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Post-emergence herbicides for the control of resistant littleseed canarygrass in wheat

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ABSTRACT

Farmers' participatory field trials were conducted at village Kheri Raiwali in Kaithal district of Haryana during winter seasons of 2011-12 and 2012-13 to evaluate the bio-efficacy of post-emergence herbicides, their mixtures and sequential application for the control of the resistant littleseed canarygrass (*Phalaris minor*) and other weeds in wheat. Application of clodinafop 60 g/ha, fenoxaprop 120 g/ha and sulfosulfuron 25 g/ha at 35 days after sowing (DAS) did not provide satisfactory control of *P. minor*; however, mesosulfuron + iodosulfuron 14.4 g/ha provided better control (85-90%). Pinoxaden 50 g/ha resulted in 80% control of *P. minor* during first year but it provided only 55% control during second year. Ready-mix combination of metribuzin with fenoxaprop and clodinafop significantly improved the control of *P. minor* and broad-leaf weeds as compared to alone application of fenoxaprop and clodinafop. Maximum weed control efficiency (WCE) and highest grain yield (5.2 t/ha) was recorded with the application of sulfosulfuron + metsulfuron 32 g/ha during 2011-12, which was statistically at par with mesosulfuron + iodosulfuron and clodinafop + metribuzin; whereas during the second year, sulfosulfuron + metsulfuron 40 g/ha resulted in highest grain yield. Sequential application of sulfosulfuron + metsulfuron 32 g/ha at 25 DAS before irrigation *fb* sulfosulfuron + metsulfuron 32 g/ha at 40 DAS (after first irrigation) registered 97% WCE but its continuous adoption may lead to rapid development of resistance. The study indicates the need of new post-emergence herbicide with different mechanism of action (MOA), which can be integrated with non-chemical weed control strategies.

Key words: Herbicide mixture, Herbicide resistance, Metribuzin, *Phalaris minor*, Wheat

Wheat (*Triticum* a*estivum* L.) is the second most important grain crop of India after rice and thus crucial for the food security of the country. Being the main winter season crop, it occupies an area of 31.0 million ha with production of 86.5 million tons and average productivity of 2.79 t/ha. Wheat competes with several grassy and broad-leaf weeds during its growth period depending upon the adopted agronomic practices, soil types, underground water quality, weed control techniques and cropping system followed. For realizing potential crop yield, proper weed management is essential. *Phalaris minor* has become the most dominant weed of wheat in the rice-wheat cropping system (RWCS) in the north-western Indo-Gangetic Plains of India due to congenial agro-ecological conditions. PS II inhibitor herbicides were adopted on large scale for effective control of *P. minor* and other weeds during eighties, but continuous use of isoproturon resulted in the evolution of resistance in *P. minor* biotypes in north-western India (Malik and Singh 1995, Singh *et al.* 1997). This was the most serious case of herbicide resistance in the world, resulting in total crop failure from heavy weed infestations (2000-3000 plants/m^2). Alternate herbicides *viz.* clodinafop, sulfosulfuron and fenoxaprop were recommended to control isoproturon resistant population of *P. minor* during 1997. These herbicides provided effective control of this weed up to 2007 (Chhokar and Sharma 2008) and played a crucial role in restoring the productivity of wheat under RWCS in the country. Over the years, loss of efficacy to these herbicides has made the task of managing herbicide resistant *P. minor* biotypes more daunting (Dhawan *et al.* 2009). Presently, its control has become even more difficult after it evolved multiple herbicide resistance to recommended herbicides: diclofop-methyl, fenoxaprop-p-ethyl, clodinafop-propargyl, pinoxaden (ACCase); sulfosulfuron and premix of mesosulfuron + iodosulfuron (ALS inhibitors); mediated by enhanced metabolism and target site mutations (Punia *et al.* 2010, Dhawan *et al.* 2012). Multiple herbicide resistant populations of *P. minor* in wheat in RWCS is again threatening wheat productivity and profitability as it did in the early 1990s when resistance to isoproturon first occurred. Based on the observations recorded from farmers' interviews and previous field experiments, it was assumed that *P. minor* is not

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being effectively controlled by the available herbicides (Punia *et al.* 2012). The use of multiple herbicide mechanism of action (MOAs) either as herbicide mixtures or sequential application can be investigated to work out a realistic strategy for the management of resistant *P. minor*. Metribuzin has been observed to cause phytotoxicity at high doses; however, its use in mixture at lower doses may be advantageous in management of multiple herbicide resistant *P. minor* (Singh 2015b, Yadav *et al.* 2016). So, the present experiment was planned to evaluate the bio-efficacy of herbicides, their mixtures and sequential use for management of the resistant *P. minor* at farmers' field.

MATERIALS AND METHODS

To study the bio-efficacy of different herbicides against *P. minor* and other broad-leaf weeds, a field experiment was laid out during winter seasons of 2011-12 and 2012-13 at village- Kheri Raiwali in district Kaithal, Haryana. The soil of the experimental field was clay loam in texture, low in available N, medium in phosphorus, high in potassium and slightly alkaline in reaction (pH 8.3). The treatments included pinoxaden 50 g/ha, clodinafop 60 g/ha, fenoxaprop 120 g/ha, sulfosulfuron 25 g/ha, mesosulfuron + iodosulfuron (ready-mix, RM) 14.4 g/ha, fenoxaprop + metribuzin (RM) 100+175 g/ha, clodinafop + metribuzin (RM) 60+210 g/ha, sulfosulfuron + metsulfuron (RM) 32 g/ha during *Rabi* 2011-12 whereas four new treatments of pinoxaden 60 g/ha, clodinafop 120 g/ha, sulfosulfuron + metsulfuron (RM) 40 g/ha and sulfosulfuron + metsulfuron (RM) 32 g/ha before irrigation (25 DAS) *fb* sulfosulfuron + metsulfuron (RM) 32 g/ha after irrigation (40 DAS) were added to the above treatments during 2012-13. The treatment of two sequential applications of sulfosulfuron + metsulfuron was the farmers' practice being followed in that area to combat the herbicide resistance problem. The experiment was laid out in randomized complete block design with three replications with a plot size of 20 x 8 m. There were small untreated plots during both the years in which herbicides were not sprayed. During 2011-12, wheat cultivar '*PBW 550*' was sown on 10 November, 2011 whereas wheat cultivar '*HD 2967*' was sown on 12 November 2012 during 2012-13. Seeding rate was 100 kg/ha at 20 cm row spacing. All the herbicides were sprayed with battery operated knapsack sprayer fitted with flat fan nozzle using spray volume of 375 l/ha at 40 psi pressure. Phyto-toxicity in terms of chlorosis, stunting, leaf burning, scorching, hyponasty and epinasty was visually observed at 15 days after treatment (DAT) and 45 DAT using rating scale of 0 – 100 scale, where 0 = no effect on plant and 100 = complete death of plant. Control of *P. minor* and broad-leaf weeds was also visually estimated by using a scale of 0 (no control) to 100 (complete control) at 75 days after sowing. The data on weed density were recorded with two 0.5 m x 0.5 m quadrants per plot at harvest and were subjected to square root transformation before statistical analysis. The weed control efficiency was computed for *P. minor*, broad-leaf weeds and total weeds control as a per cent reduction in weed population at harvest under different herbicidal treatments in comparison to weedy check. Biometric observations were recorded on effective tillers per meter row length, ear length and crop yield. Crop was harvested on 18 April, 2012 and 21 April, 2013 during 2011-12 and 2012-13, respectively. Grain yield of wheat was recorded by harvesting two samples from an area of 4.0 x 4.0 m in each plot. Data on visual per cent weed control were subjected to angular transformation before statistical analysis to improve the homogeneity of the variance. Year wise data were subjected to ANOVA separately and means were compared using Fisher's protected LSD test at 5% level of significance using the 'OPSTAT' software of CCS Haryana Agricultural University, Hisar.

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was infested with natural weed flora of the wheat crop and it was mainly dominated by *Phalaris minor*¸ which alone constituted 77-81% of the total weed flora. The other weed flora consisted of *Rumex dentatus*, *Chenopodium album*, *Coronopus didymus*, *Anagallis arvensis*, *Medicago denticulata* and *Melilotus indica*. Per cent control of *P. minor* and broad-leaf weeds was significantly affected by herbicides treatments as compared to weedy check at 75 days after sowing (**Table 1**). During both the years, clodinafop 60 g/ha, fenoxaprop 120 g/ha and sulfosulfuron 25 g/ha did not provide satisfactory control of *P. minor* in wheat (30%, 25-28% and 60-70%, respectively); however, mesosulfuron + iodosulfuron 14.4 g/ha provided better control (85-90%) of *P. minor*. Pinoxaden 50 g/ha resulted in 80% control of *P. minor* during first year but it provided only 55% control of *P. minor* during second year. Increasing the dose of clodinafop from 60 to 120 g/ha and pinoxaden from 50 to 60 g/ha significantly improved *P. minor* control (30 to 45 and 55 to 88%, respectively) at 75 DAS during 2012-13. Clodinafop, fenoxaprop and pinoxaden did not provide any control of broadleaf weeds and sulfosulfuron provided only 65-80% control; however, mesosulfuron + iodosulfuron effectively controlled (90%) broad-leaf weeds during both the years. Ready-mix combination of metribuzin with fenoxaprop and clodinafop significantly improved the control of *P. minor* (70-75%) and broad-leaf weeds (90-92%) as compared to alone application of fenoxaprop and clodinafop. The resistant populations of *P. minor* were also found susceptible to triazine (metribuzin and terbutryn) and dinitroaniline (pendimethalin) herbicides as reported by Chhokar and Sharma (2008) and Singh (2015b). Sulfosulfuron + metsulfuron 32 g/ha gave 85-92% control of *P. minor* along with 85-90% broad-leaf weeds during both the years. Increase in dose of sulfosulfuron + metsulfuron from 32 to 40 g/ha significantly enhanced the control of *P. minor* and broad-leaf weeds during 2012-13. The sequential application of sulfosulfuron + metsulfuron 32 g/ha at 25 DAS *fb* sulfosulfuron + metsulfuron 32 g/ha at 40 DAS resulted in significantly higher control of *P. minor* (98%) and broad-leaf weeds (98%) as compared to all other herbicidal treatments.

All the treatments except fenoxaprop 120 g/ha, were significantly superior to weedy check in reducing the population of *P. minor* at harvest during both the years (**Table 1**). Ready-mix herbicides at their normal dose significantly reduced the *P. minor* population as compared to clodinafop 60 and 120 g/ha; fenoxaprop 120 g/ha and pinoxaden 50 g/ha but

Table 1. Per cent control of weeds at 75 DAS and weed population at harvest as influenced by different herbicidal treatments in wheat at farmers' fields

Treatment	Dose (g/ha)	Visual weed control (%)*				Weed population (no./m^2)**			
		P. minor		BLW		*P. minor*		BLW	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Pinoxaden	50	64.0 (80.7)	48.1 (55.3)	0.0 (0.0)	0.0 (0.0)	5.2 (26.7)	8.4 (69.3)	6.4 (41.3)	6.3 (38.7)
Pinoxaden	60	-	63.7 (80.3)	-	0.0 (0.0)	-	5.7 (32.0)	-	6.0 (36.0)
Clodinafop	60	33.2 (30.0)	32.9 (29.7)	0.0 (0.0)	0.0 (0.0)	9.9 (97.3)	10.2 (104)	6.3 (38.7)	6.5 (41.3)
Clodinafop	120	-	41.9 (44.7)	-	0.0 (0.0)	-	8.8 (77.3)	-	6.3 (38.7)
Fenoxaprop	120	32.1 (28.3)	30.0 (25.0)	0.0 (0.0)	0.0 (0.0)	10.4 (107)	11.5 (132)	6.6 (42.7)	6.4 (40.0)
Sulfosulfuron	25	50.7 (60.0)	56.8 (70.0)	64.7 (81.7)	53.7 (65.0)	7.5 (56.0)	6.0 (36.0)	3.7 (13.3)	3.9 (14.7)
Mesosulfuron + iodosulfuron	14.4	71.5 (90.0)	67.2 (85.0)	71.5 (90.0)	71.9 (90.0)	3.2 (12.0)	4.8 (22.7)	2.9 (8.0)	2.3 (5.3)
Fenoxaprop + metribuzin	100+175	56.8 (70.0)	57.0 (70.0)	73.4 (91.7)	71.5 (90.0)	6.8 (45.3)	7.1 (50.7)	3.2 (9.3)	2.5 (5.3)
Clodinafop + metribuzin	60+210	59.8 (74.7)	59.9 (74.7)	72.0 (90.3)	71.5 (90.0)	6.0 (34.7)	6.2 (37.3)	3.2 (9.3)	2.2 (4.0)
Sulfosulfuron + metsulfuron	32	76.2 (91.7)	67.2 (85.0)	71.5 (90.0)	67.4 (85.0)	2.9 (9.3)	5.0 (24.0)	2.7 (8.0)	3.1 (9.3)
Sulfosulfuron + metsulfuron	40	-	73.4 (91.7)	-	73.4 (91.7)	-	4.1 (16.0)	-	2.7 (6.7)
Sulfosulfuron + metsulfuron *fb* sulfosulfuron + metsulfuron	32 & 32	-	85.7 (98.3)	-	85.7 (98.3)	-	1.9 (4.0)	-	1.4 (1.3)
Weedy check	-	0.0 (0.0)	0.0 (0.0)	(0.0)	0.0 (0.0)	11.8 (139)	12.3 (152)	6.6 (42.7)	6.1 (37.3)
LSD (P=0.05)	-	7.5	5.1	2.7	5.2	1.4	1.3	1.1	0.8

*Original figures in parentheses were subjected to angular transformation before statistical analysis; **Original figures in parentheses were subjected to square root transformation before statistical analysis

Table 2. Crop injury, yield and yield attributes of wheat as influenced by different herbicidal treatments at farmers' fields

Treatment	Dose (g/ha)	Crop injury (%) 15 DAT		Crop injury (%) 45 DAT		Plant height (cm)		Effective tillers/m row length		Ear length (cm)		Grain yield (t/ha)	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Pinoxaden	50	0	0	0	0	78.5	88.6	81	86	10.4	10.6	4.40	4.40
Pinoxaden	60	-	0	-	0	-	91.4	-	90		11	-	4.60
Clodinafop	60	0	0	0	0	77.4	87.4	72	74	10.5	10.2	3.96	3.95
Clodinafop	120	-	0	-	0	-	88.0	-	82		10.5	-	4.20
Fenoxaprop	120	0	0	0	0	75.6	85.3	66	68	9.4	9.8	3.80	3.95
Sulfosulfuron	25	0	0	0	0	74.9	92.3	83	93	11	10.9	4.50	4.50
Mesosulfuron+iodosulfuron	14.4	5	5	0	0	77.1	90.9	97	102	11.9	12.4	5.00	4.85
Fenoxaprop+ metribuzin	100+175	15	15	10	10	73.0	89.6	85	93	10.9	11.2	4.60	4.60
Clodinafop+metribuzin	60+210	0	15	0	10	79.2	90.0	96	94	11.6	11	4.96	4.60
Sulfosulfuron+metsulfuron	32	0	0	0	0	75.5	90.4	99	97	11.8	11.5	5.20	4.76
Sulfosulfuron+metsulfuron	40		0	-	0	-	90.2	-	103		12.5	-	4.90
Sulfosulfuron+metsulfuron *fb* sulfosulfuron+metsulfuron	32 & 32	-	5	-	0	-	92.7	-	105		12.4	-	4.85
Weedy check						72.7	82.6	57	59	9.1	8.7	3.30	3.15
LSD (P=0.05)	-		-		-	NS	6.1	6	7	1.1	1.4	0.37	0.24

remained at par with sulfosulfuron 25 g/ha and pinoxaden 60 g/ha during 2012-13. Minimum population of *P. minor* and broad-leaf weeds was recorded with the sequential application of sulfosulfuron + metsulfuron *fb* sulfosulfuron + metsulfuron, indicating that the sequential application of herbicides can improve weed control when single application even at increased rates have poor efficacy. Among the herbicidal treatments, highest weed control efficiency (97%) was recorded with sequential application of sulfosulfuron + metsulfuron *fb* sulfosulfuron + metsulfuron during 2012-13; followed by sulfosulfuron + metsulfuron 32 g/ha and mesosulfuron + iodosulfuron, which registered 90 and 89% WCE, respectively during 2011-12 (**Figure 1** and **2**). However, lower weed control efficiency was recorded with clodinafop, fenoxaprop and pinoxaden as these herbicides showed no efficacy against broad-leaf weeds and provided unsatisfactory control of *P. minor*. Ready-mix combination of metribuzin with fenoxaprop and clodinafop resulted in higher WCE due to better control of *P. minor* and broad-leaf weeds. The data on visual mortality indicated that *P. minor* has developed a high level of resistance against ACCase inhibitor herbicides (clodinafop, fenoxaprop) and medium level of resistance against ALS inhibitor herbicides (sulfosulfuron) at village- Kheri Raiwali in district Kaithal, Haryana. Poor efficacy of these herbicides during second year inferred that level of resistance increased over the years. The earlier literature also reported the varying levels of herbicide resistance in *P. minor* populations in Haryana (Dhawan *et al.* 2012, Chhokar *et al.* 2015, Singh 2015b).

Effect on crop

Ready-mix combinations of fenoxaprop + metribuzin showed 15% phyto-toxicity on the wheat (Var. *PBW 550* and *HD 2967*) at 15 DAT, however crop recovered with time (**Table 2**). Wheat crop also recovered from the initial suppression caused by the application of clodinafop + metribuzin and mesosulfuron + iodosulfuron. Differential varietal sensitivity to metribuzin has been reported earlier as well (Yadav *et al.* 2012). Among the herbicidal treatments, lowest yield and yield attributes of wheat were recorded with fenoxaprop 120 g/ha (3.80 and 3.95 t/ha) and clodinafop 60 g/ha (3.95 and 3.96 t/ha), though these treatments were significantly better than the weedy check (3.30 and 3.15 t/ha) during both the years (**Table 2**). During 2012-13, increasing the dose of clodinafop from 60 to 120 g/ha and pinoxaden from 50 to 60 g/ha resulted in increased grain yield of wheat, but the differences were not significant. However, combination of metribuzin with clodinafop and fenoxaprop significantly improved grain yield as compared to their alone application. Highest grain yield (5.2 t/ha) was recorded with the application of sulfosulfuron + metsulfuron, which was statistically at par with mesosulfuron + iodosulfuron and clodinafop + metribuzin during 2011-12, which might be attributed to the increased number of tillers and ear length of wheat under these treatments. During the second year, application of sulfosulfuron + metsulfuron 40 g/ha resulted in highest grain yield (4.90 t/ha), which remained at par with the sequential application of sulfosulfuron + metsulfuron (4.85 t/ha), mesosulfuron + iodosulfuron (4.85 t/ha) and sulfosulfuron + metsulfuron 32 g/ha (4.76 t/ha).

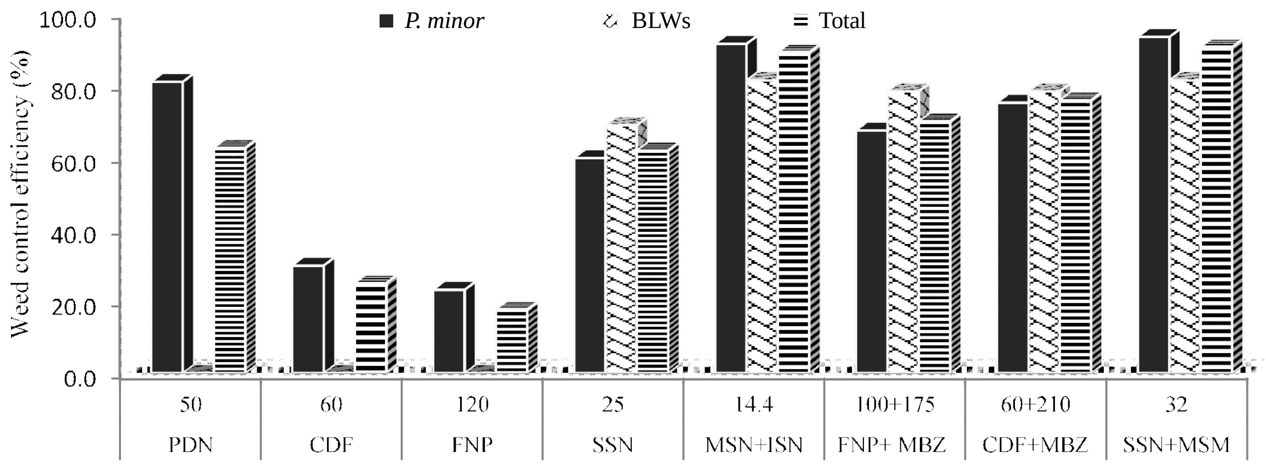

Figure 1. Weed control efficiency of different herbicides for *P. minor*, broad-leaf weeds (BLWs) and total weeds in wheat during 2011-12. The herbicide doses are in g/ha. PDN, pinoxaden; CDF, clodinafop; FNP, fenoxaprop; SSN, sulfosulfuron; MSN, mesosulfuron; ISN, iodosulfuron; MBZ, metribuzin; MSM, metsulfuron

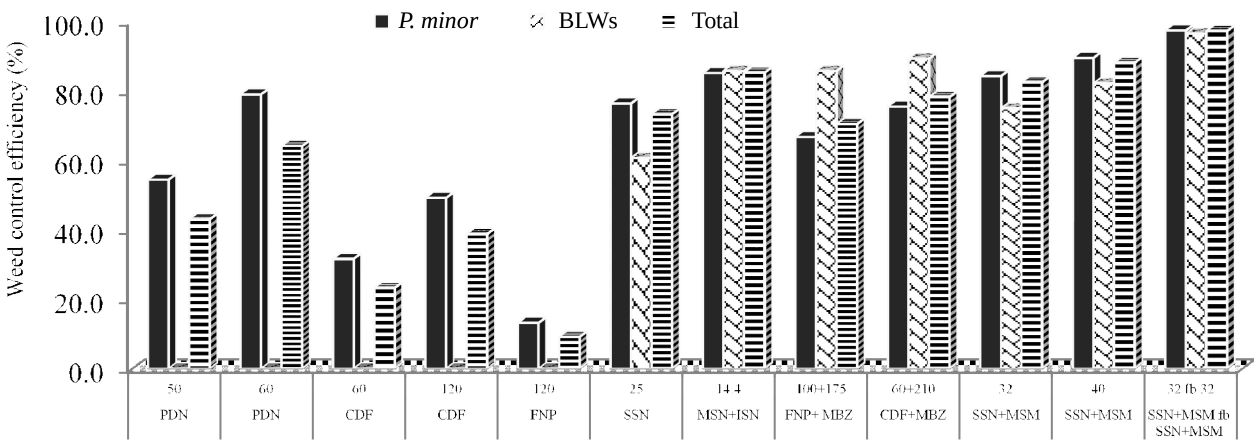

Fig. 2. Weed control efficiency of different herbicides for *P. minor*, broad-leaf weeds (BLWs) and total weeds in wheat during 2012-13. The herbicide doses are in g/ha. PDN, pinoxaden; CDF, clodinafop; FNP, fenoxaprop; SSN, sulfosulfuron; MSN, mesosulfuron; ISN, iodosulfuron; MBZ, metribuzin; MSM, metsulfuron; *fb*, followed by.

So, application of herbicide mixtures such as mesosulfuron + iodosulfuron, fenoxaprop + metribuzin, clodinafop + metribuzin provided some relief from resistant *P. minor* and could be exploited as alternative options but it is not an enduring solution. Use of metribuzin in long run may not remain effective because of higher propensity of *P. minor* for enhanced metabolism of PSII inhibitors (Singh 2015a). Similarly, application of sulfosulfuron + metsulfuron at higher dose or its sequential use before and after irrigation, provided effective control of all the weeds but it will again lead to rapid development of resistance. The resistance in weeds as such needs to be addressed with integrated weed management approaches, including crop and herbicide rotations, herbicide combinations with cultural and mechanical methods.

REFERENCES

Chhokar RS and Sharma RK. 2008. Multiple herbicide resistance in littleseed canarygrass (*Phalaris minor*): A threat to wheat production in India. *Weed Biology and Management* **8**: 112-123.

Chhokar RS, Sharma RK and Sharma I. 2015. Herbicide resistant weeds and their management in wheat, p. 141. In: *Proceedings, Volume II (oral papers), 25th Asian-Pacific Weed Science Society Conference*. Hyderabad, India. Indian Society of Weed Science, Jabalpur.

Dhawan RS, Punia SS, Singh S, Yadav D and Malik RK. 2009. Productivity of wheat (*Triticum aestivum*) as affected by continuous use of new low dose herbicides for management of littleseed canarygrass (*Phalaris minor*) in India. *Indian Journal of Agronomy* **54**: 58-62.

Dhawan RS, Singh N and Singh S. 2012. Littleseed canarygrass resistance to sulfonyl-urea herbicides and its possible management with pendimethalin. *Indian Journal of Weed Science* **44**(4): 218-224.

Malik RK and Singh S. 1995. Littleseed canarygrass (*Phalaris minor*) resistance to isoproturon in India. *Weed Technology* **9**: 419-425.

Punia SS, Yadav DB, Singh S, Dhawan RS and Yadav A. 2010. Present status of herbicide resistance to wheat herbicides in India, pp 10. In: *Biennial Conference on Recent Advances in Weed Science Research*, 25-26 February 2010, Raipur. Indian Society of Weed Science, Jabalpur.

Punia SS, Singh S, Yadav DB and Yadav A. 2012. Survey on efficacy of herbicides against resistant population of *Phalaris minor* in wheat at Farmer's field in Haryana, p 22. In: *Biennial Conference on Weed Threat to Agriculture, Biodiversity and Environment*, 19-20April 2012, Trissur. Indian Society of Weed Science, Jabalpur.

Singh S. 2015a. Herbicide mixture and sequential application for managing resistant *Phalaris minor*, p 186. In: *Weed Science Society of America Annual Meeting,* 9-12 February 2015, Lexington, Kentucky.

Singh S. 2015b. Management of multiple herbicide resistant in *Phalaris minor i*n India, p 21. In: *Proceedings, Volume II (oral papers). 25th Asian-Pacific Weed Science Society Conference*. Hyderabad, Indian Society of Weed Science, Jabalpur.

Singh S, Kirkwood RC and Marshall G. 1997. Effects of isoproturon on photosynthesis in susceptible and resistant biotypes of *Phalaris minor* and wheat. *Weed Research* **37**: 315-324.

Yadav A, Hooda VS, Yadav DB and Duhan A, 2012. Screening the sensitivity of wheat varieties against fenoxaprop + metribuzin, pp 255-256. In: *Proc. National Seminar on Sustainable Agriculture and Food Security: Challenges in Changing Climate*, 27-28 March 2012, Hisar.

Yadav DB, Yadav A, Punia SS and Chauhan BS. 2016. Management of herbicide-resistant *Phalaris minor* in wheat by sequential or tank-mix applications of pre- and post-emergence herbicides in north-western Indo-Gangetic Plains. *Crop Protection* **89**: 239-247.