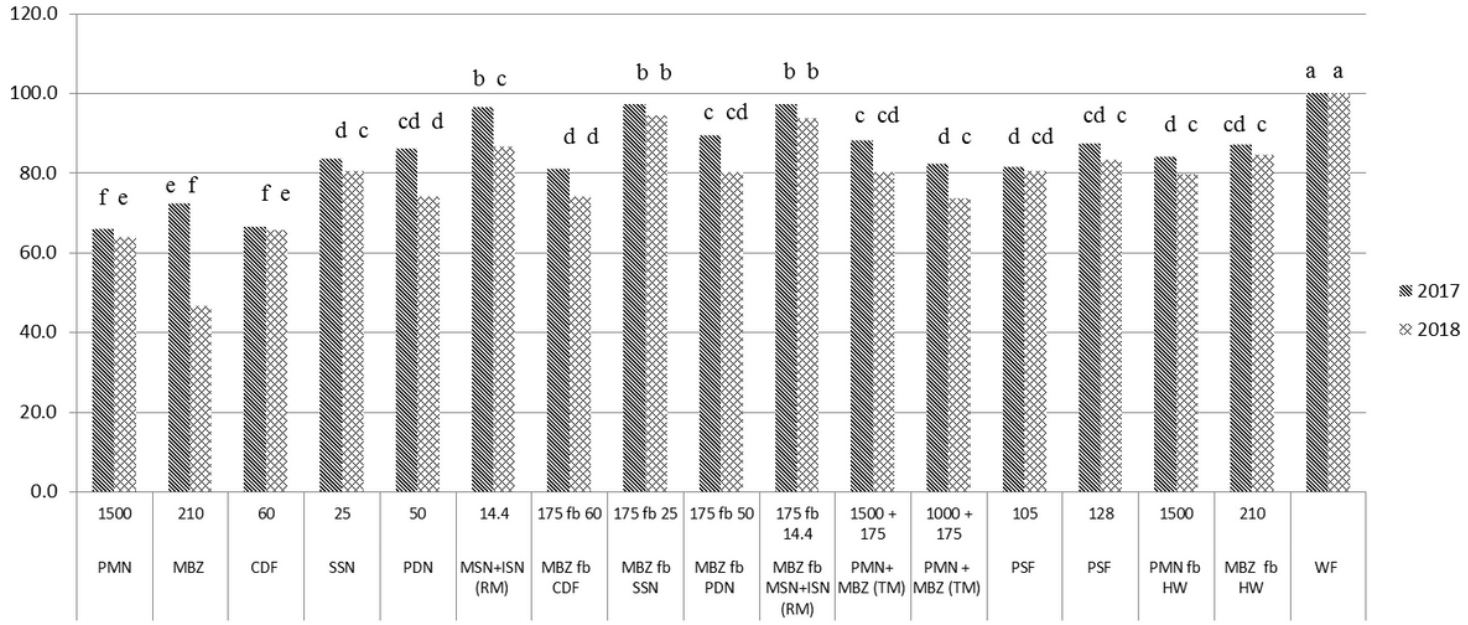


Figure 1

Weed control efficiency (%) of different herbicidal treatments in wheat in the *rabi* seasons of 2017 and 2018 recorded at 120 DAS. The herbicide doses are in g ha^{-1}. The treatments superscripted with different letters significantly differ with each other. Abbreviations: PMN, pendimethalin; MBZ, metribuzin; CDF, clodinafop; SSN, sulfosulfuron; PDN, pinoxaden; MSN+ISN, mesosulfuron + iodosulfuron (ready mix); PSF- pyroxasulfone; WF-weed free; fb, followed by