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Interaction of Stage of Application and Herbicides on Some *Phalaris minor* Populations

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ABSTRACT

Pot studies were carried out at Agronomy Research Farm of CCSHAU, Hisar during the **rabi** seasons of 2005-06, 2006-07 and 2007-08 using isoproturon resistant, susceptible and pristine populations of *Phalaris minor*. Ten herbicides (isoproturon, chlorotoluron, sulfosulfuron, clodinafop-propargyl, fenoxaprop-P-ethyl, quizalofop-ethyl, premix of mesosulfuron-methyl+iodosulfuron-methyl-sodium, sulfosulfuron+metsulfuron-methyl, pinoxaden and tank mix of pinoxaden+carfentrazone-ethyl) were applied at two growth stages (4 leaf and tillering) of five *P. minor* populations [J-35 (Jind), F-42 (Fatehabad), K-15 (Karnal), H-2 (Hisar) from Haryana and B-6 (Bihar)] using three application rates by a knapsack sprayer fitted with flat fan multi nozzle boom delivering 500 l water/ha. The pots were arranged in a CRD design with three replicated earthen pots for each herbicide treatment and populations. Plant height, weed mortality and fresh/dry weight were recorded to evaluate herbicides effect on *P. minor* populations. When combined data were analyzed, no significant interaction of weed stage, populations and herbicides was observed for per cent mortality and dry weight, whereas highly significant effect of weed stage, populations and herbicides was recorded. There was significant interaction of populations and herbicides for mortality data. Significant interaction for stage, dose and herbicides was recorded when data for each population at two growth stages were subjected to ANOVA, which shows large variations among populations to different herbicides. *P. minor* populations, J-35 and K-15 had significantly lower mortality and higher dry weight, data averaged over herbicides, compared to B-6 and H-2, whereas F-42 was intermediate in mortality and accumulated higher dry weight compared to B-6 and H-2. Among the herbicides, lowest mortality was recorded with clodinafop and isoproturon followed by fenoxaprop and quizalofop, whereas highest mortality was recorded with pinoxaden tank mixed with carfentrazone and its alone application followed by chlorotoluron and mesosulfuron+iodosulfuron. Sulfosulfuron alone and premix with metsulfuron had lower mortality compared to pinoxaden±carfentrazone and chlorotoluron. Similar results were recorded for dry weight also. Delayed application from 4 leaf to tillering stage lowered the mortality of sulfosulfuron±metsulfuron, mesosulfuron+iodosulfuron, isoproturon and chlorotoluron. The GR_{50} (growth reduction by 50%) of herbicides increased with stage of herbicide application; increase was more in isoproturon and clodinafop compared to other herbicides. Populations, K-15 and J-35 had resistance factor (Rf) of 10.85 and 4.91 for isoproturon and 1.70 and 1.25 for clodinafop, respectively, when applied at tillering stage compared to H-2 population. Some variations were also observed in GR_{50} with other herbicides, but not reflected in dry weight. The study indicated ensuing problems with clodinafop, fenoxaprop and even sulfosulfuron, but there was no loss of efficacy with pinoxaden±carfentrazone or chlorotoluron.

Key words : Growth stages, herbicide efficacy, resistance, management

INTRODUCTION

Wheat occupies 22% of total area under food grains in India constituting 36% (84.27 m t) of total food produced from 29.4 m ha during 2010-11. The national productivity is one third less than Punjab and Haryana that is again one third less compared to the UK which demonstrates vast potential for improving wheat yield to meet the demand of burgeoning population of India. There are several constraints to achieve desired yield potential, but the most ubiquitous being weed abundance and among weeds, *Phalaris minor* is the most dominant weed of wheat in north-west India (Singh *et al*., 1995; Franke *et al*., 2003). Average yield losses of 20-30% are common; however, heavy infestation of this formidable weed can inflict huge crop losses (Malik and Singh, 1995; Singh *et al*., 1999). The problem of *P. minor* exacerbated where rice-wheat was the foremost cropping system as it grows lavishly under high moisture/fertility conditions (Singh *et al*., 1995). Chlorotoluron (Gill and Brar, 1977), isoproturon (Gill *et al*., 1979) and other PSII inhibitors were found effective for the control of this dreaded weed (Singh *et al*., 1999), but due to varietal sensitivity and crop injury, isoproturon was the herbicide of choice of north-west Indian farmers with broad-spectrum weed management. Application time, method and doses of these PSII inhibitor herbicides had significant effect on weed mortality (Balyan *et al*., 1989; Yaduraju, 1991; Singh and Malik, 1994; Singh *et al*., 1995; Walia *et al*., 2002). Timely application of herbicides not only provided effective weed control, but also required lower doses, which saved cost and was more environment friendly (Sharma *et al*., 1985; Singh and Malik, 1993).

However, continuous use of isoproturon coupled with agronomic practices led to evolution of resistant biotypes of *P. minor* (Malik and Singh, 1995). New herbicides were evaluated for the control of isoproturon resistant biotypes (Malik and Yadav, 1997; Chhokar and Malik, 2002; Chhokar *et al*., 2006), along with other management factors viz., crop/herbicide rotations, herbicide mixtures, agronomic practices and herbicide application methods (Singh *et al*., 1999; Yadav *et al*., 2006; Singh, 2007).

P. minor has been observed to emerge in several flushes in the growing season of wheat and its early sowing is recommended for effective weed management (Malik and Singh, 1993). New herbicides recommended for the control of isoproturon resistant populations of *P. minor* (fenoxaprop-P-ethyl, clodinafop-propargyl and sulfosulfuron) vary in their efficacy on different weed species of wheat and several factors viz., moisture at spraying, stage of weeds, water volume, nozzle types and application methods contribute for their weed control efficacy (Walia and Brar, 2006; Yadav *et al*., 2006). Mahajan *et al.* (2002) found significant interaction of planting dates and herbicides on the control of *P. minor* and grain yield of wheat. Continuous use of these new herbicides also sprang up new problems of cross- or multiple-resistances to these herbicides (Walia and Brar, 2006; Yadav *et al*., 2006); manipulation of sowing methods and application time of these herbicides may have significant effect on weed mortality. Herbicide use history and cropping system may impact their efficacy particularly on resistant populations of *P. minor*. Keeping this in view, experiments were conducted to evaluate the efficacy of major wheat herbicides when applied at two growth stages of different *P. minor* populations grown in pots under field conditions.

MATERIALS AND METHODS

Studies were carried out in earthen pots during **rabi** seasons of 2005-06, 2006-07 and 2007-08 at Agronomy Research Farm of CCS Haryana Agricultural University, Hisar. Field soil of medium fertility and sandy loam texture was mixed with dunal sand and vermi-compost in 2 : 1 : 1 ratio by volume to fill the pots of 25 cm height and top diameter with 6.5 kg soil capacity. After watering, the pots were allowed emergence of natural weed flora in the soil for 7-10 days which were pulled out before planting 30 seed of each population of *P. minor*. Progenies of *P. minor* populations collected earlier from Jind (J-35), Fatehabad (F-42), Karnal (K-15), Hisar (H-2) and a pristine biotype (B-6) from Bihar (where no herbicides were applied) were used in the present study. The seeds of these populations were collected from untreated plants grown in the screen house in the previous year. Planting was done on January 6, 2006, December 28, 2006 and November 30, 2007 with three replicated pots for each population and treatment. Pots were watered as and when required. Thinning was done two weeks after emergence and 10 plants per pot were maintained for spraying. Ten herbicides at three rates were compared at two application stages; 4 leaf stage (0-1 tiller) and tillering stage (2-5 tillers) along with untreated control for each herbicide and population. Sulfosulfuron 75% WG (20, 25 and 30 g/ha), clodinafop-propargyl 15% WP (50, 60 and 70 g/ha), fenoxaprop-P-ethyl 10% EC (100, 120 and 150 g/ha), premix of sulfosulfuron 75% WG+metsulfuron-methyl 5% WG (24, 32 and 40 g/ha), mesosulfuron-methyl 3% WDG+iodosulfuron-methyl-sodium 0.6% WDG (9.8, 14.4 and 19.0 g/ha), isoproturon 75% WP (1.0, 1.5 and 2.0 kg/ha), chlorotoluron 70% SC (1.0, 1.5 and 2.0 kg/ha), quizalofop-ethyl 5% EC (50, 100 and 200 g/ha), pinoxaden 5% EC (40, 45 and 50 g/ha) and tank mix of pinoxaden 5% EC with carfentrazone-ethyl 40% DF (40+20, 45+20 and 50+20 g/ha) were sprayed with a knapsack sprayer fitted with three flat fan nozzles using 500 l water/ha volume. PumaSuper formulation of fenoxaprop was replaced in the third year with PumaPower at 80, 100 and 120 g/ha; equivalent potency to that of PumaPower, but results are expressed based on PumaSuper. After spraying pots were arranged in a completely randomized design. Observations were recorded for plant height and mortality at weekly intervals and fresh/dry weight at harvest. Experiments were repeated thrice to confirm yearly variations in herbicide response to different *P. minor* populations. Pooled data from three years were subjected to ANOVA using SPSS and GR_{50} (growth reduction by 50% was calculated based on mortality data) were calculated by using ARM software.

RESULTS AND DISCUSSION

Weed Mortality

Sulfosulfuron±metsulfuron and mesosulfuron + iodosulfuron provided similar mortality of different *P. minor* populations when applied at both the stages, the effect; however, was lower by 10% at tillering stage compared to 4 leaf stage, when data were averaged over populations and rates (Fig. 1). Significant differences were observed with clodinafop among *P. minor* populations; higher mortality was recorded for B-6 and H-2 compared to J-35 and K-15, though effects of weed stage were not large. Similarly, variations in stage and populations were less with fenoxaprop and quizalofop. Isoproturon was not effective against J-35 and K-15, but these were knocked down by chlorotoluron; effect of both these herbicides decreased with stage of application, but differences were not significant. Pinoxaden was most effective against all the test populations of *P. minor* and there was no loss of activity when applied at the four leaf stage or tillering (Fig. 1). Tank mixing of carfentrazone with pinoxaden was more effective against *P. minor* populations irrespective of resistant or susceptible populations.

Interaction of application stage, application rates and herbicides was significant for J-35 population. Efficacy of sulfosulfuron±metsulfuron and chlorotoluron was significantly reduced when sprayed at tillering compared to the 4 leaf stage (Fig 2.); reduction was not significant for other herbicides, except isoproturon which was not effective at any used rate. Tank mix of pinoxaden+ carfentrazone provided more than 95% control at the lowest used rate of 40 g/ha and was most effective. Lowest mortality was recorded with clodinafop at both the application stages followed by fenoxaprop. Chlorotoluron provided effective control of this population. Similarly, quizalofop provided more than 90% control at 200 g/ha and was better than premix of mesosulfuron + iodosulfuron (Fig. 2).

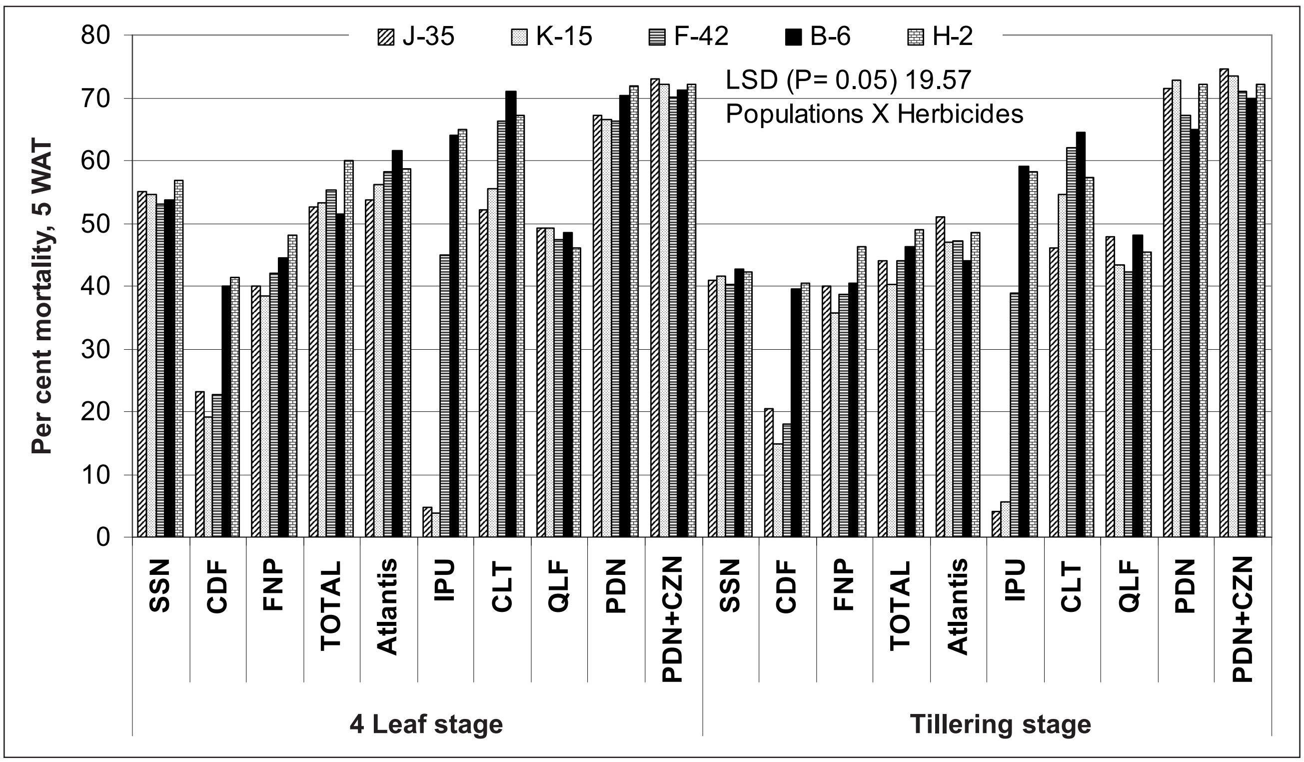

Fig. 1. Effect of different herbicides on mortality at two growth stages of *P. minor* populations.

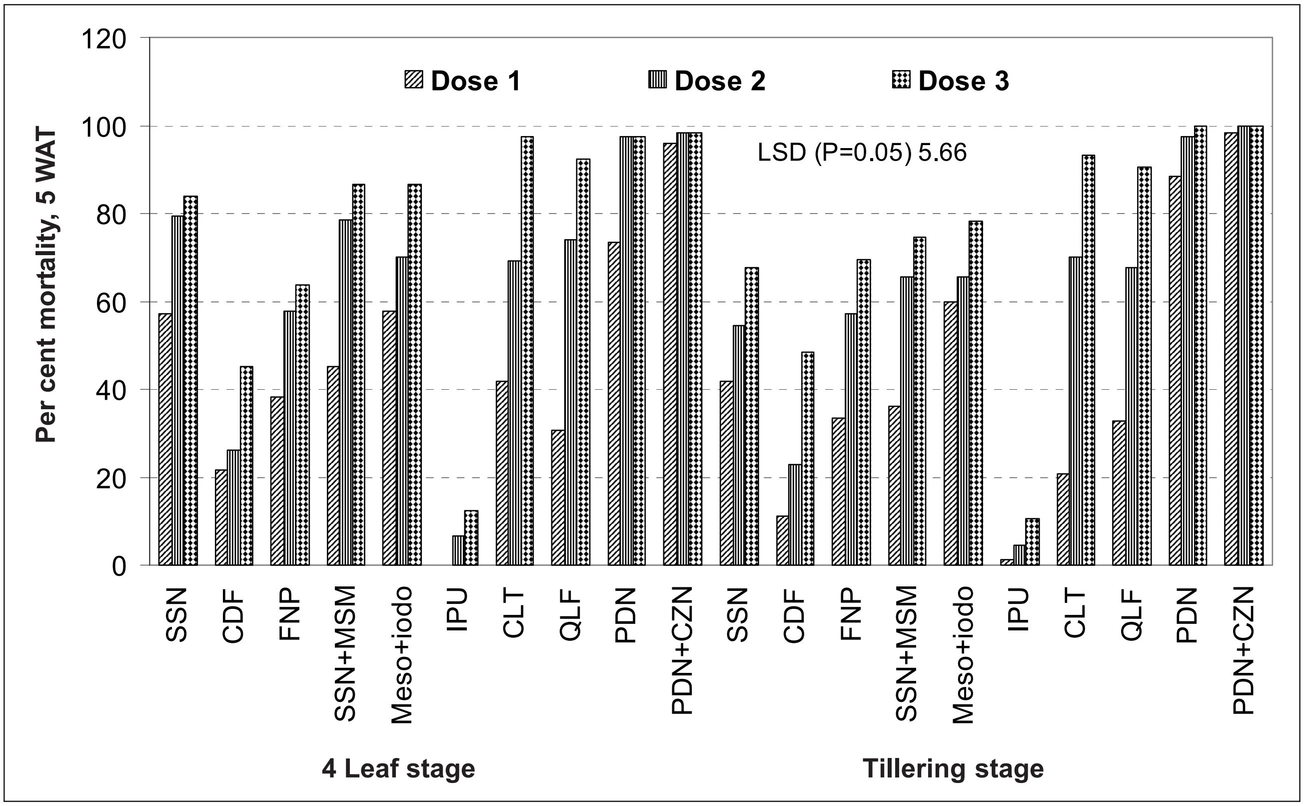

Fig. 2. Effect of different herbicides applied at two growth stages on the mortality of J-35 population of *P. minor* (SSN–Sulfosulfuron, CDF–Clodinafop, FNP–Fenoxaprop, MSM–Metsulfuron, Meso+iodo–Mesosulfuron+iodosulfuron, IPU–Isoproturon, CLT–Chlorotoluron, QLF–Quizalofop, PDN–Pinoxaden and CZN–Carfentrazone).

Clodinafop was least effective of the 10 herbicides, except isoproturon, so it could provide less than 40% control of K-15 population at 70 g/ha rate, whereas chlorotoluron provided 99 and 93% mortality at 4 leaf and tillering stage, respectively (Fig. 3). Similarly, fenoxaprop, sulfosulfuron applied alone and premix with metsulfuron were inferior to chlorotoluron, pinoxaden alone and tank mixed with carfentrazone (Fig. 3). Delayed application of sulfosulfuron±metsulfuron and mesosulfuron+iodosulfuron was less effective compared to their application at the 4 leaf stage; the difference of stage of application was non-significant for other herbicides.

Similarly, per cent control of F-42 population was significantly reduced with late application of sulfosulfuron±metsulfuron, mesosulfuron+iodosulfuron and isoproturon (Fig. 4). The reduction in herbicide efficacy of clodinafop, fenoxaprop, quizalofop and chlorotoluron was non-significant and no decrease in pinoxaden efficacy was observed (Fig. 4). Clodinafop provided only 65% control of F-42 population at 70 g/ha when applied at the tillering stage. Similarly, isoproturon and fenoxaprop at highest application rates failed to provide more than 65% control at tillering. Contrarily, pinoxaden applied alone or tank mixed with carfentrazone provided 100% mortality when plants were treated at the tillering stage (Fig. 4).

B-6, a pristine population from Bihar with no prior exposure to herbicide, was effectively controlled by isoproturon and chlorotoluron, but the efficacy of sulfosulfuron±metsulfuron, clodinafop, fenoxaprop and mesosulfuron+iodosulfuron was less than 80% at the highest dose rate when applied at tillering stage, whereas pinoxaden±carfentrazone provided complete control (Fig. 5). Delay in application from 4 leaf to tillering stage, significantly reduced the mortality of sulfosulfuron± metsulfuron, mesosulfuron+iodosulfuron and chlorotoluron; the decrease in fenoxaprop, quizalofop and isoproturon efficacy was non-significant and no decrease was observed in pinoxaden±carfentrazone efficacy (Fig. 5).

Mortality of H-2 biotype, the standard check for isoproturon resistance, decreased when sulfosulfuron ± metsulfuron, mesosulfuron+iodosulfuron, isoproturon

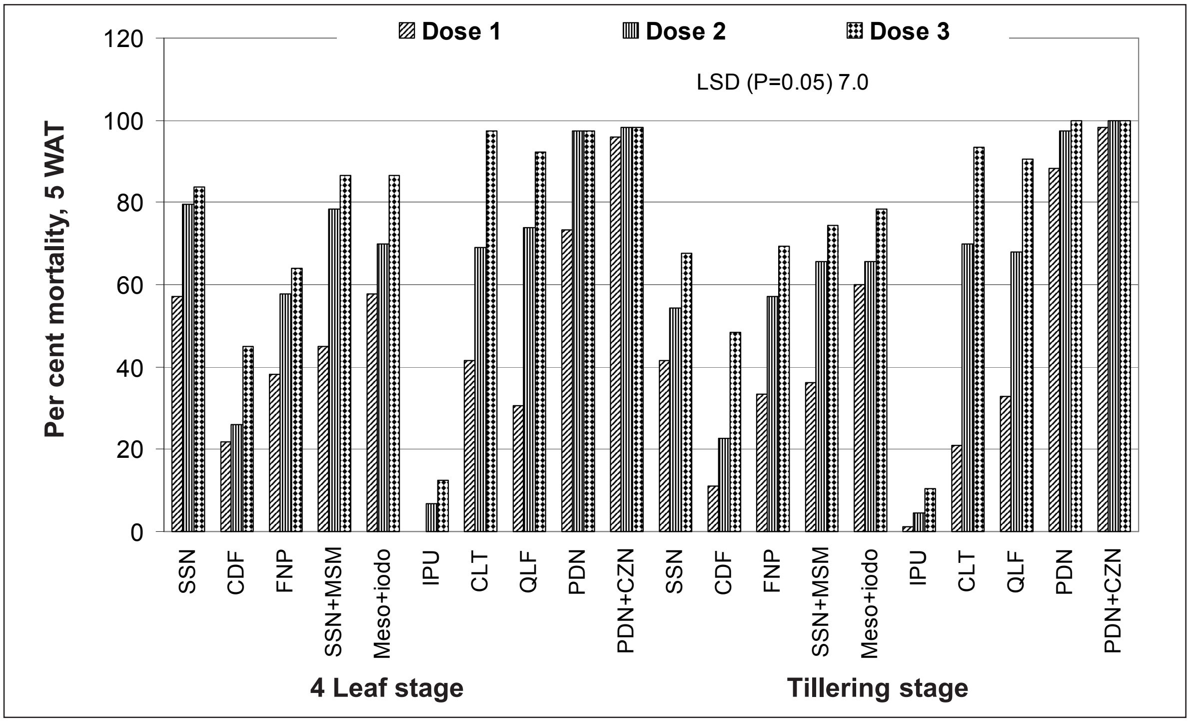

Fig. 3. Effect of different herbicides applied at two growth stages on the mortality of K-15 population of *P. minor* (SSN–Sulfosulfuron, CDF–Clodinafop, FNP–Fenoxaprop, MSM–Metsulfuron, Meso+iodo–Mesosulfuron+iodosulfuron, IPU–Isoproturon, CLT–Chlorotoluron, QLF–Quizalofop, PDN–Pinoxaden and CZN–Carfentrazone).

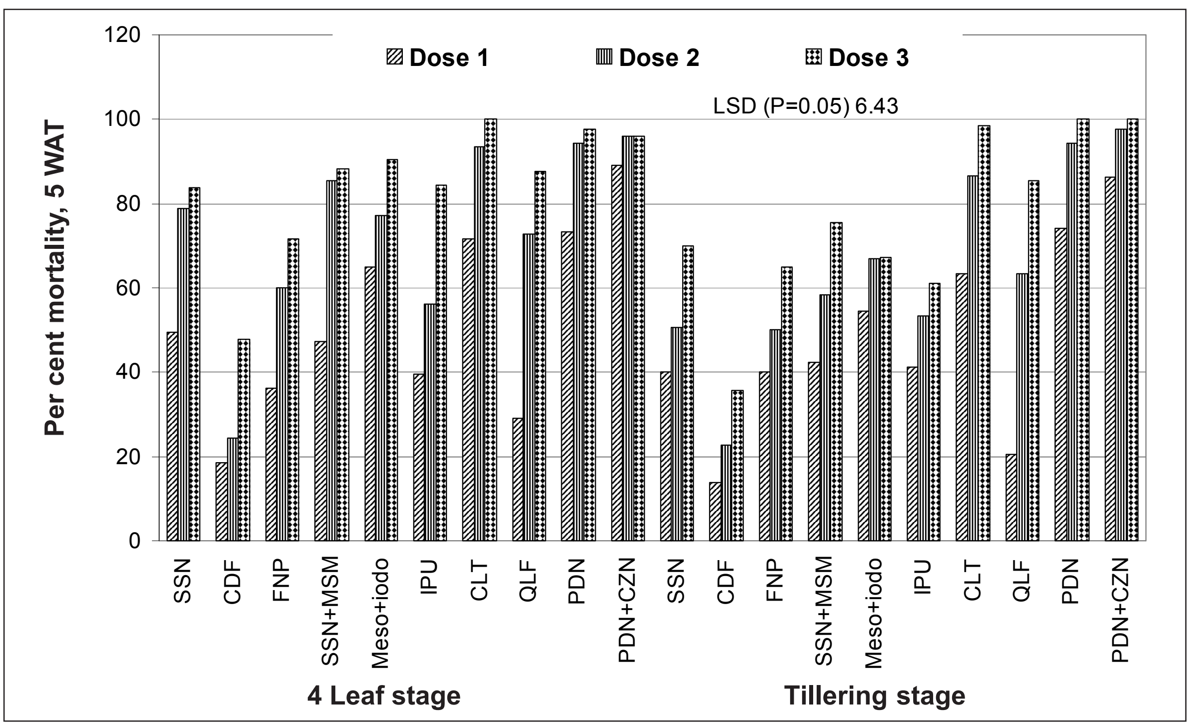

Fig. 4. Effect of different herbicides applied at two growth stages on the mortality of F-42 population of *P. minor* (SSN–Sulfosulfuron, CDF–Clodinafop, FNP–Fenoxaprop, MSM–Metsulfuron, Meso+iodo–Mesosulfuron+iodosulfuron, IPU–Isoproturon, CLT–Chlorotoluron, QLF–Quizalofop, PDN–Pinoxaden and CZN–Carfentrazone).

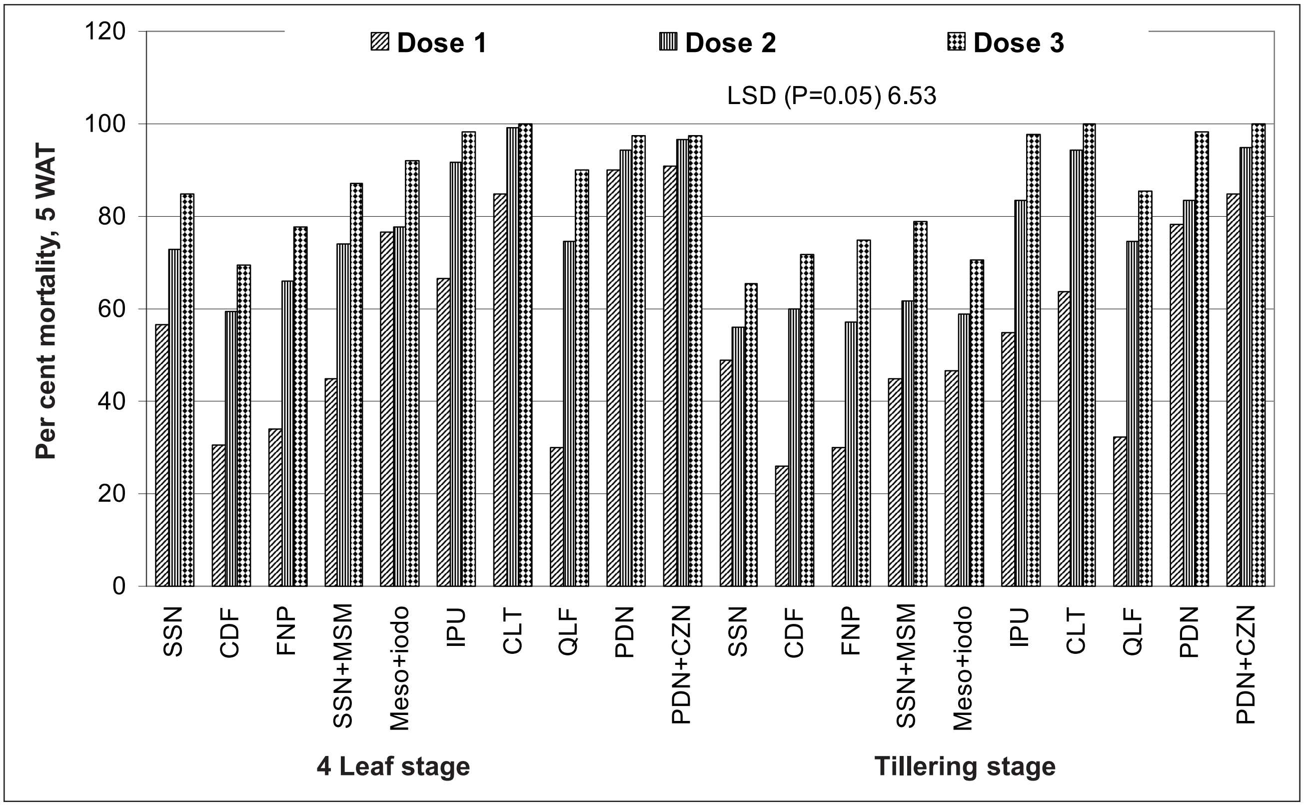

Fig. 5. Effect of different herbicides applied at two growth stages on the mortality of B-6 population of *P. minor* (SSN–Sulfosulfuron, CDF–Clodinafop, FNP–Fenoxaprop, MSM–Metsulfuron, Meso+iodo–Mesosulfuron+iodosulfuron, IPU–Isoproturon, CLT–Chlorotoluron, QLF–Quizalofop, PDN–Pinoxaden and CZN–Carfentrazone).

and chlorotoluron were applied at the tillering stage compared to the 4 leaf stage of plants (Fig. 6); no decrease in efficacy of other herbicides, however, was observed for stage of application. Mortality of H-2 population was 90 to 100% at the highest application rate of pinoxaden±carfentrazone, isoproturon, chlorotoluron and quizalofop when applied at the tillering stage; the effect of other herbicides was 70-80% at this stage (Fig. 6).

Effect on GR_{50}

The mortality data were subjected to Probit analysis to generate GR_{50} (growth reduction by 50%) values and resistance factor (GR_{50} of resistant population/ GR_{50} of susceptible population). The GR_{50} of all populations was similar or less than the susceptible population with sulfosulfuron (Table 1). With clodinafop, however, a Rf of 1.2 to 1.7 was recorded with isoproturon resistant populations of J-35, K-15 and F-42. Application of herbicides at tillering compared to the 4 leaf stage required higher GR_{50} values by the *P. minor* populations. The GR_{50} values with sulfosulfuron+metsulfuron were higher than sulfosulfuron alone, whereas the visible mortality of these populations was same or higher with the mixture. This may be due to variations in data over the years and greater than 50% mortality even at the lowest used rates. The GR_{50} values with fenoxaprop and premix of mesosulfuron+iodosulfuron were same for all the populations except some variations in isoproturon resistant populations (Rf of 1.1 to 1.4). Requirement of isoproturon for 50% growth reduction in J-35 and K-15 was 4 to 11 fold higher compared to susceptible population (Table 1). F-42 population, which has a mixture of susceptible and resistant plants to isoproturon, exhibited a Rf factor of 1.4. The GR_{50} values of isoproturon resistant populations were also higher for chlorotoluron compared to susceptible or pristine populations. All the populations exhibited similar level of dose requirement for quizalofop for reducing their growth by 50% (Table 1). Tank mixing of pinoxaden with carfentrazone caused 80-96% mortality of the test populations at the lowest used rate (40 g/ha); the higher rates produced similar

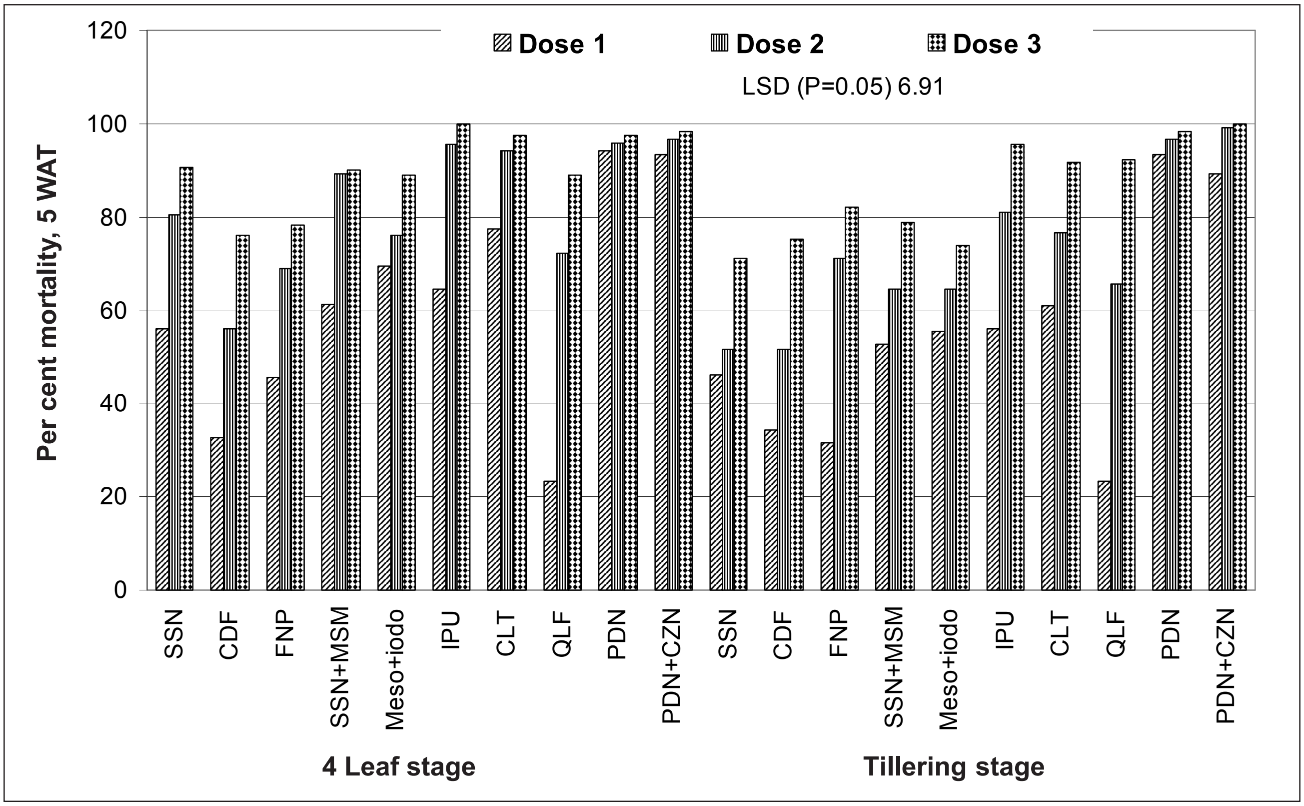

Fig. 6. Effect of different herbicides applied at two growth stages on the mortality of H-2 population of *P. minor* (SSN–Sulfosulfuron, CDF–Clodinafop, FNP–Fenoxaprop, MSM–Metsulfuron, Meso+iodo–Mesosulfuron+iodosulfuron, IPU–Isoproturon, CLT–Chlorotoluron, QLF–Quizalofop, PDN–Pinoxaden and CZN–Carfentrazone).

results with or without mixture and the same was reflected in the GR_{50} values of pinoxaden ± carfentrazone (Table 1). Some variations were observed in the GR_{50} values when pinoxaden was used alone in isoproturon resistant and pristine populations.

Effect on Dry Weight

Lowest weed dry weight was recorded with the application of pinoxaden±carfentrazone followed by chlorotoluron and mesosulfuron+iodosulfuron that was significantly less than clodinafop when the data were averaged over populations and herbicides. (Fig. 7). Significantly higher dry weight was recorded by J-35 and K-15 populations with the application of isoproturon at both the stages of application compared to H-2 or B-6 populations. Higher dry weight was recorded when plants were treated at tillering compared to the 4 leaf stage, but it was not statistically significant when averaged over populations and herbicides. Dry weight accumulation did not vary significantly among different populations with sulfosulfuron±metsulfuron, mesosulfuron+iodosulfuron, chlorotoluron, quizalofop or fenoxaprop (Fig. 7). Dry matter accumulation by different populations reflected the trend of weed mortality recorded with different herbicides.

Isoproturon was more effective when applied at 2-4 leaf stage of grassy weeds (*Avena ludoviciana* and *P. minor*) compared to its delayed application at tillering stage (Gupta *et al*., 1985; Sharma *et al*., 1985; Balyan *et al*., 1989; Yaduraju, 1991). Present results also indicate that delay in application of PSII and ALS inhibitors resulted in reduced efficacy against different *P. minor* populations. The reduction in herbicide efficacy from 4 leaf (0-1 tillers) to tillering (2-5 tillers) was less with ACCase inhibitors (clodinafop, fenoxaprop, quizalofop and pinoxaden) in the present study. Reduced efficacy of clodinafop in some populations of *P. minor* may be due to lower level of resistance as indicated in higher GR_{50} values and dry matter accumulation.

Mahajan *et al*. (2002) found significant interaction of planting dates and herbicides on the control

Table 1. Effect of stage of application and herbicides on GR_{50} of some populations of *P. minor* (Mean data of three years)

Herbicide	Population	4 Leaf stage			Tillering stage		
		GR_{50} (g)	Regression equation	Rf	GR_{50} (g)	Regression equation	Rf
Sulfosulfuron	J-35	17.92	Y= -0.9950+4.7868X	0.95	22.93	Y= -0.1550+3.7896X	1.03
	K-15	18.34	Y= -1.3325+5.0124X	0.97	23.22	Y= -2.8531+5.7493X	1.05
	F-42	19.63	Y= -2.7254+5.9749X	1.04	23.48	Y= 0.9270+4.3242X	1.06
	B-6	18.57	Y= -1.1989+4.8859X	0.98	20.85	Y=1.8340+2.4001X	0.94
	H-2	18.87	Y=-3.5441+6.6969X	1.00	22.20	Y=0.1714+3.5864X	1.00
Clodinafop	J-35	77.28	Y= -3.5460+4.5271X	1.36	71.77	Y= -10.2477+8.2156X	1.25
	K-15	84.60	Y= -3.6308+4.4780X	1.48	97.93	Y= -3.0107+4.0236X	1.70
	F-42	73.72	Y= -5.9207+5.8474X	1.29	83.83	Y= -4.4633+4.9021X	1.46
	B-6	57.85	Y= -7.4193+7.0472X	1.01	58.33	Y= -9.7887+8.3745X	1.01
	H-2	57.08	Y=-8.8525+7.8865X	1.00	57.52	Y=-7.8985+7.3296X	1.00
Fenoxaprop	J-35	115.2	Y= -2.4810+3.6290X	1.13	116.9	Y= -5.9012+5.2709X	1.06
	K-15	119.2	Y= -2.9260+3.8175X	1.17	125.4	Y= -4.0390+4.3075X	1.14
	F-42	113.4	Y= -5.7047+5.2104X	1.11	118.3	Y= -2.5418+3.6380X	1.07
	B-6	111.2	Y= -8.6554+6.6734X	1.09	116.9	Y= -8.9830+6.7615X	1.06
	H-2	102.0	Y=-5.2221+5.0892X	1.00	110.2	Y=-11.2778+7.9707X	1.00
SSN+MSM	J-35	27.75	Y= -3.0866+5.8020X	1.36	27.87	Y= -1.7532+4.6728X	1.20
	K-15	24.54	Y= -3.3590+6.0134X	1.21	28.80	Y= -1.1752+2.6206X	1.23
	F-42	23.89	Y= -3.4396+6.1233X	1.17	27.32	Y= -0.6592+3.9396X	1.17
	B-6	25.10	Y= -3.0576+5.7562X	1.23	26.15	Y= -0.8243+4.1092X	1.12
	H-2	20.36	Y=-1.4372+4.9180X	1.00	23.32	Y= 0.5991+3.2179X	1.00
Meso+iodo	J-35	8.74	Y= 2.1872+2.9873X	1.42	7.41	Y= 3.4844+1.7428X	0.89
	K-15	6.71	Y= 3.1725+2.2099X	1.09	9.26	Y= 3.1943+1.8676X	1.11
	F-42	7.52	Y= 2.3510+3.0227X	1.22	7.44	Y= 3.9328+1.2242X	0.90
	B-6	4.55	Y= 3.7241+1.9376X	0.74	10.89	Y= 2.7763+2.1444X	1.31
	H-2	6.15	Y= 3.2073+2.2715X	1.00	8.29	Y= 3.4318+1.7067X	1.00
Isoproturon	J-35	3884	Y= -8.8860+3.8687X	4.36	4628	Y= -7.6435+3.4495X	4.91
	K-15	3620	Y= -11.6293+4.6728X	4.06	10216	Y= -1.9045+1.7221X	10.85
	F-42	1225	Y= -7.2774+3.9755X	1.38	1353	Y= -0.0.2871+1.6885X	1.44
	B-6	838	Y= -11.2117+5.5458X	0.94	963	Y= -11.7344+5.6087X	1.02
	H-2	890	Y=-16.8486+7.3973X	1.00	942	Y= -9.3622+4.8289X	1.00
Chlorotoluron	J-35	1125	Y= -12.5177+5.7413X	1.72	1278	Y= -18.8145+7.6627X	1.50
	K-15	1088	Y= -17.0195+7.2512X	1.66	983	Y= -7.1703+4.0670X	1.15
	F-42	800	Y= -11.7171+5.7586X	1.22	872	Y= -10.2756+5.1951X	1.02
	B-6	657	Y= -11.2809+5.7789X	1.00	893	Y= -15.8469+7.0643X	1.04
	H-2	655	Y=-6.7724+4.1802X	1.00	854	Y= -5.0814+3.4389X	1.00
Quizalofop	J-35	68.92	Y= -1.0432+3.2873X	0.89	70.48	Y= -0.4165+2.9309X	0.89
	K-15	66.71	Y= -0.3054+2.9084X	0.87	83.91	Y= -1.5528+3.4062X	1.06
	F-42	72.00	Y= -0.4431+2.93060X	0.94	85.90	Y= -1.0999+3.1541X	1.09
	B-6	69.60	Y= -0.6951+3.0908X	0.91	68.40	Y= -0.2315+2.5977X	0.87
	H-2	76.72	Y=-1.2503+3.3160X	1.00	78.86	Y= -1.8123+3.5914X	1.00
Pinoxaden	J-35	36.22	Y= -19.6101+15.7857X	1.39	33.00	Y= -16.7740+14.3385X	1.41
	K-15	35.50	Y= -15.9928+13.5392X	1.36	29.68	Y= -11.7702+11.3888X	1.27
	F-42	36.16	Y= -18.2458+14.9187X	1.39	36.96	Y= -24.3181+18.7011X	1.58
	B-6	25.94	Y= -4.5276+6.7380X	1.00	33.94	Y= -9.8311+9.6892X	1.45
	H-2	26.05	Y= 0.2625+3.9299X	1.00	23.45	Y= -3.8744+6.4766X	1.00
Pinoxaden+ Carfentrazone	J-35	16.13	Y= -0.4053+4.4757X	0.69	13.94	Y= -0.3920+4.7121X	0.42
	K-15	16.26	Y= 0.1109+4.0371X	0.69	29.11	Y= -11.9709+11.5914X	0.88
	F-42	23.59	Y= -2.6581+5.5786X	1.00	34.00	Y= -19.0369+15.6929X	1.02
	B-6	25.53	Y= -4.8127+6.9738X	1.09	33.71	Y= -15.9417+13.7072X	1.02
	H-2	23.45	Y=-3.8744+6.4766X	1.00	33.21	Y= -18.8037+15.6463X	1.00

Rf [(resistance factor; GR_{50} of resistant popupations/GR_{50} of susceptible population (H-2)].

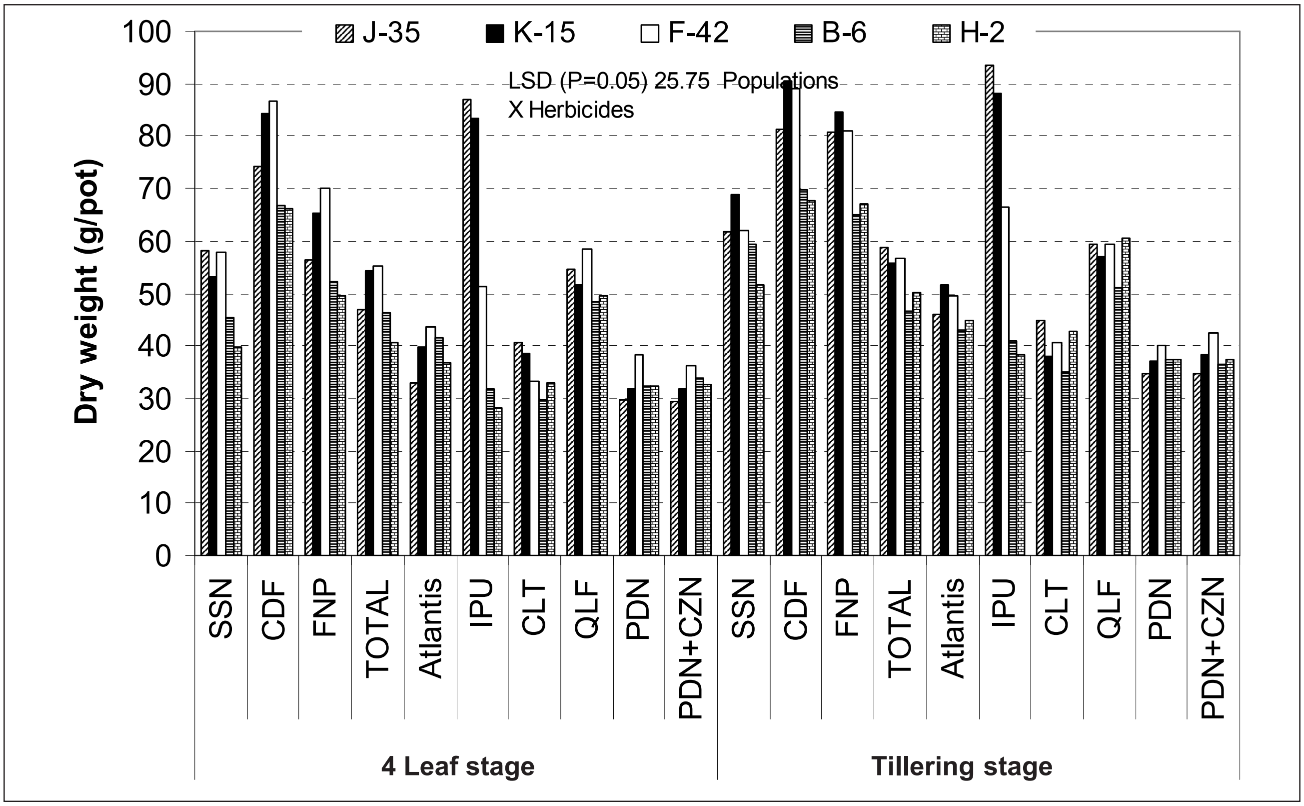

Fig. 7. Effect of different herbicides on dry weight at two growth stages of *P. minor* populations.

of *P. minor* and grain yield of wheat. Chhokar *et al.* (2001) found that application of sulfosulfuron 25 g/ha at 37 DAS was less effective on weeds than its early applications (25 or 27 DAS) and required double the dose for similar weed control and grain yield of wheat. However, Brar *et al.* (2003) and Walia and Singh (2005) reported no significant reduction in the efficacy of sulfosulfuron or mesosulfuron+iodosulfuron when applied upto 6 WAS. In the present study, efficacy of sulfosulfuron used alone or in mixture with metsulfuron resulted in reduced efficacy with delayed applications. Also there was regeneration in plants treated with sulfosulfuron or mesosulfuron+iodosulfuron irrespective of resistant or susceptible populations. This has also been observed under farmers' field and is a major cause of concern for loosing these herbicides in the management strategy for *P. minor* population in the near future. Application of these herbicides at five-tiller stage during the first year in the present study resulted in lower weed mortality compared to 2006-07 and 2007-08.

Other factors may also contribute to reduced herbicide efficacy. Walia *et al.* (2002) reported that post-emergence application of metoxuron 1.5 and 3.0 kg, diclofop-methyl 0.90 kg, tralkoxydim 0.35 kg, clodinafop 50 g, fenoxaprop-p-ethyl 100 g and sulfosulfuron 25 g/ha provided complete control of *P. minor* growing on 8.1 and 9.2 pH soils of Punjab during 1995-96 to 1997-98, whereas isoproturon 0.94 kg/ha (recommended level) was significantly inferior on slightly high pH soil as compared to normal pH soil.

Chhokar and Malik (2002) studied 10 biotypes in pots and found them resistant to isoproturon, but were effectively controlled by clodinafop, fenoxaprop and sulfosulfuron. In the present study, susceptible (H-2) and pristine (B-6) populations were effectively controlled by isoproturon and chlorotoluron, whereas J-35 and F-42 were not controlled by isoproturon, but chlorotoluron was effective against these populations. Singh *et al.* (1998) also reported that isoproturon resistant biotypes were susceptible to chlorotoluron and clodinafop. The isoproturon resistant population in the present study showed a low level of resistance to clodinafop, but not to fenoxaprop or quizalofop (not selective for wheat). This may be that these populations were collected in 2002 and may not have enough field exposure to the new herbicides. Yadav *et al.* (2006) reported a resistance factor of 1.0 to 9.3 for fenoxaprop, 1.0 to 1.9 to clodinafop and 1.0 to 1.5 for sulfosulfuron in some biotypes of *P. minor* studied in 2000-01. Higher level of resistance (multiple resistance) in some biotypes to these herbicides has been observed later on (Chhokar and Sharma, 2008; Singh *et al*., 2009). Fenoxaprop is out of marked in the resistance affected area in Haryana due to its decreased efficacy and during the current season (2010-11) even 2-3 applications of clodinafop or sulfosulfuron failed to provide satisfactory control of resistant biotypes at farmers' field (unpublished data). Higher GR_{50} (Rf of 1.3 to 1.5) of pinoxaden for different populations in the present study (Table 1) may not be due to evolution of multiple resistance as the Rf values were lower with pinoxaden+carfentrazone, but resistance to pinoxaden, even without its field exposure is possible and document in field and pot studies (Chhokar *et al.,* 2006; Singh *et al*., 2009; Dhawan *et al*., 2010). Kirkwood *et al*. (1997) reported that isoproturon resistant biotypes of *P. minor* were cross-resistant to diclofop-methyl without their field exposure to this herbicide. Tank mixing of pinoxaden with carfentrazone was more toxic to *P. minor*, though the mixture also resulted in temporary crop injury (due to carfentrazone), but can be effectively used for effective control of resistant populations of *P. minor*.

Due to large variations in different populations of *P. minor* to selective herbicides (wheat); some populations may not be controlled by a single herbicide and their rotation and tank mix application offers an opportunity for effective control under field conditions. Early application has an edge in higher *P. minor* mortality; however, emergence of multi-flushes of *P. minor* may complicate the management strategy. So far, single application (time) of herbicide was sufficient to manage *P. minor* in wheat, but this warrants reorienting the management strategy by using more than one herbicide or repeat applications based on emergence pattern of *P. minor* under field condition. Sequential application of more than one herbicide (pre-followed by post) may be required, where resistance to the existing herbicide is serious. Other agronomic practices viz., field preparation (zero or conventional), planting methods/time, seed rate, varieties, fertilizer and irrigation applications, tillage/ interculture and crop rotation contribute significantly in efficient management of *P. minor* (Singh, 2007) and need integration with herbicide for sustainable weed management.

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