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Status of herbicide resistance in *Phalaris minor* in wheat in Haryana

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ABSTRACT

Herbicide resistance in little seed canary grass (*Phalaris minor* Retz.) in wheat is the major sustainability issue, which puts the rice-wheat (R-W) system in north-western Indo-Gangetic Plains (IGP) under serious threat. To assess the resistance level, a questionnaires based survey with a systematic approach was conducted during *rabi* 2017–18 in five districts (Yamuna Nagar, Kaithal, Karnal, Fatehabad and Rohtak) of Haryana. The study revealed that at present, farmers of Haryana are closely back to square one, similar to the situation of herbicide resistance in *P. minor* like 1990's and currently, no herbicide is satisfactorily effective against resistant *P. minor*. Farmers are using every possible combination of herbicides in a hit and trial way. In 2017–18, half of the farmers (50%) went for the second spray, 13% applied the third spray, and even 3% of farmers opted for the fourth spray. The same pattern followed in the case of herbicide dose; in 2017–18, 38% of farmers opted for 2-4 X-dose, 16% of farmers for 4-6 X-dose, 3% of farmers for 6-8 X-dose, and even one percent farmers applied 8-10 X-dose. Negative relationship between percent control with higher dose (X) (Chi-Square value 72.560[a], DF = 12 and p = <0.001) and multiple sprays (Chi-Square 67.076[a], DF = 8 and P = <0.001) recorded during 2017–18 also indicates strong chances/evidences of herbicide resistance development.

Keywords: Herbicide resistance, *P. minor*, Rice-wheat cropping system, Survey

Phalaris minor Retz. is one of the most troublesome grassy weeds in wheat; globally it has been reported in more than 60 countries of the world, widely covering all the continents except for the Polar Regions. It is one of the most troublesome grassy weeds in wheat (Jabran *et al.* 2010). In many cases, cereal fields are heavily infested by *P. minor,* which emerges with the germinating wheat crop, competes for water and nutrient requirement, and significantly reduces the grain yield (Malik and Singh 1995). Among various weed control measures, herbicides are widely preferred by wheat farmers for control of *P. minor* due to cost- and time effectiveness. Also, the morphological similarity of this weed with wheat makes it difficult to remove manually within crop rows. Until the early 1990s, *P. minor* could be effectively controlled by isoproturon, a substituted urea herbicide first recommended in 1977-78 and widely used since the early 1980s. But continuous use of the same herbicide for more than 10-15 years coupled with monocropping resulted in the evolution of resistance in this weed against isoproturon (Malik and Singh 1995). Consequently, isoproturon was withdrawn from recommendation, and alternate post-emergence herbicides (clodinafop, fenoxaprop and sulfosulfuron) were recommended in 1997-98. New herbicides work effectively for 10-12 years, but after that again, there are reports of lower efficacy or failure of one or more of these herbicides against *P. Minor* and an increase in GR_{50} values (dose required to achieve 50% growth reduction) (Yadav *et al.* 2016) was reported. Multiple and cross-resistance reported by researchers in IGP. Populations having resistance against clodinafop also exhibited cross-resistance to fenoxaprop (fop-group), tralkoxydim (dim-group) and pinoxaden (den-group). Similarly, a population resistant to sulfosulfuron showed cross-resistance to mesosulfuron and pyroxsulam (Chhokar *et al*. 2012). Till date, whatever studies were conducted random and inconclusive in nature, that's why a systematic study was planned, in which a questionnaires-based survey was conducted to assess the current status of herbicide resistance in *P. minor* at farmers' field level.

MATERIALS AND METHODS

Study area: A systematic household survey was conducted during *rabi* 2017–18 (end of January to February 2018) in five districts (Yamuna Nagar, Kaithal, Karnal, Fatehabad, and Rohtak) of Haryana state. Two blocks were

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selected from each district and three villages from each block, and ten farmers from each village, thus involving a total number of 300 farmers from 30 villages. One farmer left wheat cultivation, and the other one was following organic farming, so 298 farmers were included in the final calculation.

Data collection: Detailed questionnaires based survey proforma was prepared in advance with the consultation of experts. Survey proforma validity was also checked before the survey was initiated by consulting with progressive farmers, excluding the targeted group. The absolute value of herbicide used by the farmer at his own field in one-acre area was asked and then converted into times of recommended dose/hectare (X) applied by the farmer. CCSHAU recommended dose of herbicide was used as reference for conversion. Selective field visit at key respondent's field and focused group discussion was conducted to measure the level of problem. Rating of herbicides by farmers was asked on a Likert scale 1-6 (where 1 = most liked and 6 = most dislike).

Data analysis: Survey data were analyzed through SPSS and prepared crosstab accordingly; a chi-square test was used to assess the association among attributes. For herbicide rating, Henery Garrett's rank technique was used. The order given by farmers was converted into percent position as;

Percent position = 100 $(R_{ij}-0.5)/N_j$

where, R_{ij}, Rank given for i^{th} herbicide by the j^{th} farmer; Nj, Number of herbicides ranked by the j^{th} farmer;

The percent position derived for each rank was converted into a score with Henery Garrett's table. The score of an individual farmer for each herbicide was added and divided by the total number of farmers for whom scores were added. A higher mean value denotes the prime preference of a particular herbicide among the farmers.

RESULTS AND DISCUSSION

Herbicide use and spraying pattern: At present, two PRE herbicides (pendimethalin and metribuzin) and four POST herbicides (clodinafop, sulfosulfuron, pinoxaden and mesosulfuron + iodosulfuron) generally used by farmers who are easily available in the market. Maximum farmers are relying on POST herbicide; only a few are using PRE herbicides at a small scale (Table 1). Farmers are opting for each and every possible combination of these herbicides and used 2.91 X-dose in 2017–18 with merely 70-80% control of *P. minor*. Over the years, farmers needed to apply more and more herbicides 2.06 X-dose in 2015-16 and 2.33 X-dose in 2016-17 to get desirable control. Intensive rice-wheat

Table 1 Information about the herbicide use pattern against *P. minor* during last three years (2015-16 to 2017-18) (N=298)

District	Times of herbicide used (X-dose)						TOTO (X-Dose)	Percent control
	PMN	MBZ	CDF	SSN	PDN	MSN+ISN (RM)		
				2017-18				
Fatehabad	0.03	0.00	1.47	0.84	0.31	0.18	2.84 (0.17)*	79.6
Y Nagar	0.03	0.12	1.04	0.37	0.37	0.21	2.13 (0.16)	80.8
Kaithal	0.17	0.25	1.28	1.03	0.87	0.04	3.64 (0.20)	74.0
Karnal	0.03	0.34	1.70	0.82	1.09	0.13	4.13 (0.22)	69.1
Rohtak	0.00	0.01	1.57	0.08	0.15	0.00	1.80 (0.09)	75.1
Average	0.05	0.14	1.41	0.63	0.56	0.11	2.91 (0.09)	75.7
				2016-17				
Fatehabad	0.00	0.00	1.39	0.72	0.25	0.18	2.56 (0.16)	86.3
Y Nagar	0.02	0.04	0.82	0.23	0.35	0.18	1.65 (0.12)	86.5
Kaithal	0.08	0.03	1.02	1.02	0.63	0.10	2.88 (0.15)	79.2
Karnal	0.00	0.09	1.63	0.56	0.99	0.07	3.33 (0.15)	72.7
Rohtak	0.00	0.00	1.13	0.03	0.05	0.00	1.22 (0.05)	83.4
Average	0.02	0.03	1.20	0.51	0.45	0.11	2.33 (0.07)	81.6
				2015-16				
Fatehabad	0.02	0.00	1.27	0.72	0.22	0.10	2.32 (0.14)	91.7
Y Nagar	0.00	0.00	0.78	0.19	0.31	0.15	1.43 (0.09)	91.4
Kaithal	0.02	0.00	0.97	0.97	0.58	0.017	2.57 (0.14)	85.2
Karnal	0.00	0.03	1.48	0.57	0.74	0.07	2.89 (0.13)	79.2
Rohtak	0.00	0.00	1.05	0.02	0.00	0.00	1.07 (0.03)	89.0
Average	0.01	0.01	1.11	0.49	0.37	0.07	2.06 (0.06)	87.3

*Figures in parenthesis representing the Standard Error of Mean SEm±. PMN, pendimethalin; MBZ, metribuzin; CDF, clodinafop; SSN, sulfosulfuron; PDN, pinoxaden; MSN+ISN, mesosulfuron + iodosulfuron (ready mix); TOTO, total times of.

growing areas, viz. Karnal, Kaithal districts, and Bilaspur block of Yamuna Nagar district faced more problems than the diversified one (Fatehabad, Rohtak and Bilaspur block of Yamuna Nagar). Even few farmers used up to 9.0 X-dose of herbicide during 2017-18 and still could not get desirable control of *P. minor*. Farmers know the importance of crop rotation, but only 14% followed that, because of no other cropping system remunerative than rice-wheat. Nowadays, farmers are applying different herbicide as tank-mix spray, or they are opting for more sprays.

In 2015-16, around 60.4% of farmers applied single spray and got 89.9% control, but in 2017-18 only one-third (33.9%) of farmers went for single spray and got 84.2% control (Table 2). In 2017-18, half of the farmers (50.0%) went for the second spray, 13.1% applied the third spray, and even 3.0% of farmers opted for the fourth spray. The same story repeated in the case of herbicide dose in 2015-16, 37.9% of farmers restricted up to X-dose and got 92.1% control, but in 2017-18, around 19.5% of farmers opted for X-dose and got 87.2% control (Table 2). In 2017-18, 37.6% farmers opted for 2-4 X-dose, 16.1% farmers for 4-6 X-dose, 2.7% farmers for 6-8 X-dose and even one percent farmers applied 8-10 X-dose. Those who went for single spray or X-dose got better control (obviously due to less resistance problem as following diversified cropping system) than those who opted for a second and third spray with multiple-dose (2-8 X-dose). However, they got higher control at the fourth spray or with the higher dose (> 8 X-dose) in 2017–18 (in more resistance affected areas). A similar trend was there in the previous two years; however, no farmer went for a fourth spray or a higher dose > 8 X-dose. It indicated that due to herbicide resistance development in certain areas (Karnal, Kaithal districts, and Bilaspur block of Yamuna Nagar district), farmers were not getting desirable control and therefore, they increased the number of sprays with multiple-dose and beyond certain threshold level got desirable control but compromised with yield due to photo-toxicity and lesser economic returns due to more money spent on herbicides. Those farmers, who opted for fourth spray or higher dose, were desperate to kill/eradicate *P. minor* from their fields at any cost. Farmers had a tendency to apply more sprays with increased doses up to the extent possible. Presently, they were applying herbicides against *P. minor* from the very first day (just after sowing) to the time of panicle initiation in few extreme cases. Further, the detailed analysis of the data showed very strong evidence of negative relationship between percent control with higher dose (X) (Chi-Square value 72.560[a], DF = 12 and P = <0.001) and multiple sprays (Chi-Square 67.076[a], DF = 8 and P=<0.001) during 2017-18 (Table 3). It also indicates herbicide resistance development. Previous field surveys also indicated that over the years, *P. minor* evolved itself against alternate herbicides and step-by-step/year-wise, the farmers were compelled to increase herbicides X-doses and number of sprays to get satisfactory control (Lathwal and Ahlawat 2011, Bhullar *et al.* 2014).

Rating of herbicides by farmers: Herbicide rating by the farmers is mainly decided by herbicides price, residual effect, the window of the application, crop safety, cropping system, and level of herbicide resistance at a particular farmer's field. Overall, farmers gave the first rank to pinoxaden, 46.3% chosen as there first choice among the herbicides and reported that it was found the most effective against clodinafop and sulfosulfuron resistant *P. minor* and widely used in Kaithal, Karnal districts, and Bilaspur block of Yamuna Nagar district. But higher price (2.5 times costlier) than other prevailing herbicides is an obstacle for its broader adoption. After pinoxaden, sulfosulfuron was the second choice of farmers, and they experienced that it gave the best results at small-sized (2-3 leaf stage) *P. minor* and also found it very useful in dry soil application before first irrigation at 20 DAS. Findings of Rasool *et al*. (2017) also

Table 2 Information about the spraying pattern, herbicides dose pattern and percent control of *P. minor* during last three years (2015-16 to 2017-18) (N=298)

	2017-18		2016-17		2015-16	
	Number of farmers	Percent control	Number of farmers	Percent control	Number of farmers	Percent control
Spray						
First spray	101 (33.9%)	84.2	159 (53.4%)	85.13	180 (60.4%)	89.9
Second spray	149 (50.0%)	72.1	120 (40.3%)	78.43	112 (37.6%)	84.6
Third spray	39 (13.1%)	72.0	19 (6.4%)	80.79	6 (2.0%)	87.5
Fourth spray	9 (3.0%)	73.9				
Dose (times of X-dose)						
Up to 1	58 (19.5%)	87.2	98 (32.9%)	88.11	113 (37.9%)	92.1
> 1 to 2	69 (23.2%)	77.9	69 (23.2%)	82.46	85 (28.5%)	87.9
>2 to 4	112 (37.6%)	72.8	110 (36.9%)	77.15	90 (30.2%)	82.9
>4 to 6	48 (16.1%)	71.4	19 (6.4%)	80.26	10 (3.4%)	84.5
>6 to 8	8 (2.7%)	61.9	1 (0.3%)	65.00	0 (0.0%)	
>8 to 10	3 (1.0%)	70.0	0 (0.0%)		0 (0.0%)	

Table 3 Association between percent control with dose (X) and number of spray during 2017–18 (N=298)

		Percent control					
		Very good control (91 to 100%)	Good control (81 to 90%)	Average control (71 to 80%)	Poor control (61 to 70%)	Very poor control (<60%)	Total
Doses (X)	Up to 1	14	27	13	2	2	58
	>1 to 2	5	19	24	16	5	69
	>2 to 4	5	20	33	28	26	112
	>4 (4 to 10)	2	8	11	20	18	59
Total		26	74	81	66	51	298
	Pearson Chi-Square 72.560[a]; df = 12; P=<0.001; Cramer's V=0.285						
Number of sprays	Single	19	44	24	9	5	101
	Double	5	23	42	46	33	149
	Multiple (3 or 4)	2	7	15	11	13	48
Total		26	74	81	66	51	298
	Pearson Chi-Square 67.076[a]; df = 8; P=<0.001; Cramer's V = 0.335						

supports these results. In some areas, it was also felt that resistance had developed against sulfosulfuron. Besides, its residual effects on sorghum and maize restrict its broader adoption in Rohtak district. Rohtak farmers were using <5% sulfosulfuron compared to other surveyed districts (17-30%), due to sorghum and pearl millet (fodder crops) in rotation with wheat, which were susceptible to residues of sulfosulfuron. The higher persistence of sulfosulfuron and its residual effects on sensitive succeeding crops is well established. The residue of sulsosulfuron was found up to 150 days after its application in wheat (Brar *et al.* 2007), and its carryover nature affects the succeeding crops, viz. sorghum, pea, barley, and oilseed rape (Geier and Stahlman 2001).

Farmers adopted pendimethalin as PRE (though at a very small scale) and metribuzin as POST-tank-mix with alternate herbicides, mainly in problematic areas, viz. Kaithal, Karnal districts, and Bilaspur block of Yamuna Nagar. Farmers have given 3rd rank to these herbicides. The reason for liking is that these herbicides help to curb resistant *P. minor*, and disliking is due to pendimethalin not working in cloddy field conditions, as it requires a fine seedbed (Das 2008). Metribuzin shows phytotoxicity on wheat and WH-2851, WH-1105, KRL-210, and PBW-550 varieties were more affected by metribuzin. Varietal sensitivity of wheat against metribuzin was already reported by different researchers (Runyan *et al*. 1982). Clodinafop was reported not showing any control, or it only suppressed the growth of *P. minor* instead of killing it, and the seed set was there; still, it was placed at 4th position by farmers. Approximate 30% of farmers given it the first rank; it is still a favorite herbicide in those areas which have a low issue of resistance, e.g. Rohtak and Radaur block of Yamuna Nagar. Mesosulfuron + iodosulfuron (RM) was quite effective against clodinafop, sulfosulfuron and pinoxaden resistant *P. minor*. However, still, its adoption by farmers was very poor, and farmers gave it rank below clodinafop. It is only because of farmers' fear of phytotoxicity in wet conditions or overlapped/repeat spraying. Sulfosulfuron+ metsulfuron was also not so popular among farmers.

Herbicides resistance time-line: Farmers were not in the position to tell exact time-line, but they told about how many years particular herbicide worked on their fields or in areas around their locations. Farmers reported that isoproturon worked for around 12 years, clodinafop for 9 years, sulfosulfuron for 7.5 years, pinoxaden and mesosulfuron + iodosulfuron (RM) for 5 years. However, all surveyed farmers might not have yet used sulfosulfuron, pinoxaden and mesosulfuron + iodosulfuron (RM) at their fields. The values in years are only for those who felt that particular herbicide is not working now. This confirms earlier findings that high-risk prone herbicides, when used continuously, resistance develops within 5-7 years. In the case of *P. minor,* resistance developed against isoproturon (Group C-medium risk) in 10-15 years, but after that, in the case of clodinafop (group A-high risk) and sulfosulfuron (group B-high risk), cross-resistance was developed within 6-7 years (Das, 2011). Pinoxaden (group A) and mesosulfuron + iodosulfuron (group B) also come under the high-risk group and face the same fate of resistance development within five years. It was also realized by the farmers that once resistance is developed against any earlier recommended herbicide against *P. minor*, it required comparatively less time to develop further resistance against new herbicides. So, without diversifications in the cropping system, continuous dependency on new herbicides would increase the chances of the early development of cross-resistance and further related complicacies. There is a need to keep this in mind while introducing any new herbicide in the recommendation, as all the herbicides recommended after isoproturon resistance like clodinafop, fenoxaprop, sulfosulfuron, pinoxaden and mesosulfuron + iodosulfuron (RM) fall under high risk (group A and B). There should be a rotation of high and low-risk groups to delay the development of cross-resistance. Farmers tend to use the same herbicide up to it give results, or they do not know the importance of herbicide rotation.

Pesticide dealers were the primary source of information (95.7%); this is one of the prime reasons that farmers do not follow standard guidelines.

Farmers' perception about alternate sowing method (zero-till): Overall, 88.7% of farmers knew about zero till (ZT) wheat, and 66.3% of farmers had tried it in their fields. Among surveyed farmers, 40.3% of farmers were still using it and having 31.7% wheat area under ZT. Regarding the alternate sowing method, almost all farmers accepted that ZT faced less problem of *P. minor* (16.4%) than CT-drill and CT-rotavator. But few farmers faced weed problem under ZT where need-based non-selective herbicides (paraquat/ diquat) was not used before sowing (a pre-requisite for ZT, if *P. minor* already emerged before wheat sowing). Less problem of *P. minor* under ZT than CT has been well established by different studies earlier (Franke *et al*. 2007). However, it required the adoption of ZT with the full package of practices, particularly pre-seeding herbicide (which is often missed/ignored by farmers).

Based on the present investigation, it can be concluded that farmers of Haryana are in a haphazard situation and applying multiple herbicide doses against *P. minor* by opting more number of sprays which not only reduces farmer saving but also creates health issues for consumers. Farmers applying up to 3 times of herbicide dose still achieving sub-optimal control (70-80%). Very strong evidence of the negative relationship between percent control and multiple sprays at the higher dose (X) affirms the theory of resistance development in *P. minor* against prevailing herbicide in IGP. Farmers should promote adopting crop rotation, ZT with the full package, and teach them about the importance of herbicide rotation in delaying resistance development.

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