OPEN ACCESS Freely available online

Journal of
Agricultural Science and Food Research

Research Article

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

Prinsa*, **Hem C. Joshi, Babita Joshi and S.K. Guru**

Department of Plant Physiology, College of Basic Sciences and Humanities, G.B.P.U.A. & T. Pantnagar, U.S. Nagar (263145), Uttarakhand, India

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/m^2) [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

Correspondence to: Prinsa, Department of Plant Physiology, College of Basic Sciences and Humanities, G.B.P.U.A. & T. Pantnagar, U.S. Nagar (263145), Uttarakhand, India, Tel.No.+919760313511; E-mail: prinsaramola914@gmail.com

Received: October 18, 2018, **Accepted:** August 16, 2019, **Published:** August 23, 2019

Citation: Prinsa*, Hem C. Joshi, Babita Joshi and S.K. Guru (2019) Management of Isoproturon-Resistant *Phalaris minor* in Wheat by Alternate Herbicides under Tarai Region Conditions. J Agri Sci Food Res 10:263. doi: 10.35248/2593-9173.19.10.263

of chlorophyll content of wheat leaves subjected to two sulfonylurea 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*2m. 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˚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 crop was harvested at full physiological maturity. The grain weight was recorded after threshing and cleaning. Grain yield was recorded from a harvested area of 1 m^{-2} in each plot. Threshing was accomplished with a plot thresher followed by cleaning. Chlorophyll content was estimated by the procedure of Hiscox and Israelstam [17] and NR-Activity in freshly harvested wheat leaves was estimated by using the method given by the Hageman and Hucklesby [18].

Weed control efficiency (WCE): To know the performance of treatments WCE is calculated on the basis of weed density:

$$\text{Weed control efficiency} = \frac{(WPc - WPt)}{WPc} \times 100$$

WPc = weed population (no/m²) in untreated plot; WPt = weed population (no/m²) in treated plot.

Weed control index (WCI): It is calculated on the basis of dry weight of weeds

$$\text{Weed control index} = \frac{(WDc - WDt)}{WDc} \times 100$$

WDc = Weed dry matter in untreated plot; WDt = Weed dry matter in treated plot.

Data were subjected to analysis using the STPR statistical software.

RESULTS

Effect of herbicides on density (no./m²) 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./m²) of *Phalaris minor*. The mean data showed that density of *Phalaris minor* was gradually decreased under few treatments like T2 Pendimethalin+Metribuzin, T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*, T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)*, T5 Pendimethalin fb** Clodinafoppropargyl, T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* and T8 Clodinafop+Metsulfuron-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/m²). After 60 days of application, almost all herbicide treatments showed efficacy towards controlling isoproturon resistance *Phalaris minor* except T1 Pendimethalin, T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)* and T9 Mesosulfuron+Idosulfuron (RM)* treatments.

Effect of herbicides on density (no/m²) 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/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), otherwise rest of the treatment includes T2 Pendimethalin+Metribuzin, T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*, T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)*, T5 Pendimethalin fb** Clodinafoppropargyl, T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)* and T8 Clodinafop+Metsulfuron-methyl (RM)* were found effective to control this weed and their biomass was gradually decreased after application of herbicides.

Weed control efficiency (WCE) of different herbicides for controlling *Phalaris minor*

Weed control efficiency (WCE) of different herbicides for controlling *Phalaris minor* is presented in Table 3. The data on weed control efficiency showed that few herbicide treatments namely T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*, T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* and T5 Pendimethalin fb** Clodinafoppropargyl had cent percent weed control efficiency at 75DAS for both the trials and eventually the mean data indicated the similar result but

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	42.67	18.67	30.67	93.33	25.33	59.33
T2	Pendimethalin+Metribuzin	0.13	1.33	0.73	3.53	4.93	4.23	0	0	0
T3	Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*	13.33	14.67	14	1.88	5.33	3.61	0	0	0
T4	Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)*	8	13.33	10.67	0.13	3.6	1.87	0	0	0
T5	Pendimethalin fb** Clodinafoppropargyl	5.31	5.33	5.32	0	0	0	0	0	0
T6	Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)*	16	21.33	18.67	5.04	2.53	3.79	6.4	10.67	8.53
T7	Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)*	22.67	28	25.33	9.2	24	16.6	0	0	0
T8	Clodinafop+Metsulfuron-methyl (RM)*	65.33	102.6	84	85.33	53.33	69.33	0	0	0
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	149.3	208.6	196	249.3	222.6
	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	15	22.6	18.8	196.9	21.4	109.1
T2	Pendimethalin+Metribuzin	0.01	0.04	0.03	0.01	1.03	0.52	0	0	0
T3	Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*	0.3	0.32	0.31	0	0.17	0.08	0	0	0
T4	Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)*	0.24	0.25	0.24	0	0.02	0.01	0	0	0
T5	Pendimethalin fb** Clodinafoppropargyl	0.11	0.12	0.11	0	0	0	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	0	0
T8	Clodinafop+Metsulfuron-methyl (RM)*	2.53	3.5	3.01	14.13	6.63	10.4	0	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	44.4	52.9	313	201.6	257.3
	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

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*

Weed control index (WCI) of 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. 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 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.

Weed control efficiency (WCE)										
Herbicide treatments		Days after sowing								
		30			60			90		
		2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
T1	Pendimethalin	89	87.1	88	83.7	86.8	85.3	67.5	61.8	64.7
T2	Pendimethalin+Metribuzin	99.9	99.3	99.6	98.6	96.7	97.7	99.6	97.9	98.7
T3	Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*	89	88.2	88.6	99.3	96.5	97.9	100	100	100
T4	Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)*	93.3	90	91.7	100	97.5	98.7	100	100	100
T5	Pendimethalin fb** Clodinafoppropargyl	95.6	96.1	95.8	100	100	100	100	100	100
T6	Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)*	86.7	83.9	85.3	98	98.3	98.1	98	95.3	96.7
T7	Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)*	81.2	77.7	79.5	96.4	83.9	90.2	96.8	87.8	92.3
T8	Clodinafop+Metsulfuron-methyl (RM)*	46.4	20	33.2	67.7	64	65.8	86.3	85.5	85.9
T9	Mesosulfuron+Idosulfuron (RM)*	51.6	49.5	50.6	15.3	60.4	37.8	74.9	42	58.5
	S.Em±	1.98	4.21	5.96	1.39	2.96	4.19	0.87	1.85	2.61
	CD at 5%	5.71	12.1	17.1	4.01	8.52	12	2.5	5.32	7.52

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.

Weed control index (WCI)										
Herbicide treatments		Days after sowing								
		30			60			90		
		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	98.8	99.2	99.9	97.6	98.8	100	96.4	98.2
T3	Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*	90.7	90.7	90.7	99.9	99.6	99.8	100	100	100
T4	Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)*	92.6	92.4	92.5	100	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	79.6	81.3	98.7	99.5	99.1	99.6	98.7	99.2
T7	Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)*	79.5	77.6	78.6	97.2	96	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 40min. The mean data on nitrate reductase activity was recorded maximum in T10 Weedy plot followed by T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)* treatment while minimum activity was found in T2 Pendimethalin+Metribuzin treatment.

Biological yield (kg/m²)

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/m²) treatment followed by T2 Pendimethalin+Metribuzin treatment (1.325 kg/m²) while the T10 Weedy plot carried lowest biological yield; it was 0.929 kg/m². 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).

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 content of wheat (mg/g FW) – 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

Table 7: Nitrate reductase activity in wheat leaves (μmol of NO_2- g^1 FW) treated with herbicides.

Herbicide treatments		NR-10min			NR-40min			NR activity		
		2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
T1	Pendimethalin	25.14	22.39	23.76	39.98	37.61	38.8	10.298	7.16	8.73
T2	Pendimethalin+Metribuzin	25.06	24.21	24.63	40.5	42.45	41.48	9.607	5.98	7.79
T3	Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron (RM)*	26.14	24.89	25.51	35.85	34.55	35.2	16.416	15.22	15.82
T4	Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)*	24.58	24.58	24.58	38.17	37.38	37.78	10.995	11.78	11.39
T5	Pendimethalin fb** Clodinafoppropargyl	25.8	23.7	24.75	37.93	37.95	37.94	13.669	9.46	11.56
T6	Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)*	24.85	23.64	24.25	35.23	36.08	35.66	14.478	11.19	12.83
T7	Pendimethalin fb** Mesosulfuron+Idosulfuron (RM)*	24.84	24.43	24.63	37.58	34.49	36.03	12.094	14.37	13.23
T8	Clodinafop+Metsulfuron-methyl (RM)*	27.33	25.71	26.52	38.45	36.98	37.72	16.218	14.44	15.33
T9	Mesosulfuron+Idosulfuron (RM)*	26.41	25.17	25.79	38.1	33.77	35.93	14.71	16.57	15.64
T10	Weedy	25.46	23.23	24.35	32.32	32.27	32.3	18.602	14.19	16.4
	S.Em±	0.236	0.529	0.748	0.451	1.009	1.428	0.563	1.26	1.782
	CD at 5%	0.677	1.514	2.141	1.293	2.891	4.088	1.614	3.609	5.104

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

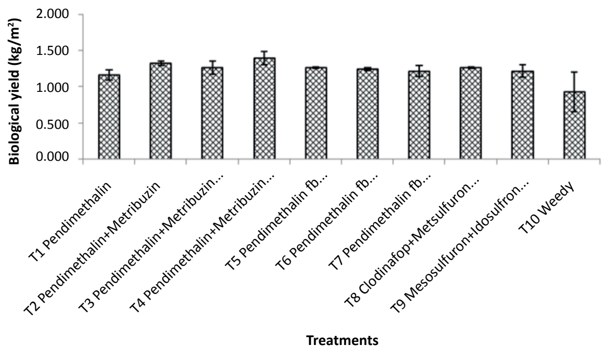

Figure 1: Mean data on biological yield of wheat crop treated with herbicides.

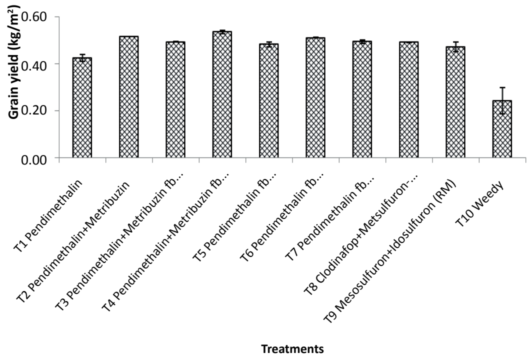

Figure 2: Mean data on grain yield (kg/m^2) of wheat crop treated with herbicides.

Grain yield

Figure 2 sowing mean data on economic yield (kg/m^2) of wheat crop under different treatment. T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)* treatment (0.53 kg/m^2) 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/m^2 in I year trial and 0.528 kg/m^2 in II year trial whereas lowest grain yield was achieved in weedy situation; it was 0.188 kg/m^2 and.

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 meosulfuron-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 chlorsulfuron 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/m^2 in I year trial and 0.528 kg/m^2 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+Idosulfuron (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/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 21.43 g/m^2 in II-trial) at 90 DAS, otherwise rest of the treatment includes T2 Pendimethalin+Metribuzin, T3 Pendimethalin+Metribuzin fb** Mesosulfuron+Idosulfuron(RM)*, T4 Pendimethalin+Metribuzin fb** Clodinafop+Metsulfuron-methyl (RM)*,T5 Pendimethalin fb** Clodinafoppropargyl, T6 Pendimethalin fb** Clodinafop+Metsulfuron-methyl (RM)*, T7 Pendimethalin fb** Mesosulfuron+Idosulfuron (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/m^2 and 1.483 kg/m^2 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 sulfosulfuron 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-mehtyl 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.

REFERENCES

1. Yadav A, Malik RK. Herbicide resistant *Phalaris minor* in wheat a sustainability issue. Resource Book; epartment of Agronomy and Directorate of Extension Education. CCSHAU. Hisar. India. 2005; 1:152.
2. Malik RK, Singh S. Little seed canary grass (*Phalaris minor*) resistance to isoproturon in India. Weed Technology 1995; 9: 419-425
3. Sardana V, Mahajan G, Jabran K, Chauhan BS. Role of competition in managing weeds: An introduction to the special issue. Crop Prot. 2017; 95:1–7.
4. Jabran K, Mahmood K, Melander B, Bajwa AA, Kudsk P. Weed dynamics and management in wheat. Advances in Agronomy. 2017; 145: 97-166.
5. Labrada R (2003) The need for improved weed management in rice.2003
6. Malik RK, Singh SA. Effect of biotype and environment on the efficacy of isoproturon against wild canary grass. Tests of agrochemicals and cultivars. 1994.
7. Malik RK, Singh S. Little seed canary grass (*Phalaris minor*) resistance to isoproturon in India. Weed Technology 1995; 9: 419-425.
8. Yadav A, Malik RK, Chauhan BS, Gill G. Present status of herbicide resistance in Haryana. In Herbicide Resistance Management and Zero-tillage in Rice wheat Cropping System. Proceedings of the International Workshop 2002;15-23.
9. Chhokar RS, Singh S, Sharma RK. Herbicides for control of isoproturon-resistant Littleseed Canarygrass (*Phalaris minor*) in wheat. Crop Prot 2008; 27: 719-726.
10. Suria AJ, Juraimi AS, Rahman M, Man AB. Selamat A. Efficacy and economics of different herbicides in aerobic rice system. African Journal of Biotechnology. 2011;10: 8007-8022.
11. Hana S, Leila MA, Nedjoud G, Reda DM. Physiology and biochemistry effects of herbicides Sekator and Zoom on two varieties of wheat (Waha and HD) in semi-arid region. Annual Research & Review in Biology. 2015; 449-459.
12. Vincentz M, Moureaux T, Leydecker MT, Vaucheret H, Caboche M. Regulation of nitrate and nitrite reductase expression in *Nicotiana plumbaginifolia* leaves by nitrogen and carbon metabolites. The Plant Journal. 1993; 315-24.
13. Kaiser WM. Weiner H. Huber SC. Nitrate reductase in higher plants: A case study for transduction of environmental stimuli into control of catalytic activity. *Physiologia plantarum*. 1999;105: 384-389.
14. Reilly ML. The nitrate assimilation capacity of Some Irish-Grown wheat (*Triticum vulgare*) varieties: I. Levels of nitrate reductase activity and its distribution in the plant." Proceedings of the Royal Irish Academy. Section B: Biological. Geological and Chemical Science 1976; 76: 543-554.
15. Chhokar RS, Malik RK. Isoproturon-resistant littleseed canarygrass (*Phalaris minor*) and its response to alternate herbicides. Weed Technology. 2002; 16:116-123.
16. Chhokar RS, Sharma RK. Chauhan DS, Mongia AD. Evaluation of herbicides against *Phalaris minor* in wheat in north-western Indian plains. Weed research. 2006; 46: 40-9.
17. Hiscox JD, Israelstam GF. A method for the extraction of chlorophyll from leaf tissue without maceration. Canadian journal of botany. 1979; 57: 1332-1334.
18. Hageman RH, Hucklesby DP. Nitrate reductase from higher plants. In: Methods in enzymology 1971; 23: 491-503.

19. Rao AN, Ladha JK. Possible approaches for ecological weed management in direct-seeded rice in a changing world. In: 23rd Asian-Pacific Weed Science Society Conference 201: 444.

20. Rao AN. Weed management research in India an analysis of past and outlook for future. 2014; 1 -26.

21. Zand E, Baghestani MA, Agha Alikhani M, Soufizadeh S, Khayami MM, Pour Azar R, et al. Chemical control of weeds in wheat (*Triticum aestivum* L.) in Iran. Crop Protection. 2010; 29: 1223-1231.

22. Baghestani MA, Zand E, Soufizadeh S, Beheshtian M, Haghighi A, Barjasteh A, et al. Study on the efficacy of weed control in wheat (*Triticum aestivum* L.) with tank mixtures of grass herbicides with broadleaved herbicides. Crop protection. 2008; 27:104-111.

23. Zand E, Baghestani MA, Soufizadeh S, Eskandari A, Pour Azar R, Veysi M, et al. Evaluation of some newly registered herbicides for weed control in wheat (*Triticum aestivum* L.) in Iran. Crop Protection. 2007; 26:1349-1358.

24. Yadav DB, Yadav A, Singh S, Lal R. Compatibility of fenoxaprop Pethyl with carfentrazone ethyl. metsulfuron methyl and 2, 4-D for controlling complex weeds of wheat. Indian Journal of Weed Science. 2009; 41:157-160.

25. Sharma R, Pahuja SS, Balyan RS, Malik RK. Effect of sulfonylurea herbicides applied alone and tank mix with metribuzin on weeds in wheatand their residual effect on succeeding crop of sorghum. Indian Journal of Weed Science. 2002; 34: 178-183.

26. Hessain TF. Efficacy of clodinafop, isoproturon and their sequential application on durum wheat as influenced by fertilizer application. Indian Journal of Weed Science. 2013; 45: 86-89.

27. Baghestani MA, Zand E, Soufizadeh S, Jamali M, Maighany F. Evaluation of sulfosulfuron for broadleaved and grass weed control in wheat (*Triticum aestivum* L.) in Iran. Crop protection. 2007; 26: 1385-1389.

28. Sirazuddin Singh SP, Singh VP, Mahapatra BS. Dynamics of *Phalaris minor* in wheat (*Triticum aestivum* L.) under different establishment methods and weed control measures. International Journal of Environmental & Agriculture Research 2015; 1: 20-25.

29. Yadav DB, Yadav A, Punia SS, Chauhan BS. 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. 2016; 89: 239-247.

30. Netondo GW, Onyango JC, Beck E. Sorghum and salinity: II. Gas exchange and chlorophyll fluorescence of sorghum under salt stress. Crop Science. 2004; 44: 806.