Management of Isoproturon-Resistant *Phalaris minor* in Wheat by Alternate Herbicides under Tarai Region Conditions

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ABSTRACT

*Phalaris minor* Retz. is a major weed of wheat crop across many continents. It is highly competitive in nature and mimics the wheat morphology. Consideration is given to the eradication of isoproturon resistance *Phalaris minor* and management approaches designated to minimize the impact of resistance. For management of isoproturon-resistant *Phalaris minor* in wheat crop in the tarai region by alternate herbicides, a field experiment was carried out during the winter season of 2016-17 and 2017-18. The broadcasting of isoproturon resistant *Phalaris minor* seeds was done before sowing of wheat in field. Treatments included (T1) Pendimethalin @ 750 g a.i./ha, (T2) Pendimethalin+Metribuzin @ 750+210 g a.i./ha, (T3) Pendimethalin+Metribuzin fb mesosulfuron+Idosulfuron (RM) @ 750+210 fb 12+2.4 g a.i./ha, (T4) Pendimethalin+Metribuzin fb 'Clodinafop+Metsulfuron-methyl'(RM) @ 750+210 fb 60+4 g a.i./ha, (T5) Pendimethalin fb Clodinafop propargyl @ 750 fb 60 g a.i./ha, (T6) Pendimethalin fb 'Clodinafop+Metsulfuron-methyl'(RM) @ 750 fb 60+4 g a.i./ha, (T7) Pendimethalin fb Mesosulfuron+Idosulfuron (RM) @ 750 fb 12+2.4 g a.i./ha, (T8) 'Clodinafop+Metsulfuron-methyl'(RM) @ 60+4 g a.i./ha, (T9) Mesosulfuron+Idosulfuron (RM) @ 12+2.4 g a.i./ha, (T10) Weedy. There was no phytotoxicity of any of the herbicide treatments on crop during both the years. The tank-mix or sequential application of herbicides would be a better option than their applications alone to manage the serious problem of herbicide-resistant *P. minor* in wheat.

Keywords: Isoproturon; *Phalaris minor*; Herbicide; Weed control index

INTRODUCTION

Undoubtedly the development of isoproturon-resistant *Phalaris minor* is an epidemic in wheat production mainly. In late 1970s, isoproturon herbicide was recommended for controlling *Phalaris minor* and continued to work properly for nearly 20 years. The resistance case was first reported by Malik in 1995 [1] and it was the most serious incident of herbicide resistance in the world ever, resulting in entire crop failure from serious weed infestations (2000-3000 plants/m²) [2].

Wheat (*Triticum aestivum* L.) is leading food grain crop being a staple diet, and contributes about 21% to the daily dietary protein intake of humans [3]. Reduction in wheat production by means of various biotic or abiotic factors may affect global food security adversely. Weeds are the most detrimental pest of wheat crop causing in total 24% losses in wheat grain yield [4] and one of the principal limiting biological factor in global food production [5]. The isoproturon resistant affected area is ranged between 0.8 and 1.0 million ha in north-western India, mostly in the states of Punjab, Haryana, Uttarakhand, and other foothill plains areas which accounts for 3 million ha of the rice-wheat cropping system out of India’s 10 million ha in this cropping system and about 35% of wheat production [6-8]. The *Phalaris minor* trouble has further aggravated in the North-western Indian plains owing to the evolution of isoproturon resistance. Infestation of isoproturon resistance population caused more than 65% reduction in wheat grain yield with the recommended dose of isoproturon (1000 g ha⁻¹) application [9].

Chlorophyll is a pigment molecule that plays very important role in photosynthesis and light harvesting. Higher leaf chlorophyll content is the indication of higher photosynthetic efficiency of plants resulting in higher yield. The higher value of chlorophyll content was observed in some herbicide treated plants suggested that the herbicide application does not create negative impact on leaf chlorophyll content and photosynthesis of rice crop [10]. Level
of chlorophyll content of wheat leaves subjected to two sulfonyleurea herbicides were significantly lower compared to untreated plants [11]. Nitrate reductase catalyzes the reduction of nitrate to nitrite in plants. Nitrate reductase is very sensitive to nitrogen supply levels. It is also known to be a positively regulated by nitrate availability and limiting factor for nitrogen assimilation [12]. NR is also a rate limiting enzyme and regulated by nitrate concentration, light, growth hormones, reduced nitrogen metabolites and phosphorylation [13]. Vegetative productivity of wheat was closely related to nitrogen assimilatory capacity at post-germination and post-tillering stages. The relation between nitrate reductase activity and grain yield was less definite [14]. For managing isoproturon resistant Phalaris minor, several alternate herbicides with different modes and mechanisms of action have been screened [15,16]. Herbicides are applied alone, combinations or sequentially have been regarded as essential tools in the weed management. However information on their bioefficacy as well as their effect on growth and yield of wheat in the state of Uttarakhand has not been evaluated in a systematic manner. Keeping these points in view, the present investigation was undertaken.

MATERIALS AND METHODS

The isoproturon resistance seeds were collected from the Crop Research Centre, GBPUA&T Pantnagar and they were subjected to grow along with wheat crop in Ravi season of 2016-17 and 2017-18 as well. One genotype of wheat (DBW-17) was sown in field with ten treatments and three replications including control. The broadcasting of isoproturon resistant Phalaris minor seeds was done before sowing of wheat in field. Each plot size was 5m$^2$. Wheat was sown at 20 cm row spacing. The pre-emergent herbicide pendimethalin and metribuzin was applied immediately after sowing in moist soil, and other post-emergent herbicides were applied at 30 DAS with sprayer. The crop was managed according to the standard agronomic practices. Weed samples from different randomly selected spots for each plot were taken with the help of a quadrate method. The weeds were separated as P, minor and other weeds including grasses, sedges and broadleaf weeds from each sample. The samples were oven dried at 70 $^\circ$C until constant weights were achieved. Then dried weed samples were weighed and the weight taken was expressed in terms of g m$^{-2}$ before subjecting to statistical analysis. The weed control efficiency was computed as a percent reduction in total weed biomass under different treatments in comparison to weedy check at different stages. The other physiological and biochemical parameters regarding wheat crop were estimated after spraying of post emergence herbicides. The mean data on weed biomass of isoproturon resistant Phalaris minor was highest at 90DAS (222.67 plants/m$^2$). After 60 days of application, almost all herbicide treatments showed efficacy towards controlling isoproturon resistance Phalaris minor except T1 Pendimethalin, T6 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* and T9 Mesosulfuron+Idosulfuron (RM)* treatments.

Effect of herbicides on density (no/m$^2$) of Phalaris minor

Weed density was recorded at different growth stages viz 30 DAS, 60 DAS, and 90 DAS. The Table 1 present the effect of herbicides on weed density (no/m$^2$). The mean data showed that density of Phalaris minor gradually decreased under few treatments like T2 Pendimethalin+Metribuzin, T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*, T4 Pendimethalin+Metribuzin fb** Clodinafop+Metalsulfuron-methyl (RM)*, T5 Pendimethalin fb** Clodinafoppropargyl, T7 Pendimethalin fb*** Mesosulfuron+Idosulfuron (RM)* and T8 Clodinafop+Metalsulfuron-methyl (RM)*. Apparently, the weed density was maximum in T10 weedy situation at each growth stage and it was highest at 90DAS (222.67 plants/m$^2$). After 60 days of application, almost all herbicide treatments showed efficacy towards controlling isoproturon resistance Phalaris minor except T1 Pendimethalin, T6 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* and T9 Mesosulfuron+Idosulfuron (RM)* treatments.

Effect of herbicides on density (no/m$^2$) of Phalaris minor

The mean data on weed biomass of isoproturon resistant Phalaris minor is presented in Table 2. At 90DAS, the biomass was found maximum in T10 weedy situation (313.07 g/m$^2$ in I-trial and 201.60 g/m$^2$ in II-trial) followed by T1 pendimethalin treatment (196.93 g/m$^2$ in I-trial and 214.43 g/m$^2$ in II-trial), otherwise rest of the treatment includes T2 Pendimethalin+Metribuzin, T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*, T4 Pendimethalin+Metribuzin fb** Clodinafop+Metalsulfuron-methyl (RM)*, T5 Pendimethalin fb** Clodinafoppropargyl, T7 Pendimethalin fb*** Mesosulfuron+Idosulfuron (RM)* and T8 Clodinafop+Metalsulfuron-methyl (RM)*. Apparently, the weed dry matter was maximum in T10 weedy situation at each growth stage and it was highest at 90DAS (222.67 plants/m$^2$). After 60 days of application, almost all herbicide treatments showed efficacy towards controlling isoproturon resistance Phalaris minor except T1 Pendimethalin, T6 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* and T9 Mesosulfuron+Idosulfuron (RM)* treatments.
at the same time, the efficiency of T2 Pendimethalin+Metribuzin, T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)* and T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* treatments were near about 100% and found effectual to control this weed. At 75DAS, minimum WCE was observed in T9 Mesosulfuron+Idosulfuron (RM)* treatment (58.46%) followed by T1 Pendimethalin treatment (64.69%).

Weed control index (WCI) of different herbicides for controlling Phalaris minor was calculated at different time interval. The data on weed control index (WCI) had quite resemblance with weed control efficiency (WCE). Weed control index (WCI) was achieved 100% under few treatments named T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*, T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* and T5 Pendimethalin fb** Clodinafoppropargyl at 75 DAS for both the trials. Whereas the other herbicide treatments, T2 Pendimethalin+Metribuzin, T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)*, T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)*, T8 Clodinafop+Metsulfuron-methyl (RM)* and T9 Mesosulfuron+Idosulfuron (RM)* were also effective in controlling Phalaris minor.

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### Table 1: Density of Phalaris minor in wheat crop treated with herbicides.

| Herbicide treatments                | Density of Phalaris minor (No/m²) | Days after sowing |
|-------------------------------------|-----------------------------------|-------------------|
|                                     |                                   | 30 60 90          |
|                                     |                                   | 2016-17 2017-18 Mean 2016-17 2017-18 Mean 2016-17 2017-18 Mean |
| T1 Pendimethalin                    | 13.33                             | 16 14.67          |
| T2 Pendimethalin+Metribuzin         | 0.13                              | 1.33 0.73         |
| T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)* | 13.33 | 14.67 14 |
| T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* | 8 | 13.33 10.67 0.13 3.6 1.87 |
| T5 Pendimethalin fb** Clodinafoppropargyl | 5.31 | 5.33 5.32 |
| T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)* | 16 | 21.33 18.67 5.04 2.53 3.79 |
| T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* | 22.67 | 28 25.33 9.2 24 |
| T8 Clodinafop+Metsulfuron-methyl (RM)* | 65.33 | 102.6 84 85.33 53.33 69.33 |
| T9 Mesosulfuron+Idosulfuron (RM)* | 58.67 | 64 61.33 221.3 60 140.6 25.2 70.67 47.93 |
| T10 Weedy                           | 121.3                             | 134.6 128 268 |
| S.Em ±                             | 2,094                             | 4.684 6.624 3.116 6.967 9.853 3.559 7.958 11.25 |
| CD at 5%                            | 5.997                             | 13.41 18.96 8.921 19.94 28.21 10.18 22.78 32.22 |

RM*- Readymade mixture; fb**- followed by treatments; T1 & T2; Pre-emergence application of herbicides. T3 – T9:- Post-emergence application of herbicides

### Table 2: Biomass of Phalaris minor in wheat crop treated with herbicides.

| Herbicide treatments                | Biomass of Phalaris minor (g/m²) | Days after sowing |
|-------------------------------------|-----------------------------------|-------------------|
|                                     |                                   | 30 60 90          |
|                                     |                                   | 2016-17 2017-18 Mean 2016-17 2017-18 Mean 2016-17 2017-18 Mean |
| T1 Pendimethalin                    | 0.52                              | 0.58 0.55         |
| T2 Pendimethalin+Metribuzin         | 0.01                              | 0.04 0.03         |
| T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)* | 0.3 | 0.32 0.31 0 |
| T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* | 0.24 | 0.25 0.24 0 0.02 0.01 |
| T5 Pendimethalin fb** Clodinafoppropargyl | 0.11 | 0.12 0.11 0 0 0 |
| T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)* | 0.55 | 0.7 0.63 0.82 0.18 0.5 0.08 6.45 3.27 |
| T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* | 0.65 | 0.76 0.7 1.76 1.72 1.74 0 |
| T8 Clodinafop+Metsulfuron-methyl (RM)* | 2.53 | 3.5 3.01 14.13 6.63 10.4 0 0 |
| T9 Mesosulfuron+Idosulfuron (RM)* | 1.85 | 2.12 1.99 37.33 4.32 20.8 7.23 4.39 5.81 |
| T10 Weedy                           | 3.22                              | 3.6 3.41 61.47 |
| S.Em ±                             | 0.12                              | 0.27 0.38 1.21 2.71 3.83 3.02 6.75 9.55 |
| CD at 5%                            | 0.35                              | 0.78 1.11 3.47 7.76 10.9 8.65 19.3 27.3 |

RM*- Readymade mixture; fb**- followed by treatments; T1 & T2; Pre-emergence application of herbicides. T3 – T9:- Post-emergence application of herbicides
Phalaris minor. Weed control index (WCI) of T1 Pendimethalin treatment was minimum (73.84%) then rest of the treatments at 75 DAS (Table 4).

Effect of herbicides on biomass of wheat crop

The mean data on biomass of wheat crop is presented in Table 5. The biomass was gradually increased with respect to the time of growth and development and the mean data were calculated at 30, 60 and 90 days after sowing. At 30 DAS, highest and lowest biomass was recorded in T5 Pendimethalin fb** Clodinafoppropargyl (0.23g/plant) and T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* treatment (0.17g/plant) respectively, otherwise there was no significant difference among biomass of herbicides treatments. Similarly at 90 DAS, T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)* treatment had maximum and T10 Weedy plot had minimum biomass.

Effect of herbicides on chlorophyll content of wheat leaves (mg/g FW)

Chlorophyll content was estimated after 7 days of post emergence herbicide treatments. The mean data on chlorophyll content of wheat crop was estimated after 7 days of post emergence herbicides (POE) application. The chlorophyll content includes chlorophyll a, chlorophyll b and total chlorophyll content. Maximum chlorophyll content was estimated in T10 weedy treatment; chlorophyll a (1.69 mg/g FW), chlorophyll b (0.36 mg/g FW) and total chlorophyll content (2.01 mg/g FW) whereas minimum was estimated in T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* treatment;

Table 3: Weed control efficiency (WCE) of herbicides for controlling Phalaris minor.

| Herbicide treatments | 30 days after sowing | 60 days after sowing | 90 days after sowing |
|---------------------|----------------------|----------------------|----------------------|
|                     | 2016-17 | 2017-18 | Mean | 2016-17 | 2017-18 | Mean | 2016-17 | 2017-18 | Mean |
| T1 Pendimethalin    | 83.6    | 82.9    | 83.3 | 75.5    | 45.4    | 60.5 | 50.8    | 96.8    | 73.8  |
| T2 Pendimethalin+Metribuzin | 99.5    | 96.3    | 95.8 | 60.5    | 65.8    | 65.3 | 50.8    | 96.8    | 73.8  |
| T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)* | 89.0    | 89.5    | 89.7 | 99.9    | 99.6    | 99.5 | 100     | 100     | 100   |
| T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* | 92.6    | 92.4    | 92.5 | 99.9    | 99.9    | 99.9 | 100     | 100     | 100   |
| T5 Pendimethalin fb** Clodinafoppropargyl | 96.7    | 96.3    | 96.5 | 100     | 100     | 100  | 100     | 100     | 100   |
| T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)* | 83.0    | 79.6    | 81.3 | 99.8    | 99.5    | 99.8 | 100     | 100     | 100   |
| T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* | 79.5    | 77.6    | 78.6 | 97.2    | 96.6    | 96.6 | 99.9    | 97.8    | 98.9  |
| T8 Clodinafop+Metsulfuron-methyl (RM)* | 20.1    | 2.2     | 11.2 | 74.8    | 84.1    | 79.4 | 95.9    | 97.9    | 96.9  |
| T9 Mesosulfuron+Idosulfuron (RM)* | 41.6    | 34.4    | 38   | 33.2    | 89.6    | 61.4 | 93.4    | 87.9    | 90.6  |
| S.Em±               | 4.26    | 9.05    | 12.8 | 1.8     | 3.82    | 5.41 | 1.2     | 2.55    | 3.61  |
| CD at 5%            | 12.2    | 26      | 36.8 | 5.18    | 11      | 15.5 | 3.46    | 7.34    | 10.3  |

RM*- Readymade mixture; fb**- followed by treatments; T1 & T2; Pre-emergence application of herbicides. T3 – T9: Post-emergence application of herbicides

Table 4: Weed control index (WCI) of herbicides for controlling Phalaris minor.

| Herbicide treatments | 30 days after sowing | 60 days after sowing | 90 days after sowing |
|---------------------|----------------------|----------------------|----------------------|
|                     | 2016-17 | 2017-18 | Mean | 2016-17 | 2017-18 | Mean | 2016-17 | 2017-18 | Mean |
| T1 Pendimethalin    | 83.6    | 82.9    | 83.3 | 75.5    | 45.4    | 60.5 | 50.8    | 96.8    | 73.8  |
| T2 Pendimethalin+Metribuzin | 99.5    | 96.3    | 95.8 | 60.5    | 65.8    | 65.3 | 50.8    | 96.8    | 73.8  |
| T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)* | 89.0    | 89.5    | 89.7 | 99.9    | 99.6    | 99.5 | 100     | 100     | 100   |
| T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* | 92.6    | 92.4    | 92.5 | 99.9    | 99.9    | 99.9 | 100     | 100     | 100   |
| T5 Pendimethalin fb** Clodinafoppropargyl | 96.7    | 96.3    | 96.5 | 100     | 100     | 100  | 100     | 100     | 100   |
| T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)* | 83.0    | 79.6    | 81.3 | 99.8    | 99.5    | 99.8 | 100     | 100     | 100   |
| T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* | 79.5    | 77.6    | 78.6 | 97.2    | 96.6    | 96.6 | 99.9    | 97.8    | 98.9  |
| T8 Clodinafop+Metsulfuron-methyl (RM)* | 20.1    | 2.2     | 11.2 | 74.8    | 84.1    | 79.4 | 95.9    | 97.9    | 96.9  |
| T9 Mesosulfuron+Idosulfuron (RM)* | 41.6    | 34.4    | 38   | 33.2    | 89.6    | 61.4 | 93.4    | 87.9    | 90.6  |
| S.Em±               | 4.26    | 9.05    | 12.8 | 1.8     | 3.82    | 5.41 | 1.2     | 2.55    | 3.61  |
| CD at 5%            | 12.2    | 26      | 36.8 | 5.18    | 11      | 15.5 | 3.46    | 7.34    | 10.3  |

RM*- Readymade mixture; fb**- followed by treatments; T1 & T2; Pre-emergence application of herbicides. T3 – T9: Post-emergence application of herbicides.
chlorophyll a (1.21 mg/g FW), chlorophyll b (0.26 mg/g FW) and total chlorophyll content (1.45 mg/g FW). Chlorophyll b content was comparable in T2 Pendimethalin+Metribuzin, T9 Mesosulfuron+Idosulfuron (RM)* and T10 Weedy plot (Table 6).

Effect of herbicides on NR-Activity of wheat leaves (µmol of NO$_2$·g$^{-1}$ FW)

Effect of herbicides on nitrate reductase activity was estimated at 45 days after sowing. The following Table 7 showing the mean data on nitrate reductase activity of wheat crop. T8 Clodinafop+Metsulfuron-methyl (RM)* treatment had maximum NR-activity at 10 min followed by T9 Mesosulfuron+Idosulfuron (RM)* treatment whereas T2 Pendimethalin+Metribuzin treatment showed maximum NR-activity at 40 min. The mean data on nitrate reductase activity was recorded maximum in T10 Weedy plot followed by T3 Pendimethalin+Metribuzin fb**

**Table 5:** Biomass of wheat crop at different growth stages treated with herbicides.

| Herbicide treatments | Biomass (g) | Days after sowing |
|----------------------|------------|-------------------|
|                      |            | 30     | 60     | 90     | 2016-17 | 2017-18 | Mean 2016-17 | 2017-18 | Mean 2016-17 | 2017-18 | Mean |
| T1 Pendimethalin     | 0.17       | 0.19   | 0.18   | 1.34   | 1.18   | 1.27   | 6.31       | 4.7     | 5.51       |
| T2 Pendimethalin+Metribuzin | 0.24      | 0.2    | 0.22   | 1.53   | 1.14   | 1.34   | 7.36       | 4.11    | 5.73       |
| T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)* | 0.17 | 0.22 | 0.2 | 2    | 1.04  | 1.52 | 10.03 | 4.95 | 7.49 |
| T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* | 0.2 | 0.2 | 0.2 | 2.23 | 1.04 | 1.64 | 7.03 | 4.35 | 5.69 |
| T5 Pendimethalin fb** Clodinafoppropargyl | 0.22 | 0.23 | 0.23 | 1.91 | 1.01 | 1.46 | 6.81 | 4.78 | 5.8 |
| T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)* | 0.17 | 0.22 | 0.2 | 1.48 | 1.18 | 1.33 | 5.69 | 4.28 | 4.99 |
| T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* | 0.17 | 0.17 | 0.17 | 1.61 | 0.94 | 1.28 | 4.74 | 3.8 | 4.27 |
| T8 Clodinafop+Metsulfuron-methyl (RM)* | 0.25 | 0.19 | 0.22 | 2.08 | 0.94 | 1.51 | 6.46 | 4.57 | 5.52 |
| T9 Mesosulfuron+Idosulfuron (RM)* | 0.19 | 0.24 | 0.22 | 1.08 | 0.78 | 0.93 | 5.77 | 4.34 | 5.06 |
| T10 Weedy | 0.19 | 0.19 | 0.19 | 1.44 | 1.11 | 1.28 | 5.26 | 3.62 | 4.44 |

RM*: Readymade mixture; fb**: followed by treatments; T1 & T2; Pre-emergence application of herbicides. T3 – T9:- Post-emergence application of herbicides

**Table 6:** Mean data on chlorophyll content (chlorophyll ‘a’, ‘b’ & total chl.) of wheat crop under different herbicide treatments.

| Herbicide treatments | Chlorophyll a | Chlorophyll b | Total chlorophyll |
|----------------------|---------------|---------------|-------------------|
|                      | 2016-17 | 2017-18 | Mean 2016-17 | 2017-18 | Mean 2016-17 | 2017-18 | Mean |
| T1 Pendimethalin     | 1.542   | 1.628   | 1.585 | 0.348 | 0.346 | 0.347 | 1.861 | 1.944 | 1.903 |
| T2 Pendimethalin+Metribuzin | 1.2     | 1.684   | 1.442 | 0.416 | 0.307 | 0.361 | 1.593 | 1.96  | 1.776 |
| T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)* | 1.273 | 1.827 | 1.55 | 0.251 | 0.344 | 0.298 | 1.5   | 2.138 | 1.819 |
| T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* | 1.352 | 1.521 | 1.436 | 0.27  | 0.318 | 0.294 | 1.597 | 1.811 | 1.704 |
| T5 Pendimethalin fb** Clodinafoppropargyl | 1.394 | 1.441 | 1.417 | 0.277 | 0.272 | 0.275 | 1.645 | 1.686 | 1.666 |
| T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)* | 1.577 | 1.651 | 1.614 | 0.302 | 0.323 | 0.313 | 1.85  | 1.943 | 1.896 |
| T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* | 1.329 | 1.098 | 1.214 | 0.302 | 0.21  | 0.256 | 1.606 | 1.288 | 1.447 |
| T8 Clodinafop+Metsulfuron-methyl (RM)* | 1.309 | 1.458 | 1.384 | 0.268 | 0.301 | 0.284 | 1.552 | 1.732 | 1.642 |
| T9 Mesosulfuron+Idosulfuron (RM)* | 1.261 | 1.696 | 1.478 | 0.362 | 0.349 | 0.356 | 1.599 | 2.013 | 1.806 |
| T10 Weedy | 1.755 | 1.634 | 1.695 | 0.39  | 0.32  | 0.355 | 2.113 | 1.924 | 2.018 |
| S.Em± | 0.144 | 0.171 | 0.128 | 0.084 | 0.058 | 0.032 | 0.165 | 0.193 | 0.14 |

RM*: Readymade mixture; fb**: followed by treatments; T1 & T2; Pre-emergence application of herbicides. T3 – T9:- Post-emergence application of herbicides

Biological yield (kg/m$^2$)

The effect of herbicides on mean data of biological yield is presented in following graph. It was recorded highest in T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* (1.392 kg/m$^2$) treatment followed by T2 Pendimethalin+Metribuzin treatment (1.325 kg/m$^2$) while the T10 Weedy plot carried lowest biological yield; it was 0.929 kg/m$^2$. The herbicide treatments, T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*, T5 Pendimethalin fb** Clodinafoppropargyl and T8 Clodinafop+Metsulfuron-methyl (RM)* had comparable biological yield (Figure 1).
Grain yield

Figure 2 sowing mean data on economic yield (kg/m²) of wheat crop under different treatment. T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* treatment (0.53 kg/m²) had maximum grain yield then rest of the treatments. This could be attributed to better control of competitive weed species. The grain yield of wheat under T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* treatment was 0.542 kg/m² in I year trial and 0.528 kg/m² in II year trial whereas lowest grain yield was achieved in weedy situation; it was 0.188 kg/m².

DISCUSSION

The herbicides use in combination or sequential application was observed to be most economical by the study under research. The dynamic nature of weeds necessitates continuous redesigning of strategies from time to time for their successful management. Furthermore, research has consistently proved that herbicides provide more effective and economical weed control leading to higher crop yields [19,20].

The degree of reduction in the weed biomass does not necessarily correspond to the degree of reduction in the weed population. When weed population decreases due to the herbicide application, more space and thus resources will be available for the remaining weeds which may result in higher growth of each plant and thus lower reduction in the weed biomass [21]. Baghestani et al. [22] found that mesosulfuron-methyl plus iodosulfuron-methyl-sodium (WG) was a good herbicide option for weed control in wheat. Good performance of sulfosulfuron plus metsulfuron-methyl is also supported by the results of Zand et al. [23]. To avoid antagonism of different herbicides, sequential applications are suggested for the effective control of weeds throughout the growing season [24]. Herbicide efficacy can be increased by tank mixing, if compatible [25] or their sequential applications for the effective control of weeds in wheat [26]. Mesosulfuron methyl plus iodosulfuron-methyl-sodium, metsulfuron-methyl, sulfosulfuron and chlorosulfuron are used for weed control in wheat [27]. Ready mix of clodinafop-propargyl+MSM @ 64 g/ha and clodinafop-propargyl @ 60 g/ha recorded complete control on Phalaris minor population at 60, 90 DAS and at maturity stage [28].

This study suggests that Phalaris minor caused more competitive pressure on wheat than others so that their effective control by this herbicide resulted in high grain yield of wheat. Thus, the application of these herbicides is suggested to have the lowest grain yield loss. The lowest wheat yield was obtained in untreated/weedy plot whereas herbicide T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* was the only treatment which resulted in high grain yield that was not significantly...
different with the treatment T2 Pendimethalin+Metribuzin treatment, which corresponded with the good performance of these herbicide on weeds. This could be attributed to better control of isoproturon resistant Phalaris minor. The grain yield of wheat under T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* treatment was 0.542 kg/m² in I year trial and 0.528 kg/m² in II year trial. Results of weed biomass reduction in different treatments corresponded with the respective weed population reductions. Weed density was gradually decreases and tends to zero in all the herbicide treatments except T1 Pendimethalin, T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)* and T9 Mesosulfuron+Iodosulfuron (RM)* treatments otherwise the rest treatments have efficacy to control Phalaris minor in wheat crop. Similarly, weed biomass was found maximum under T10 weedy plot (313.07 g/m² in I-trial and 201.60 g/m² in II-trial) followed by T1 Pendimethalin treatment (196.93 g/m² in I-trial 21.43 g/m² in II-trial) at 90 DAS, otherwise rest of the treatment includes T2 Pendimethalin+Metribuzin, T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Iodosulfuron(RM)*, T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)*, T5 Pendimethalin fb** Clodinafoppropargyl, T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)*, T7 Pendimethalin fb** Mesosulfuron+Iodosulfuron (RM)* and T8 Clodinafop+Metsulfuron-methyl (RM)* were found effective to control this weed and their biomass was gradually decreased after application of herbicides. The sequential application of pendimethalin with post-emergence herbicides can improve weed control when post-emergence herbicides have a slightly poor efficacy [29]. It was found maximum in (T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* treatment; 1.300 kg/m² and 1.483 kg/m² in first and second year trial respectively. During present investigation it was found that chlorophyll ‘a’, chlorophyll ‘b’ and total chlorophyll content were reduced after application of herbicides with a maximum fluctuation in chlorophyll b. It was also reported earlier that chlorophyll b is more sensitive than chlorophyll a and carotenoids under stress conditions [30]. Since reports of P. minor resistance to some of the herbicides used in the present study such as sulfsulfuron and clodinafop are already there, it will be necessary to continue monitoring the bio-efficacy of these herbicides in the rice-wheat cropping system. Resistance management will always be challenging till herbicides dominate the weed management strategies.

CONCLUSION

As evaluated from the study, Phalaris minor (grass weed) causes more competitive pressure on wheat so that their effective control by these herbicides resulted in high grain yield of wheat. It may be concluded from the trials conducted during 2016-17 and 2017-18 that applications of alternative herbicides were found to be very effective in controlling the isoproturon-resistant P. minor. The ready-mix and sequential application of herbicides was superior to the application of single herbicides. The ready-mix of mesosulfuron+iodosulfuron at 14.4 (12+2.4) and clodinafop+metsulfuron-methyl at 64.0 (60+4) g/ha was effective in controlling weeds and producing wheat yield. This study shows that isoproturon-resistant P. minor could be successfully controlled by using herbicides or their combination with different mechanism of action such as PSII, ACCase and ALS inhibitors. There was no adverse effect on wheat crop at recommended dose of the herbicides.

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