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Management of herbicide-resistant *Phalaris minor* in wheat by integration of malathion and post-emergence herbicides

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ABSTRACT

A field study was conducted during *Rabi* 2019-20 at Agronomy Research Farm of CCS Haryana Agricultural University, Hisar. The experiment comprised of seven post emergence herbicides (clodinafop 9% + metribuzin 20% (RM) (ACM-9), clodinafop 12% + metribuzin 42% (RM) (Shagun), metribuzin, isoproturon, sulfosulfuron, meso+iodosulfuron and pinoxaden) and their integration with malathion at different doses along with weed free and weedy check treatment. Among the treatments where herbicides were applied without integration with malathion, significantly taller plants, more dry matter accumulation, higher number of tillers and LAI were observed under pinoxaden, which remained significantly higher than all other herbicides, whereas, the values of these parameters considerably reduced after the integration with malathion as compared to solitary application of herbicides, except malathion *fb* pinoxaden. Weed free plots followed by pinoxaden at 50 g/ha and malathion *fb* pinoxaden at 1000 *fb* 50 g/ha resulted in higher number of tillers and more dry matter accumulation. Weed free plots recorded higher yield attributes *i.e.* effective tillers (408 tillers/m^2) and higher grain yield (5764 kg/ha) followed by application of pinoxaden at 50g/ha. The maximum weed control efficiency at harvest was recorded under weed free situations and was at par with malathion *fb* meso+iodosulfuron at 1000 *fb* 14.4 g/ha and malathion *fb* Shagun at 1000 *fb* 270 g/ha whereas, minimum WCE was recorded with isoproturon at 1000 g/ha (34.29 %). Integrated application of herbicides and malathion recorded lower weed density, dry weight of *Phalaris minor* and higher weed control efficiency as compared to solitary application of herbicides.

Key words: Wheat, *Phalaris minor*, pinoxaden, clodinafop, metribuzin, malathion, resistance, weed control efficiency

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the second most important staple food after rice to ensure food and nutritional security in India. The annual wheat production has been estimated at 107.59 million tonnes with all-time highest productivity of 3.51 t/ha (ICAR-IIWBR, 2020). In Haryana, wheat is grown over about 2.55 million ha with production of 12.57 million tonnes and productivity of 4.92 t/ha (DESA, Haryana, 2020). With expected inter-sectoral competition, there is hardly any scope for horizontal expansion in cultivable area under wheat; therefore, the focused emphasis would be on increasing the productivity potential by adopting ecologically and economically sustainable management practices.

The productivity of wheat in most of the northern states *i.e.* Punjab, Haryana and U.P. etc. has stagnated. There are number of factors responsible for the stagnation of wheat productivity and infestation of weeds appears to be one of the most important factors which limit the crop yield, al-

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though the extent of losses caused by weeds vary with the weed species, their density and environmental factors (Chhokar and Malik, 2002), soil type, cultural practices and crop rotation adopted. *Phalaris minor* is the most dominant grassy weed of wheat in north-west India (Singh *et al*., 1995). Few studies have documented the yield reduction to the extent of 24 per cent reduction in wheat yield due to uncontrolled weeds, particularly *P. minor* and *A. ludoviciana* (Hooda *et al*., 2017 and Kamboj *et al*., 2017). Malik and Singh (1991) also reported that increased per cent occurrence of *P. minor* upto 94 per cent in rice-wheat cropping system compared to only 48 per cent in non rice-wheat cropping system. *P. minor, popularly* known as Gullidanda, Kanki, Mandusi and Sitti in different parts of the country is a self-pollinated (2n = 28) plant with C_3 photosynthetic pathway, similar to wheat plants. It became more malicious in wheat due to its comparable morphology and developing needs.

Many herbicides have been recommended till date as a reliable economical tool to combat the problem of *P. minor* in wheat. Indiscriminate use of herbicides without following proper recommendations (timings, dose, duration, spray volume etc.); however, resulted in development of cross resistance against these herbicides (Singh *et al*., 1997). Continuous use of isoproturon for 10-15 years in rice-wheat cropping system has led to herbicide resistance (Malik and Singh, 1995; Singh *et al*., 1997) and the recommendation was withdrawn in 1998. Later, the use of fenoxaprop in wheat has gone down tremendously due to its failure against resistant *P. minor* within a few years. Scattered cases of resistance against clodinafop and even sulfosulfuron against the new biotypes of *P. minor* was also reported in Haryana (Yadav and Malik, 2005) and such cases increased every year making the situation more complex (Singh, 2007). In Haryana, clodinafop at 60, 90 and 120 g/ha provided 76 to 100 per cent control of grassy weeds (*Phalaris minor* and *Avena ludoviciana*); however, its lower dose at 30 g/ha was not quite effective in checking the weed infestation (Hooda *et al*., 2014; 2017). As of today, there is no single herbicide exhibiting effective weed control against resistant *P. minor*.

Studies on the mechanism of development of resistance in *P. minor* to isoproturon indicated that there is an increased degradation of isoproturon by increased activity of the enzyme cytochrome P450 monooxygenase in the resistant biotypes (Singh *et al.,* 1998). Malathion, an organophosphate insecticide, acts as an acetylcholinesterase inhibitor, and helps to detect the involvement of this enzyme in degradation process of applied herbicides (Christopher *et al*., 1994). It could reverse the isoproturon resistance in *P. minor* by inhibition of Cytochrome P450 monoxygenase enzymes (Dhawan and Gupta, 2007). The sole dependence on herbicide having single mode of action is not advisable as it could easily contribute to rapid evolution of multiple herbicide resistance, which is a threat to wheat production (Malik and Singh, 1995). This calls for evaluation of some herbicides with newer modes of action (MOA), either alone or in combination to broaden the weed control spectrum. As synthesis of herbicides with newer MOA is trickling, we have to rely on available herbicides either in sequence or their mixtures. Herbicide mixtures can reduce the rate of building up of resistant populations. To control complex weed flora (grass and broadleaf weeds) and provide persistent weed control, compatible herbicides combinations are need of the hour in managing and delaying the herbicide resistance problem (Wruble and Gressel, 1994). Tank mix combinations or ready mixtures are advantageous over the sequential application of herbicides considering the desired saving in application timing and cost effective. With this view the present study was undertaken to estimate the efficiency of different herbicide and their combinations with malathion to manage noxious *P. minor* weed in wheat. Furthermore, the effects of these chemical combinations on the growth and yield of wheat crop plants were also examined.

MATERIALS AND METHODS

A field study was conducted during *Rabi* season of 2019-20 at Agronomy Research Farm of CCS Haryana Agricultural University, Hisar. The experimental site is located at 29°16'N latitude and 75°7'E longitude at the mean sea elevation of 215.2 m in north-west part of India. The area has semi arid climate with very hot summers and relatively cool winters. The maximum day time temperature during summer season varies between 40 to 46 °C (104 to 115 °F), however, it remains between 1.5 and 4.0 °C during winter months. The average annual rainfall is 429 mm (of which 75-80% precipitation is received during July and August. The experimental field was sandy loam in texture, low in organic carbon (0.52 %) and nitrogen (182 kg/ha), medium in available phosphorus (18 kg/ha), high in potassium (285 kg/ha) and slightly alkaline (pH 7.73) in reaction. Wheat variety WH 1105 was sown during 3rd week of November by seed-cum-fertilizer drill at line to line spacing of 20 cm at 5-6 cm depth using 100 kg seed/ha. The crop was harvested during 3rd week of April. The experiment was laid in randomized block design and replicated thrice with seven post–emergence herbicides (clodinafop 9% + metribuzin 20% (RM) (ACM-9), clodinafop 12% + metribuzin 42% (RM) (Shagun), metribuzin, isoproturon, sulfosulfuron, meso+iodosulfuron and pinoxaden) and their integration with malathion at different doses. Two treatments as weed free and weedy check were also taken for comparison purpose (Table 1). All the herbicides were applied at 34 days after sowing (DAS) of wheat and malathion was applied 1-2 hour before herbicide application. These chemicals were sprayed with knapsack sprayer fitted with flat fan nozzles using 375 l/ha spray volume. Periodical changes in weed flora with different treatment combinations was observed by taking data on weed density by randomly placing quadrate (0.25 m^2) in each plot. The observed values were subjected to square root transformation ($\sqrt{x+1}$).

For calculating dry matter accumulation (g/m^2) of weeds, the weed samples were dried in oven at 65 ± 5^0C till constant weight. These dried samples were weighed and the weed control efficiency was calculated with the formula:

$$\text{WCE (\%)} = \frac{W_2\text{-}W_1}{W_2} \times 100$$

Where,

W_2 = Dry weight of weeds (g/m^2) in weedy check plot

W_1 = Dry weight of weeds (g/m^2) in treatment plot

The plant height, number of tillers and tillers with spike (effective tillers at harvest) were counted at three places per plot. The plant height was measured from soil surface to surface to the base of the fully opened last leaf before the ear emergence and up to the ear head after heading. For taking dry matter accumulation of plants, the plants were harvested from 0.25 cm row length from two places at different crop stages and were first dried in the sun followed by oven drying at 65°C till constant weight. Biological yield was worked out by measuring the total bundle weight after sun drying for 4-5 days from each plot and expressed as kg/ha. The biomass obtained for individual plot was threshed and weighed for grain yield (kg/ha). The grain yield so obtained was deducted from the biomass of the harvested crop to compute the straw yield. Harvest index, a ratio between grain yield and biological yield was worked out by following expression.

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield (kg/ha)}}{\text{Biological yield (kg/ha)}} \times 100$$

The experimental data were subjected to analysis of variance (ANOVA) as described by Panse and Sukhatme (1985).

RESULTS AND DISCUSSION

Assessing potential of weed management practices on resistant *Phalaris minor* in wheat

The dominant weed flora present in experimental field was *P. minor* whose share was more than ninety per cent. Minor weed species were mainly broadleaf weeds (*Chenopodium album, Anagallis arvensis, Melilotus indicus, Coronopus didymus, Lathyrus aphaca, Cirsium arvense, Medicago denticulate* etc.) which were removed manually. The density and dry weight of *P. minor* at 90 DAS was significantly lower in plots treated with different herbicides either alone or in combination with malathion as compared with weedy check plots (Table 1). The density and dry weight of *P. minor* were observed non-significant in all plots before application of herbicides. Significantly lower weed density and dry weight of *P. minor* was observed with sole application of herbicides as compared to weedy check situation. Solitary application of isoproturon recorded significantly higher weed density and dry weight of *P. minor* at 90 DAS and at harvest compared to all other herbicides and was followed by solitary application of metribuzin (Table 1). Among the treatments where herbicides were applied in integration with malathion, significantly lower weed density and dry weight of *Phalaris minor* at 90 DAS was recorded as compared to weedy check plots and it was considerably reduced as compared to solitary application of herbicides. Integration of malathion with Shagun, ACM-9, meso + iodosulfuron, pinoxaden displayed weed free like situation. Earlier studies have indicated increase in the herbicide resistant *Phalaris minor* due to isoproturon attributing it to increased enzymatic activity of cytochrome P-450 monooxygenase in the resistant biotypes and the reversal of herbicide resistance with the use of piperonyl butoxide and aminobenzotriazole (Singh *et al.*, 1998). Dhawan (2004) observed that the susceptible population of *P. minor* had GR_{50} value of 0.4 kg/ha as against the GR_{50} value of 2.25 kg/ha isoproturon treated resistant biotypes. Isoproturon alone at 1.0 kg/ha had negligible control on resistant population while application of 2.0 kg/ha resulted in only15% weed control. Integrated use of isoproturon with 1000 g/ha malathion further enhanced the herbicide efficacy registering 50% control at 1.0 kg/ha and 80-90% control at 2.0 kg/ha isoproturon. Although, about 50 per cent mortality in wheat was observed with integrated use of 2.0 kg/ha isoproturon and 1000 g/ha malathion. Though malathion had effective suppression of resistant biotypes of *P. minor,* yet it cannot be exploited for control of resistant biotypes under actual field conditions as it lacks selectivity because of its sensitivity of the growing plants to this combination.

Sole application of herbicides attained 34 to 94 per cent weed control efficiency at harvest. Within herbicides, more than 80 per cent WCE was achieved except for isoproturon and metribuzin. Combination

Table 1. Effect of herbicides integrated with malathion on population and dry weight of *Phalaris minor*

Treatments	Dose	*P. minor* population (No./m²)		Dry weight of *P. minor* (g/m²)		WCE (%)
	(ml or g/ha)	90 DAS	At harvest	90 DAS	At harvest	At harvest
T_1 : ACM-9 (clodinafop 9% + metribuzin 20%)	174	3.1 (8.2)	2.9 (7.8)	10.54 (3.40)	5.19 (25.94)	87.56
T_2 : Shagun (clodinafop 12% + metribuzin 42%)	270	2.3 (4.1)	2.2 (3.9)	5.27 (2.50)	3.74 (12.97)	93.78
T_3 : Metribuzin	175	4.1 (15.5)	3.9 (14.7)	19.92 (4.57)	7.06 (48.88)	76.55
T_4 : Isoproturon	1000	6.8 (43.3)	6.4 (41.2)	55.64 (7.53)	11.75 (136.99)	34.29
T_5 : Sulfosulfuron	25	3.6 (11.3)	3.4 (10.8)	14.52 (3.94)	6.08 (35.91)	82.78
T_6 : Meso+iodosulfuron	14.4	2.5 (5.2)	2.4 (4.9)	6.68 (2.77)	4.16 (16.29)	92.19
T_7 : Pinoxaden	50	2.9 (7.2)	2.8 (6.9)	9.25 (3.20)	4.89 (22.94)	89.00
T_8 : Malathion *fb* ACM-9	1000 *fb* 174	1.5 (1.0)	1.4 (1.0)	1.29 (1.51)	2.08 (3.33)	98.40
T_9 : Malathion *fb* Shagun	1000 *fb* 270	1.0 (0.0)	1.0 (0.0)	0.00 (1.00)	1.00 (0.00)	100.00
T_{10} : Malathion *fb* metribuzin	1000 *fb* 175	3.3 (9.3)	3.1 (8.8)	11.95 (3.60)	5.50 (29.26)	85.97
T_{11} : Malathion *fb* isoproturon	1000 *fb* 1000	6.2 (36.1)	5.9 (34.3)	46.39 (6.88)	10.73 (114.05)	45.29
T_{12} : Malathion *fb* sulfosulfuron	1000 *fb* 25	1.8 (2.1)	1.7 (2.0)	2.70 (1.92)	2.77 (6.65)	96.81
T_{13} : Malathion *fb* meso+iodosulfuron	1000 *fb* 14.4	1.0 (0.0)	1.0 (0.0)	0.00 (1.00)	1.00 (0.00)	100.00
T_{14} : Malathion *fb* pinoxaden	1000 *fb* 50	1.5 (1.0)	0.00 (1.0)	1.29 (1.51)	2.08 (3.33)	98.40
T_{15} : Weed free	-	1.0 (0.0)	1.0 (0.0)	0.00 (1.00)	1.00 (0.00)	100.00
T_{16} : Weedy check	-	8.3 (65.9)	7.9 (62.7)	84.68 (9.26)	14.47 (208.48)	0.00
SEm±		0.22	0.19	0.31	0.46	—
C.D.at 5%		0.61	0.56	0.87	1.28	—

Original data given in parenthesis were subjected to square root ($\sqrt{x+1}$) transformation before analysis of metribuzin with clodinafop (clodinafop 12% + metribuzin 42%) resulted in highest WCE (94%) at harvest (Table 1). Similar results of better weed control and higher WCE with metribuzin based mixtures were also observed by Rani *et al*. (2021). Weed control efficiency under isoproturon treated plots remained very low than all other herbicides. The weed control efficiency of different herbicides increased considerably when applied with malathion as compared to their solitary application. Integration of malathion with Shagun, ACM-9, meso+iodosulfuron, pinoxaden acquired effective weed control similar to weed free situation. Similarly, malathion reduced the tolerance of maize to the sulfonylurea herbicide, primisulfuron, by inhibition of cytochrome P-450 dependent herbicide metabolism (Kreuz and Pfister, 1992; Christopher *et al*., 1994).

Effect of herbicide based weed management practices on plant growth

Number of tillers and dry matter accumulation at 60, 90 and 120 DAS remained significantly higher under weed free situations compared to other treatments (Table 2). This could be ascribed to less competition for light, moisture, nutrients and space leading to more cell size, cell elongation and higher meristematic activity resulting in better plant growth and and yield traits (Vila *et al*., 2004). Weedy check plot had lowest tillers and dry matter accumulation. Among the treatments where herbicides were applied without integration of malathion, significantly higher number of tillers and more dry matter accumulation of wheat were observed. Among the treatments where herbicides were applied with integration of malathion, significantly higher dry matter accumulation (129/m^2) and number of tillers (484/m^2) were recorded with malathion *fb* pinoxaden which remained significantly higher than all other herbicides at 60 DAS and thereafter up to 120 DAS. This was due to effective control of weeds with application of malathion integrated with herbicides which resulted in less competition for growth factors, however, due to more phytotoxicity, number of tillers and dry matter accumulation considerably reduced after the application of the herbicides integrated with malathion as compared to solitary application of herbicides, except malathion *fb* pinoxaden.

The highest phytotoxicity score was recorded in treatments receiving malathion *fb* meso + iodosulfuron (1000 *fb* 14.4 g/ha) followed by malathion *fb* sulfosulfuron (1000 *fb* 25 g/ha) and malathion *fb* Shagun (1000 *fb* 270 g/ha) which reduced with consecutive periods *i.e.* maximum at

Table 2. Effect of herbicides integrated with malathion on number of tillers and dry matter accumulation of wheat

Treatments	Dose (ml or g/ha)	Number of tillers (No./m^2)			Dry matter accumulation (g/m^2)		
		60 DAS	90 DAS	120 DAS	60 DAS	90 DAS	120 DAS
T_1: ACM-9 (clodinafop 9% + metribuzin 20%)	174	479	396	387	127	423	1083
T_2: Shagun (clodinafop 12%+metribuzin 42%)	270	453	379	370	121	404	1035
T_3: Metribuzin	175	464	387	378	124	414	1059
T_4: Isoproturon	1000	402	336	328	107	359	918
T_5: Sulfosulfuron	25	459	383	374	123	409	1047
T_6: Meso+iodosulfuron	14.4	448	374	366	120	400	1024
T_7: Pinoxaden	50	490	409	399	131	437	1118
T_8: Malathion *fb* ACM-9	1000 *fb* 174	448	366	357	117	391	1000
T_9: Malathion *fb* Shagun	1000 *fb* 270	417	349	340	112	372	953
T_{10}: Malathion *fb* metribuzin	1000 *fb* 175	428	357	349	114	382	977
T_{11}: Malathion *fb* isoproturon	1000 *fb* 1000	412	344	336	110	368	941
T_{12}: Malathion *fb* sulfosulfuron	1000 *fb* 25	428	357	349	114	382	977
T_{13}: Malathion *fb* meso+iodosulfuron	1000 *fb* 14.4	417	349	340	112	372	953
T_{14}: Malathion *fb* pinoxaden	1000 *fb* 50	484	404	395	129	432	1106
T_{15}: Weed free	-	515	430	420	138	460	1177
T_{16}: Weedy check	-	387	323	315	103	345	883
SEm±		7.1	6.0	5.9	2.0	6.5	16.2
C.D.at 5%		19.5	16.5	16.1	5.2	17.5	45.3

15 DAT and no phytotoxicity at 60 DAT in any of the treatment. These results are in conformity with Singh *et al.* (2011), Pal *et al.* (2012), Sheoran *et al*. (2013), Jaidev *et al*. (2012) and Chhokar *et al*. (2008).

Effect of herbicides alone or in integration with malathion on wheat yield

It is evident from the data that weed free treatment resulted into higher yield attributes *i.e.* effective tillers (408 tillers/m^2) and higher crop yield [grain yield (5764 kg/ha); biological yield (14267 kg/ha)] which remained significantly higher than all other treatments (Table 3). Herbicide based weed management through pinoxaden attained significantly higher yield attributes and resultant yield (grain yield, straw yield and biological yield) than all other herbicides except ACM-9. This increase in biological yield might be due to taller plants, higher LAI and dry matter accumulation, whereas improvement in yield traits contributed towards achieving more grain yield. Biomass production is an important determinant of grain yield in wheat, therefore, more the crop biomass, greater the amount of photosynthates that can be translocated to the grain during grain filling stage. Among different treatments where herbicides were applied with malathion, significantly more yield attributes of wheat and crop yield were observed albiet to a greater extent in malathion *fb* pinoxaden followed by ACM-9. This may be due to less competition for different resources in herbicide based weed management practices being efficient in controlling weeds which resulted in more translocation of metabolites from source to sink. Combined application of the herbicides and malathion reduced the yield attributes and grain yield of wheat as compared to solitary application of herbicides, except under isoproturon. Heavy weed infestation in weedy check treatment led to lowest values of yield attributing characters and anticipated wheat yield. The combined application of these chemicals at 34 DAS extensively restricted the weeds, resulting in efficient utilization of the resources in absence of weeds and thus enhanced the growth, yield attributes and yield. Similar result had also been reported by Singh *et al*. (2012).

CONCLUSION

The results revealed that herbicides applied alone and in integration with malathion significantly reduced the density and dry matter of *P. minor* and in turn increased the plant growth,

Table 3. Effect of herbicides integrated with malathion on number of effective tillers, test weight and yield of wheat

Treatments	Dose (ml or g/ha)	Effective tillers No./m^2	1000 grain wt. (g)	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)
T$_1$: ACM-9 (clodinafop 9% + metribuzin 20%)	174	376	43.7	5303	8400	13703
T$_2$: Shagun (clodinafop 12%+metribuzin 42%)	270	359	41.6	5072	8346	13418
T$_3$: Metribuzin	175	367	42.4	5188	8610	13798
T$_4$: Isoproturon	1000	318	39.1	4496	7788	12284
T$_5$: Sulfosulfuron	25	363	41.6	5130	8406	13536
T$_6$: Meso+iodosulfuron	14.4	355	41.5	5015	8287	13302
T$_7$: Pinoxaden	50	388	44.1	5476	8422	13898
T$_8$: Malathion *fb* ACM-9	1000 *fb* 174	347	40.7	4899	8130	13029
T$_9$: Malathion *fb* Shagun	1000 *fb* 270	331	38.5	4669	8019	12688
T$_{10}$: Malathion *fb* metribuzin	1000 *fb* 175	339	39.3	4784	8287	13071
T$_{11}$: Malathion *fb* isoproturon	1000 *fb* 1000	327	37.4	4611	8341	12952
T$_{12}$: Malathion *fb* sulfosulfuron	1000 *fb* 25	339	38.0	4784	8181	12965
T$_{13}$: Malathion *fb* meso+iodosulfuron	1000 *fb* 14.4	331	37.6	4669	8053	12722
T$_{14}$: Malathion *fb* pinoxaden	1000 *fb* 50	384	45.0	5418	8728	14146
T$_{15}$: Weed free	-	408	45.6	5764	8503	14267
T$_{16}$: Weedy check	-	306	34.7	4223	7993	12216
SEm±		5.3	0.7	79.5	109.1	185.5
C.D.at 5%		15.5	2.0	219.6	326.4	547.2

yield traits and yield of wheat. Successful control of resistant *P. minor* with application of pinoxaden (50 g/ha) provided useful insights to enhance wheat production in areas heavily infested by herbicide resistant *P. Minor*.

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