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Effect of Stage of *Phalaris minor* on the Efficacy of Accord Plus (Fenoxaprop+ Metsulfuron, Readymix)

Samunder Singh, Kuldeep Singh, S. S. Punia, Ashok Yadav and Rupa S. Dhawan
Department of Agronomy
CCS Haryana Agricultural University, Hisar-125 004 (Haryana), India

ABSTRACT

Screen house and field studies were carried out at CCS Haryana Agricultural University, Hisar during 2009-10 and 2010-11 to evaluate the efficacy of ready-mix formulation of fenoxaprop and metribuzin (Accord Plus) applied at two growth stages of *Phalaris minor*. Metribuzin 150, 180 and 210 g/ha and Accord Plus 275 g a.i. /ha were compared with tank mix of pinoxaden+carfentrazone 50+20 g/ha each applied at 38 and 60 days after sowing (DAS) of wheat under field conditions during 2010-11. Delayed application resulted in 33 and 28% reduced efficiency of herbicides against *P. minor*, respectively, at 3 and 5 weeks after treatment (WAT) (data averaged over treatments). Metribuzin 150 and 180 g/ha was least effective against *P. minor* when applied 60 DAS, whereas its application at 210 g/ha and Accord Plus resulted in 44 and 16% lower mortality of *P. minor*, respectively, over their application 38 DAS. Delayed application also lowered wheat tillers resulting in lower grain yield. Wheat yield was reduced by 23 and 18% by metribuzin 210 g/ha and Accord Plus 275 g a.i./ha compared to 14% in tank mix of pinoxaden+carfentrazone when applied 60 over 38 DAS. Under screen house conditions, 19 populations of *P. minor* were evaluated at two growth stages (2-4 leaf and 4-6 leaf) with three rates of Accord Plus (137.5, 275 and 550 g a.i./ha) during 2009-10 and 2010-11. Mortality of *P. minor* populations was 44, 65 and 97% at the 4-6 leaf stage of application compared to 83, 98.5 and 100% when applied at the 2-4 leaf stage, respectively, with three rates of Accord Plus (data averaged over populations). Accord Plus 275 g a.i./ha applied at the 2-4 leaf stage provided 90-100 % control of all the populations of *P. minor*, whereas delayed application at 4-6 leaf stage provided 45 to 85% control. *P. minor* populations, Rasidan, Nangla, Barhi, Suchan Kotli and Uchana were controlled by <50% by 275 g a.i./ha of Accord Plus application at 4-6 leaf stage. *P. minor* populations, Barhi, Suchan Kotli, Koyal, Jakholi and Chanarthal were not completely knocked down by even 550 g a.i./ha of Accord Plus with delayed application at the 4-6 leaf stage. Some of these populations have already exhibited loss of efficacy against fenoxaprop and clodinafop under field conditions. Care need to be taken in timely application of Accord Plus where efficacy of one of the mixture partners (fenoxaprop) is questionable.

Key words : Resistance, application time, *Phalaris minor* stage, herbicide efficacy, tank mixture

INTRODUCTION

Grassy weeds notably *Phalaris minor* Retz and *Avena ludoviciana* Dur. are the two most competitive weeds infesting wheat in northern India. Losses caused by *P. minor* range from 5-50% but could go up to 80% under heavy infestation (Singh *et al*., 1999); similarly, decrease in wheat yield by wild oat was estimated 17-62% (Balyan *et al*., 1991). Isoproturon was more effective against *P. minor* than *A. ludoviciana* and become its own casualty due to evolution of resistance (Malik and Singh, 1995). Isoproturon resistance engulfed whole of rice-wheat rotation areas of Haryana necessitating its withdrawal because of total loss of *P. minor* control. New herbicides *viz.,* fenoxaprop-P-ethyl, clodinafop-propargyl and sulfosulfuron were recommended for the control of isoproturon resistant biotypes in 1997-98 (Chhokar and Malik, 2002), but reduced efficacy of these herbicides was observed after a few (fenoxaprop) or more repeat applications resulting in multiple resistance evolution in *P. minor* populations (Yadav *et al*., 2006; Chhokar and Sharma, 2008; Singh *et al*., 2009, 2010). Metribuzin, another PS II inhibiting herbicide was found effective against *P. minor* and other grassy and broadleaf weeds (Malik *et al*., 2005; Punia *et al*., 2005); however, its toxic effect on wheat due to higher dose or faulty application made it a limited choice herbicide among farmers. Metribuzin sensitivity to several wheat varieties is well documented (Gill and Bowran, 1990; Ratliff *et al*., 1992; Klemann and Gill, 2007). To lower the adverse effect on wheat, a new formulation, Accord Plus (22% EC) which is premix of fenoxaprop (8%) and metribuzin (14%) was found effective and was recommended for the control of complex weed flora in wheat including *P. minor* by CCS Haryana Agricultural University, Hisar during 2010-11. Metribuzin was found superior in arresting weeds growth and increasing wheat yield compared to sulfosulfuron, atrazine and tralkoxydim (Pandey and Verma, 2002). Pandey *et al*. (2006) reported that metribuzin provided highest weed control efficiency over sulfosulfuron, isoproturon or 2,4-D under mid-hills condition; the time of application, however, had significant variations in mortality of weeds with the applied herbicides. Metribuzin applied 40 DAS provided good control of *P. minor* resulting in similar yield to manual weeding, but control of *Polygonum plebijem* and *Melilotus indica* was better when applied 60 DAS. Other studies indicated that application of metribuzin at the 2-leaf stage of grass weeds was more effective. Fedoruk and Shirtliffe (2011) found that metribuzin was more effective against weeds in lentil when applied early at four node stage to avoid crop injury. Similarly, its application at the 2-leaf stage of winter wheat and 4-tiller stage of spring wheat was found better for crop safety. Stage of weed at herbicide application is important for weed control efficiency as 2-leaf stage of *P. minor* and *A. ludoviciana* proved more appropriate to achieve better control with isoproturon compared to 6-leaf weed stage (Singh and Malik, 1993; Singh *et al*., 1999). Similar results on stage of *P. minor* were observed for other graminicides (Singh *et al*., 2010). *P. minor* emerges in several flushes depending on planting time of wheat, weather conditions, moisture availability and field preparations. Under zero till conditions, emergence of first flush of *P. minor* is less compared to the conventional till sowing of wheat. Since herbicides are applied only once in wheat crop in India, time of application of herbicide is very crucial in avoiding crop-weed competition and improving weed control efficiency of the applied herbicide. There is limited information on the effect of stage of *P. minor* on the efficiency of Accord Plus. Also, it is not sure how the stage of *P. minor* will impact efficiency of Afford Plus as several populations are resistant to one of its mixture partners (fenoxaprop) under rice-wheat rotation areas (Singh *et al*., 2009, 2010; Dhawan *et al*., 2010). Present study was thus undertaken to evaluate the effect of premix formulation of fenoxaprop + metribuzin (Accord Plus 22% EC) when applied at different growth stages of *P. minor* populations collected from farmers fields with putative resistance to fenoxaprop, under pot studies in screen house conditions and susceptible population of *P. minor* and other weeds infesting wheat under field conditions, when applied at two growth stages.

MATERIALS AND METHODS

P. minor seeds collected in April 2009 from different locations of rice-wheat rotation areas (Table 1 and Plate 1) where efficacy problem with fenoxaprop-P-ethyl and clodinafop-propargyl was reported by farmers, were compared with a known susceptible population (H2 from HAU, Hisar) in the screen house. Planting of 19 populations of *P. minor* with 20 seeds in each pot was done on 11 January 2010 and 28 January 2011 in plastic pots of 20 cm height and top diameter (4.7 kg soil capacity). The field soil (sandy loam in texture with 0.4% O. C., 25 kg/ha P_2O_5, 550 kg /ha of K_2O and a pH value of 8.4) was sieved and mixed with dunal sand and vermi-compost in 4 : 2 : 1 ratio by volume. The field soil had no history of herbicide use for the last five years. A week after emergence, thinning was done and 10 plants/pot were maintained for spraying. Plants were watered by a plastic sprinkler as and when required. Accord Plus 22% EC, a premix of fenoxaprop (8%) and metribuzin (14% EC), was sprayed at 0, 137.5, 275 and 550 g a.i./ha by using a battery operated backpack sprayer fitted with two flat fan nozzle boom delivering 375 l/ha spray volume at 40 psi pressure. There were three replications for each population and herbicide treatments. Plants were sprayed at the 2-4 leaf (1-2 tillers) and 4-6 leaf (3-5 tillers) stage of *P. minor* populations. Pots were arranged in a CRD design after spraying. Visual observations on percent mortality were recorded at weekly intervals for five weeks after spraying. Since there were similar trends in herbicide effect and mortality data of five weeks after treatment from both the years were pooled and subjected to ANOVA using SPSS.

In another experiment under field conditions, wheat PBW 550 was planted at 100 kg/ha seed rate on December 15, 2010 and December 16, 2011 in a plot size of 7 x 5 m and 9.5 x 2.4 m, respectively. The field had natural infestation of grassy and broadleaf weeds with the dominance of *P. minor,* and metribuzin 150, 180 and 210 g/ha and premix of fenoxaprop+metribuzin

Table 1. Details of *P. minor* seed collected from farmer's field of Haryana state during 2008-09

S. No.	Village	District	Latitude (N)	Longitude (E)
1.	Koyal	Kaithal	29.45.134	076.10.434
2.	Rasidan	Kaithal	29.42.867	076.02.558
3.	Jakholi	Kaithal	29.38.466	076.33.984
4.	Sagga	Karnal	29.45.574	076.50.339
5.	Kutail	Karnal	29.35.082	076.59.511
6.	Uchana	Karnal	29.44.031	076.57.694
7.	Gumthala	Kurukshetra	29.56.296	076.33.918
8.	Chanarthal	Kurukshetra	30.03.936	076.52.014
9.	Barhi	Ambala	30.18.661	076.42.613
10.	Suchan Kotli	Sirsa	29.32.022	075.10.921
11.	Vaidwala	Sirsa	29.31.816	075.05.396
12.	Panjuana	Sirsa	29.37.842	074.59.297
13.	Jeevan Nagar I	Sirsa	29.32.051	074.45.197
14.	Jeevan Nagar II	Sirsa	29.32.114	074.45.189
15.	Jhinverhari	Yamunanagar	30.20.359	077.09.715
16.	Nangla I	Fatehabad	29.37.887	075.52.547
17.	Nangla II	Fatehabad	29.37.443	075.53.120
18.	Laloda	Fatehabad	29.38.246	0.75.54.337
19.	HAU	Hisar	29 08.940	075 41.087

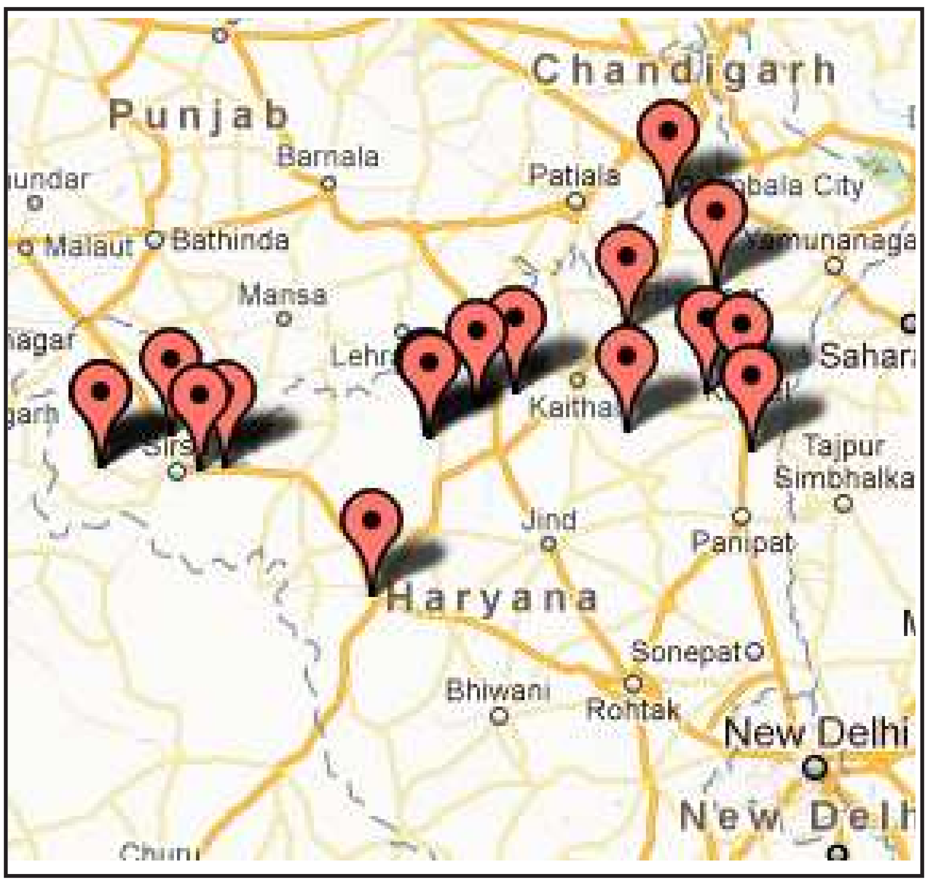

Plate 1. Map locations of *P. minor* seed collected from farmer's field sites (rice-wheat rotation areas) in Haryana used in the present study.

(Accord Plus) 275 g/ha were compared with tank mix of pinoxaden 50 g + carfentrazone 20 g/ha and a weedy check. Herbicides were sprayed at 38 and 60 days after sowing (DAS) at two growth stages of *P. minor* and other weeds using a battery operated backpack sprayer similarly as in screen house. Visual observations were recorded on weed mortality and effect on wheat was recorded by counting tiller numbers per metre row length (m. r. l.) and grain yield at harvest. Data were analyzed using SPSS and presented graphically.

RESULTS AND DISCUSSION

Screen House Conditions

Two way interactions of *P. minor* stage and populations with Accord Plus were highly significant when combined data of 19 *P. minor* populations with three doses of Accord Plus application at two growth stages were analyzed (Figs. 1-3). Similarly, interaction of populations and growth stages was significant at 1% level of significance, but three-way interactions were not significant. Increasing the rate of Accord Plus from 137.5 (half of the recommended rate) to 275 and 550 g a.i./ha resulted in 53, 98.5 and 100% mortality of *P. minor* populations (data averaged) at the 2-4 leaf stage, whereas its application at the 4-6 leaf stage resulted in 44, 65 and 97% mortality at the three rates, respectively (Figs. 1-3). *P. minor* mortality was significantly affected by three rates of Accord Plus when applied at the 4-6 leaf stage, whereas significant differences were observed only at half the recommended rates of Accord Plus when applied at the 2-4 leaf stage.

Delay in application of Accord Plus 137.5 g a.i./ ha from 2-4 to 4-6 leaf stage of Barhi (Ambala) population resulted in 33% lower mortality, followed by Sagga, Uchana (Karnal) and Suchan Kotli (Sirsa) populations of *P. minor* (Fig. 1). However, Panjuana (Sirsa)

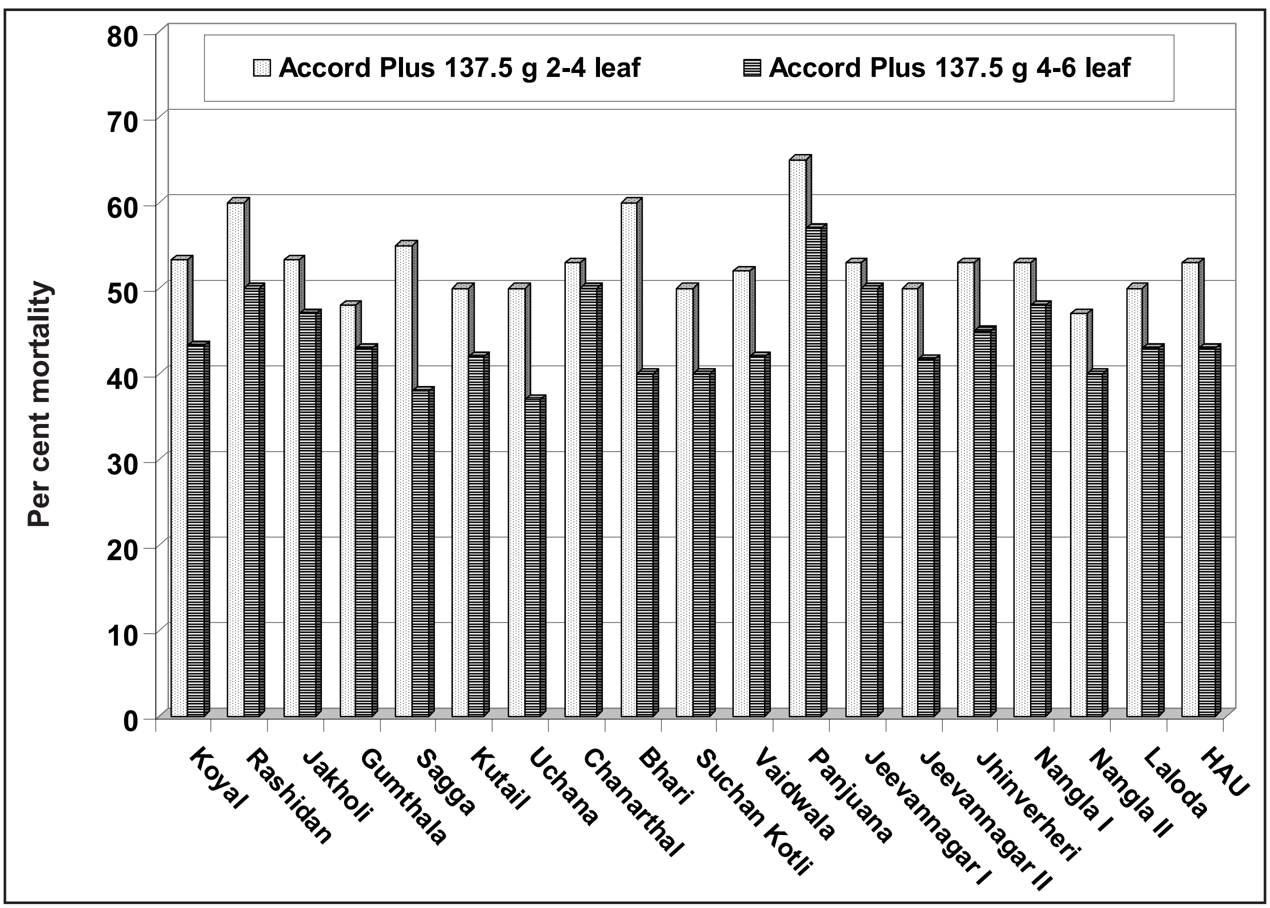

Fig. 1. Mortality of *P. minor* populations under screen house conditions with Accord Plus 137.5 g when applied at the two growth stages (mean data of two years).

population exhibited maximum mortality among the populations and delayed application also provided 57% mortality. HAU, Hisar population, which is sensitive to all the wheat herbicides, also resulted in 19% lower mortality with delayed application of Accord Plus 137.5 g a.i./ha (Fig. 1). Likewise, Vaidwala (Sirsa), Koyal (Kaithal) and Chanarthal (Kurukshetra) populations exhibited lower mortality due to 137.5 g a.i./ha of Accord Plus; the differences, however, were not statistically significant.

Mortality of *P. minor* populations increased with increase in Accord Plus rate from 137.5 to 275 g a.i./ha, but the differences with reference to application stage were more prominent (Fig. 2). The recommended rate of Accord Plus applied at the 2-4 leaf stage provided 100% control of all the populations, except Suchan Kotli, Jeevan Nagar II (Sirsa), Nangla (Fatehabad) and Jakholi (Kaithal). Application of Accord Plus 275 g a.i./ha at the 4-6 leaf stage of *P. minor* resulted in <50% mortality of Rasidan, Barhi, Suchan Kotli, Nangla and Uchana populations (Fig. 2). Accord Plus 275 g a.i./ha resulted in 34% lower control of *P. minor* populations compared to application at the 2-4 leaf stage, when data were averaged over populations (Fig. 2).

P. minor populations from Rasidan, Barhi, Uchana, Nangla and Suchan Kotli resulted in 55, 53, 50, 49 and 48% lower mortality when applied at the 4-6 leaf stage compared to 2-4 leaf stage (Fig. 2). Reduction in Accord Plus efficacy was < 20 with delayed application stage of Jeevan Nagar I, Panjuana and Jakholi populations.

Double of the recommended rate of Accord Plus was required to effectively control *P. minor* populations at delayed application stage (3-5 tillers). Even at 550 g

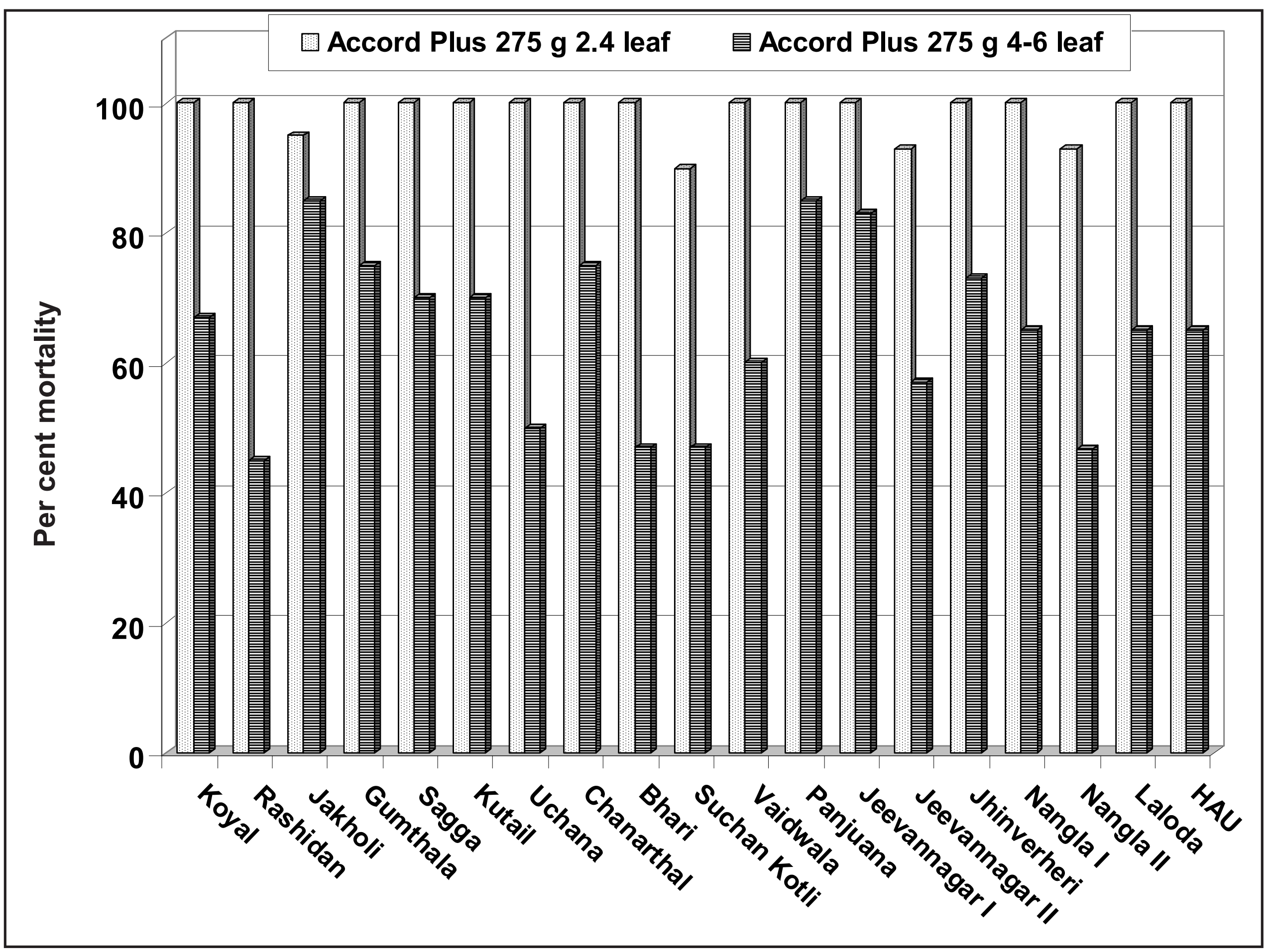

Fig. 2. Mortality of *P. minor* populations under screen house conditions with Accord Plus 275 g when applied at two growth stages (mean data of two years).

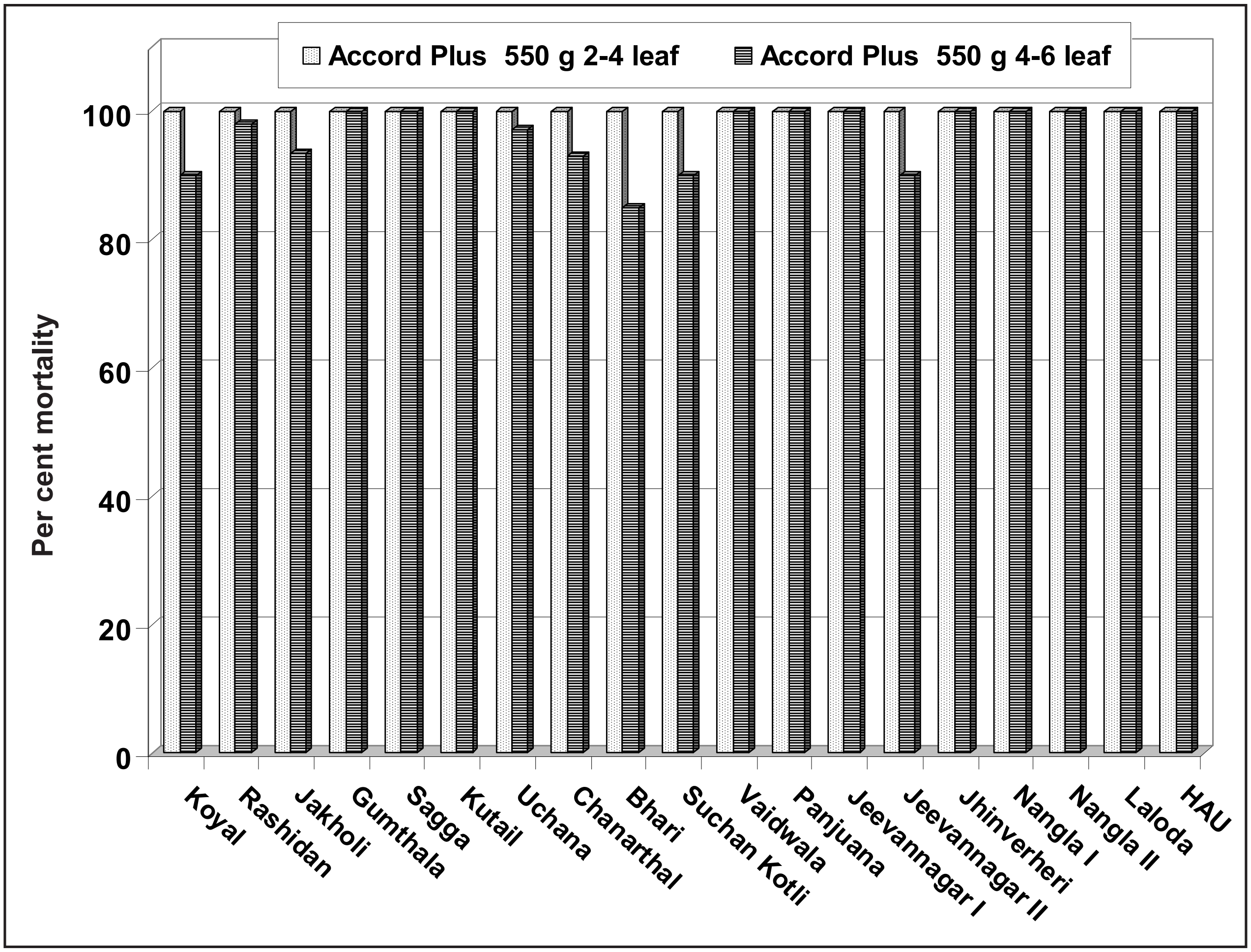

Fig. 3. Mortality of *P. minor* populations under screen house conditions with Accord Plus 550 g when applied at two growth stages (mean data of two years).

a.i./ha of Accord Plus, mortality of Barhi population was 85%; Koyal, Suchan Kotli, Chanarthal, Jakholi, Uchana and Rasidan populations also exhibited less than 100% control with delayed application (Fig. 3).

Field Conditions

There were significant differences in weed mortality influencing yield and yield parameters of wheat with application stage of herbicides. Two-way interactions of herbicides and application time were significant on *P. minor* mortality recorded at 3 and 5 weeks after treatment (WAT). All the herbicidal treatments, except metribuzin 150 g/ha provided >90% control of *Chenopodium album* and *Rumex dentatus* (data not shown). Tank mix application of pinoxaden + carfentrazone resulted in lowest control of *C. album* when applied 60 DAS over other herbicides. Maximum *P. minor* control was recorded in plots treated with pinoxaden + carfentrazone at 50+20 g/ha, which was statistically similar to Accord Plus 275 g a.i./ha, but significantly better than metribuzin alone 3 WAT when applied 38 DAS (Fig. 4). Delay in application from 38 to 60 DAS resulted in 38% lower control of *P. minor*, recorded 3 WAT compared to timely application. Delayed application reduced the efficiency of pinoxaden + carfentrazone, Accord Plus and metribuzin 210 g/ha by 17, 24 and 35% over timely application, respectively, when recorded 3 WAT. Metribuzin (150 and 180 g/ha) was not effective against *P. minor* 3 WAT (Fig. 4). Control of *P. minor* was maximum 5 WAT among all herbicidal treatments, but application at 60 DAS resulted

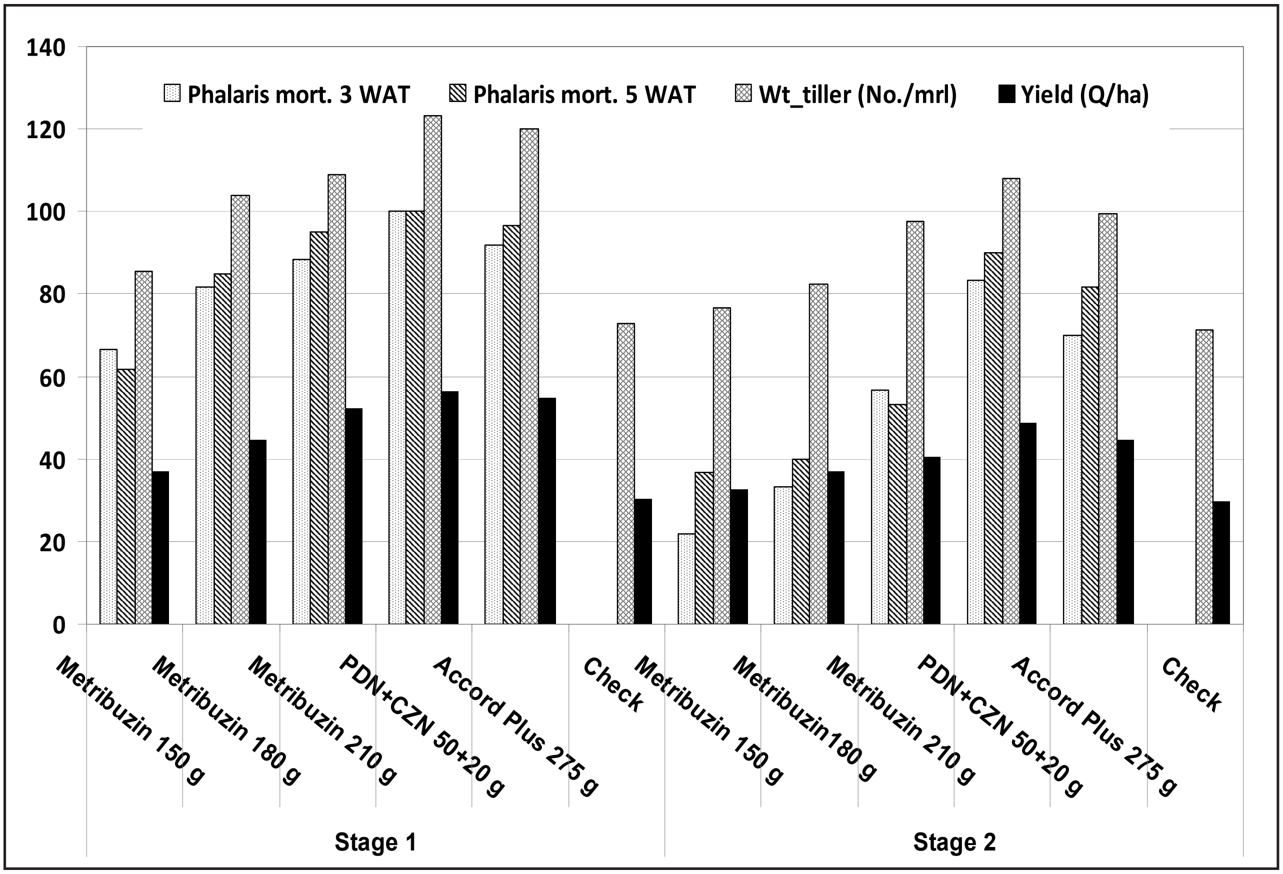

Fig. 4. Effect of metribuzin, Accord Plus and tank mix of pinoxaden+carfentrazone (PDN+CZN) on *P. minor* mortality at 3 and 5 WAT, wheat tillers and yield under field conditions (LSD P=0.05, treatments 9, 14, 18 and 8, respectively).

in 10, 15 and 44% lower mortality of *P. minor* using pinoxaden+carfentrazone 50+20 g, Accord Plus 275 g a.i./ha and metribuzin 210 g/ha, respectively, compared to their timely application (Fig. 4).

Delayed application of herbicides resulted in 13 and 15 % lower tillers/m.r.l. and wheat yield over timely application, respectively (data averaged over treatments). Maximum tillers were recorded in tank mix application of pinoxaden+carfentrazone 50+20 g/ha followed by Accord Plus 275 g a.i./ha at both the application stages, whereas delayed application resulted in 12 and 17% lower tillers, respectively, over timely application (Fig. 4). Pinoxaden+carfentrazone produced significantly, more tillers than metribuzin 150 and 180 g/ha; the differences were non-significant compared to metribuzin 210 g/ha and Accord Plus 275 g a.i./ha. Application of pinoxaden+carfentrazone 50+20 g/ha applied 38 DAS provided 56.5 q/ha grain yield of wheat which was significantly higher than untreated check and lower rates of metribuzin (150 and 180 g/ha), but statistically similar to Accord Plus 275 g a.i./ha and metribuzin 210 g/ha. Delayed application 60 DAS resulted in 14, 18 and 23% lower wheat yield with pinoxaden+carfentrazone, Accord Plus and metribuzin 210 g/ha, respectively, over their application 38 DAS (Fig. 4).

Significantly lower wheat yield in pinoxaden+ carfentrazone which provided 90 % control of *P. minor* when applied 60 DAS (Fig. 4) could be due to extended crop-weed competition over critical period compared to its application 38 DAS. Even under delayed application, this treatment provided 17 and 8% higher yield, respectively, over metribuzin 210 g/ha and Accord Plus which could be due to better control of *P. minor*. Enhanced efficacy of pinoxaden on *P. minor* when applied as tank mix application with carfentrazone has been documented earlier (Singh *et al*., 2010). Application of metribuzin beyond 210 g/ha also has been found to adversely affect wheat growth and tillering (Singh *et al*.

1999) and often results in crop injury if not properly sprayed (overlap application). However, no deleterious effect of metribuzin or Accord Plus on wheat was observed in the present study. Delayed application of metribuzin or Accord Plus resulted in reduced efficacy against *P. minor* (Fig. 4). Chhokar *et al*. (2006) reported reduced efficiency of metribuzin when applied beyond 4-5 leaf stage of *P. minor*. Significant effect of stage of weed on herbicide efficacy has been well documented for several herbicides (Singh *et al*., 1999). Balyan *et al.* (2000) recorded better efficacy of chlorsulfuron when applied at 20 than 30 DAS. Accord Plus provided 82% control of *P. minor* when applied 60 DAS compared to only 53% control by 210 g/ha of metribuzin alone and this difference could be due to the contribution of fenoxaprop as the pre mix formulation has 175 g/ha of metribuzin and 100 g/ha of fenoxaprop. Accord Plus may also result in loss of efficiency under field conditions where resistance to fenoxaprop is obvious in *P. minor* populations.

P. minor populations treated at advance growth stage (4-6 leaf or 3-5 tillers) were not effectively controlled by the recommended rate of Accord Plus (275 g a.i./ha) under pot studies (Fig. 2) is a warning for its judicious use under field conditions. Since *P. minor* emerges in more than one flush, from economical point of view, farmer tends to control these flushes with a single herbicide application which often results in delayed application. Moreover, germination is influenced by weather conditions and second or third flush is triggered by irrigation. There is no such residual herbicide which can control late emerging flushes of *P. minor* after herbicide application. Under these circumstances, it is better to have two applications of different herbicides rather than promoting resistance by applying the same herbicide twice in the growing season as is practised by many farmers. Irregular weather (temperature, cloudiness and soil moisture) conditions have also contributed to regeneration of treated plants of *P. minor* with most of the recommended wheat herbicides under field conditions; the effect is more pronounced on PS II inhibiting herbicides (isoproturon, metribuzin). Populations, where selection pressure is greater, are more prone to evolving resistance to herbicides. Dhawan *et al*. (2010) reported that fenoxaprop 120 g/ha had no effect on Rasidan population; several other populations too exhibited unacceptable control under pot studies. Other FOPS (clodinafop) and DEN (pinoxaden) herbicides were also ineffective against these fenoxaprop resistant populations of *P. minor*. Resistance in *P. minor* populations to FOPS in Pakistan (Yasin *et al*., 2011), Iran (Gherekhloo *et al*., 2011), and wild oat to FOPS (diclofop, fenoxaprop), DIMS (sethoxydim, clethodim) and DEN (pinoxaden) herbicides in Australia (Ahmad-Hamdani *et al*., 2012) implies that all the selective wheat herbicides are prone to resistance evolution. Trend from the present pot studies exhibited by some ACCase resistant populations is obviously not good for the fate of Accord Plus and it may not work if used continuously and particularly applied at late application stage of *P. minor*. An integrated approach using chemical and non-chemical approach is required to increase the shelf life of herbicide for sustainable weed control (Singh, 2007; Yasin *et al*., 2011). Sequential application of PRE (pendimethalin) followed by POE herbicides (Atlantis which is ready-mix of mesosulfuron+iodosulfuron, pinoxaden tank mix with broadleaf herbicides, sulfosulfuron+metsulfuron and Accord Plus) or two applications of POE herbicides (rotation) will be more effective in rice-wheat cropping system where reduced efficacy of fenoxaprop or clodinafop is now quite frequent. Application of Accord Plus is also subjected to sensitivity of wheat varieties and care must be taken to avoid crop injury, though in most varieties the injury is recoverable and may not cause significant yield reductions. Timely application, however, is crucial for the control of grassy and broadleaf weeds to realize full potential of herbicide and increased productivity at farmers' field.

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