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Efficacy of herbicides on broad-leaved weed and yield of wheat (*Triticum aestivum* L.)

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Abstract
A study was undertaken during *Rabi* 2016-17 at Instructional Farm of Rajasthan College of Agriculture, Udaipur to assess the Evaluation of Herbicides for Control of Broad-leaved Weeds in Wheat to identify the effective herbicides for controlling broad-leaved weed flora in wheat. The experiment consisted of eleven treatments *viz.* halauxifen methyl ester + florasulam + polyglycolat 12.76 g ha^{-1} (T_1); metsulfuron + surfactant at 4 g ha^{-1} (T_2); carfentrazoneat 20 g ha^{-1} (T_3); 2, 4-D Na Saltat 500 g ha^{-1} (T_4); 2, 4-D Esterat 500 g ha^{-1} (T_5); metsulfuron + carfentrazone + surfactantat 4 g + 20 g ha^{-1} (T_6); 2, 4-D Na + carfentrazoneat 400 g + 20 g ha^{-1} (T_7); 2, 4-D E + carfentrazone at 400 g+ 20 g ha^{-1} (T_8); halauxifen + florasulam + carfentrazone + surfactantat 10.21 g + 20 g ha^{-1} (T_9); weedy check (T_{10}); weedy free (T_{11}). All the herbicides were applied as post-emergence at 32 days after sowing. Among the herbicidal treatments, application of Halauxifen+ Florasulam+ Carfentrazone + surfactant recorded significantly lesser total broad leaf weed dry matter (2.73 g 0.5 m^{-2}), maximum broad leaf weed control efficiency (90.42 %) at 30 days. Application of Halauxifen+ Florasulam+ Polyglycol recorded minimum weed dry matter (4.67 and 6.33 g 0.5 m^{-2} during 60 days and at harvest after spraying of post-emergence herbicides, respectively), highest weed control efficiency (90.42 and 86.20% during 60 days and at harvest after spraying of post-emergence herbicides, respectively) and Minimum weed index (2.44 %). The highest grain yield (5151 kg ha-1), biological yield (12415 kg ha-1), straw yield recorded by application of halauxifen + florasulam +polyglycol followed by halauxifen + florasulam + carfentrazone + surfactant.

Keywords: Herbicides, broad-leaved weeds, wheat, yield

Introduction
Among several constraints of wheat production, weed infestation is a major one (Zimdahl, 2004). Weeds adversely affect the crop growth and yield by competing with crops for limiting resources such as light, water and nutrients (Swanton *et al*., 2015) [6]. The intensity and duration of the crop-weed competition determines the magnitude of crop yield losses (Swanton *et al*., 2015) [6]. Avoiding or reducing crop yield losses due to weed competition requires the utilization of diverse and effective weed management programs (Chauhan and Opena 2013; Swanton *et al*., 2015) [1, 6]. Weeds growing in association with irrigated and heavy fertilized crop decline its yield by 15-40 per cent or even higher besides lowering down the quality of produce by way of weed seed contamination (Yadav *et al*., 2006) [8]. Therefore, weed management is a basic requirement and major component of crop production system. Due to industrialization, labour constraints at peak growth period, small family size and under specific situations where weeds are very difficult to be removed manually, the herbicide use becomes inevitable. Conventional method of physical weed control in wheat is time consuming and labour intensive. However, the additional benefits of providing greater aeration, improving root growth enabling greater absorption of moisture and nutrients from deeper soil layers and moisture conservation cannot be ignored. The chemical control of weeds in general has been realized to be more cost effective and easy compared to manual weeding (Yadav and Malik, 2005; Garcia-Martin *et al*., 2007) [7, 2]. Herbicides form potent tool to check the mixed flora of weeds in close row crops like wheat where manual or mechanical weeding is difficult and certain grassy weeds evade farmers hoe because of botanical mimicry at early growth stage (Yasin *et al*., 2010) [9]. These necessitate evolving a strategy to screen out more herbicides to control the weed flora economically in the wheat fields on large scale. In India, herbicide shares only about 8 per cent of total pesticide consumption in country and we use an

average of only about 35 gram herbicides ha^{-1} annum^{-1} (Gupta, 2007) [3]. Keeping in view the above facts and paucity of research on above aspects the present investigation was planned to evaluate the response of wheat to application of herbicides.

Materials and Methods

The experiment was conducted at the Instructional Farm, Department of Agromomy, Rajasthan College of Agriculture, Udaipur which is situated at 24^{0}35' N latitude and 74^{0}42' E longitude. The region falls under the Agro Climatic Zone IVa of Rajasthan (*i.e*. Sub-Humid Southern Plain and Aravalli Hills). The average rainfall of Udaipur is 637 mm, most of which (80-85 %) is received through south-west monsoon during July to early September. The mean maximum and minimum humidity at Udaipur fluctuate in between 46.0 to 92.14 per cent and 10.86 to 47.0 per cent, respectively. Maximum and minimum temperature during the experimental period ranged between 20.91 ºC to 38.14 ºC and 5.64 ºC and 19.74 ºC, respectively. There was 3.0 mm rainfall received during the crop season. The soil of the experimental site was clay loam in texture and slightly alkaline in reaction. It is low in available nitrogen (287.5 kg ha^{-1}), medium in organic carbon (0.62%) and phosphorus (23.6 kg ha^{-1}) and high in available potassium (366.1 kg ha^{-1}). The experiment was laid out in Randomize Block Design and replicated thrice. Wheat variety Raj.- 4079 was used as test crop. The experiment consisted of eleven treatments *viz*. halauxifen methyl ester + florasulam + polyglycolat 12.76 g ha^{-1} (T_1); metsulfuron + surfactant at 4 g ha^{-1} (T_2); carfentrazoneat 20 g ha^{-1} (T_3); 2, 4-D Na Saltat 500 g ha^{-1} (T_4); 2, 4-D Esterat 500 g ha^{-1} (T_5); metsulfuron + carfentrazone + surfactantat 4 g + 20 g ha^{-1} (T_6); 2, 4-D Na + carfentrazoneat 400 g + 20 g ha^{-1} (T_7); 2, 4-D E + carfentrazone at 400 g+ 20 g ha^{-1} (T_8); halauxifen + florasulam + carfentrazone + surfactantat 10.21 g + 20 g ha^{-1} (T_9); weedy check (T_{10}); weedy free (T_{11}). A blanket dose of clodinafop 60 g ha-1 was applied 7 days before application of herbicidal treatments to control grassy weeds. Weed free plots were completely weed free from crop germination to harvest by manual weeding. All the herbicides were applied as post-emergence at 32 days after sowing. Ready mix herbicides were applied as per treatment through knapsack sprayer fitted with flat fan nozzle using spray volume of 500 litre ha^{-1} after calibration. Wheat variety Raj 4079 was drilled at 20.0 cm row spacing on 11th November, 2016 using 100 kg ha^{-1} seed rate. The crop was supplied 120 kg N ha^{-1} half of which was drilled in crop rows at sowing while remaining half was top dressed in two equal splits at the time of first and second irrigation. Each plot in the experiment was surveyed before herbicide application at two randomly selected places using 0.25 m^{-2} quadrate for studying weed flora composition in the experiment. To convert weed density for 0.5 m^{-2} it was doubled. The weed samples collected for recording weed density were utilized for dry matter accumulation studies. These samples were first sun-dried and then oven dried at 70 ºC till constant weight. The final dry weight of broad-leaved weeds was recorded in g 0.5 m^{-2}.

Results and Discussion

Weed Dry Matter

All herbicide combinations gave minimum weed dry matter at different growth stages compared to weedy check. However, herbicide mixtures were significantly superior to their alone application. The weed dry matter of *Chenopodium album*, *Chenopodium murale*, *Convolvulas arvensis*, *Melilotus indica* and *Fumaria parviflora* were recorded at 30 and 60 DAS. The weed biomass was significantly influenced by different weed management treatments. At 30 DAS minimum weed biomass was observed with halauxifen + florasulam + carfentrazone + surfactant (2.73 in 0.5 m^{-2}) which was statistically at par with halauxifen + florasulam + polyglycol (3.53 in 0.5 m^{-2}). However, at 60 DAS minimum dry matter (4.67 g in 0.5 m^{-2}) was recorded in plots treated with application of halauxifen + florasulam + polyglycol (1 kg + 4 g/ha) PoE which was statistically at par with halauxifen + florasulam + carfentrazone + surfactant (5.63 g in 0.5 m^{-2}) and 2, 4-D E + carfentrazone (6.88 g in 0.5 m^{-2}) (Table 2). Halauxifen-methyl is considered to mimic to plant growth hormone auxin, resulting in the disruption of growth processes in susceptible plants. Cellular effects include alterations in cell wall elasticity and gene expression. Additionally, non- productive tissue growth is induced, resulting in epinasty and phloem disruption, preventing the movement of photosynthates and causing death in days to weeks. Rest of the treatments are followed to these treatments. The results corroborate the findings of Mahmoud *et al.*, (2016) [4] and Progress report, All India Coordinated Research Project on Wheat and Barley Improvement (2017) [5].

Table 1: Effect of herbicides on weed dry matter (g 0.5 m-^{2}) before spray

Treatments	*Chenopodium album*	*Chenopodium murale*	*Convolvulus arvensis*	*Melilotus indica*	*Fumaria parviflora*	Total
Halauxifen+ Florasulam+ Polyglycol	2.63	3.80	1.07	2.20	2.80	12.50
Metsulfuron+ Surfactant	2.73	3.47	1.33	2.40	2.63	12.56
Carfentrazone	3.00	3.77	1.20	2.00	2.67	12.63
2,4-D Na Salt	2.93	4.00	1.13	2.87	3.33	14.27
2,4-D Ester	2.60	3.20	1.33	3.27	4.13	14.53
Metsulfuron+ Carfentrazone + Surfactant	2.60	3.73	1.07	2.40	3.67	13.47
2,4-D Na+ Carfentrazone	2.60	3.80	1.13	2.53	2.80	12.87
2,4-D E+ Carfentrazone	2.87	3.93	0.93	2.53	3.40	13.67
Halauxifen+ Florasulam+ Carfentrazone + surfactant	2.47	3.73	0.80	2.80	3.33	13.13
Weedy check	2.63	3.73	1.07	2.70	3.20	13.33
Weed free	0.00	0.00	0.00	0.00	0.00	0.00
SEm±	0.20	0.29	0.21	0.50	0.61	0.76
CD (P=0.5)	0.59	0.86	0.62	1.48	1.79	2.25

Table 2: Effect of herbicides on weed dry matter (g 0.5 m^{-2}) at 30, 60 Days after spray and at harvest

Treatments	*Chenopodium album* (Days after sray)			*Chenopodium murale* (Days after sray)			*Convolvulus arvensis* (Days after sray)			*Melilotus indica* (Days after sray)			*Fumaria parviflora* (Days after sray)			Total (Days after sray)		
	30	60	At Harvest	30	60	At Harvest	30	60	At Harvest	30	60	At Harvest	30	60	At Harvest	30	60	At Harvest
Halauxifen+ Florasulam+ Polyglycol	0.80	1.10	1.87	1.10	1.33	1.70	0.60	0.73	0.85	0.37	0.47	0.67	0.67	1.03	1.25	3.53	4.67	6.33
Metsulfuron+ Surfactant	2.20	3.53	3.93	2.97	4.33	4.97	0.92	1.10	1.20	1.00	1.57	2.10	1.53	2.33	2.77	8.62	12.87	14.97
Carfentrazone	2.47	4.07	4.63	3.60	5.00	6.07	1.00	1.22	1.42	1.07	2.07	2.63	1.87	2.93	3.30	10.00	15.28	18.05
2,4-D Na Salt	2.47	4.27	4.93	3.90	5.20	6.03	1.07	1.33	1.77	1.27	2.50	3.20	2.07	3.53	4.07	10.77	16.83	20.00
2,4-D Ester	2.20	3.53	4.17	3.25	4.67	5.47	0.93	1.10	1.27	1.03	2.00	2.50	1.67	2.47	3.10	9.08	13.77	16.50
Metsulfuron+ Carfentrazone + Surfactant	1.60	2.27	2.77	2.33	3.33	4.07	0.77	0.93	1.07	0.67	1.13	1.47	1.23	2.00	2.30	6.60	9.66	11.67
2,4-D Na+ Carfentrazone	1.73	3.00	3.47	2.60	3.67	4.40	0.87	1.03	1.12	0.80	1.33	1.70	1.33	2.20	2.53	7.33	11.23	13.22
2,4-D E+ Carfentrazone	1.00	1.73	2.10	1.37	2.13	2.40	0.70	0.85	1.00	0.40	0.60	0.93	0.97	1.57	1.93	4.43	6.88	8.37
Halauxifen+ Florasulam+ Carfentrazone + surfactant	0.77	1.50	1.97	0.83	1.73	1.80	0.33	0.78	0.90	0.30	0.52	0.83	0.50	1.10	1.37	2.73	5.63	6.87
Weedy check	9.30	11.83	12.93	9.47	11.93	13.07	2.98	3.25	3.40	3.03	4.23	4.97	5.23	7.00	7.87	30.02	38.25	42.23
Weed free	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SEm±	0.16	0.21	0.16	0.16	0.32	0.22	0.05	0.07	0.08	0.06	0.07	0.11	0.10	0.12	0.19	0.35	0.36	0.18
CD (P=0.5)	0.47	0.62	0.47	0.48	0.93	0.65	0.16	0.21	0.23	0.19	0.21	0.32	0.30	0.36	0.57	1.02	1.06	0.54

Weed control efficiency

The weed control efficiency showed the efficacy of herbicides with respect to controlling weeds over weedy check. Data (Table 3) revealed that the greatest weed control efficiency (90.42%) among treatments was achieved by halauxifen + florasulam + carfentrazone + surfactant followed by application of halauxifen + florasulam + polyglycol (87.07%), 2, 4-D E + carfentrazone (83.89 %), metsulfuron + carfentrazone + surfactant (77.36%), 2, 4-D Na + carfentrazone (74.53%) and metsulfuron + surfactant (70.40%) except weed free at 30 days after spray (Table 2). At 60 after spray and harvest highest weed control efficiency (86.22%) among treatments was achieved by halauxifen + florasulam + polyglycol followed application of halauxifen + florasulam + carfentrazone + surfactant (84.16%), 2, 4-D E + carfentrazone (80.85%),metsulfuron + carfentrazone + surfactant (73.79%) and 2, 4-D Na + carfentrazone (69.82%) except weed free (Table 3). The data clearly explained that the post-emergence application of halauxifen+ florasulam + polyglycol 12.76 g ha^{-1} at 32 DAS gave higher degree of control (87.07, 86.22 & 83.57 % at 30, 60 days after spray& at harvest, respectively) of total weeds. This can be reasoned to reduced weed density and weed dry matter under the effect of this herbicide sequence. The results corroborate the findings of Mahmoud *et al.*, (2016) [4] and Progress report, All India Coordinated Research Project on Wheat and Barley Improvement (2017) [5].

Table 3: Effects of herbicides on weed control efficiency (%) at 30, 60 days after spray and at harvest

Treatments	*Chenopodium album*			*Chenopodium murale*			*Convolvulus arvensis*			*Melilotus indica*			*Fumaria parviflora*			Average		
	30	60	At harvest	30	60	At harvest	30	60	At harvest	30	60	At harvest	30	60	At harvest	30	60	At harvest
Halauxifen+ Florasulam+ Polyglycol	91.35	90.69	85.55	88.39	88.80	86.92	80.37	77.33	74.96	88.01	89.05	86.55	87.22	85.23	83.88	87.07	86.22	83.57
Metsulfuron+ Surfactant	76.32	70.10	69.54	68.64	63.56	61.79	69.17	66.02	64.64	67.12	62.91	57.73	70.75	66.62	64.53	70.40	65.84	63.65
Carfentrazone	73.47	65.47	64.15	61.97	58.24	53.37	66.40	62.44	58.36	64.76	51.06	47.10	64.39	58.13	57.52	66.20	59.07	56.10
2,4-D Na Salt	73.44	63.87	61.73	58.77	56.30	53.60	64.02	58.99	47.83	58.07	40.77	35.39	60.46	49.50	47.64	62.95	53.88	49.24
2,4-D Ester	76.38	70.11	67.69	65.63	60.79	57.91	68.78	65.86	62.86	65.79	52.55	49.60	68.09	64.77	60.12	68.93	62.81	59.64
Metsulfuron+ Carfentrazone + Surfactant	82.75	80.99	78.48	75.39	72.18	68.70	74.23	71.29	68.54	78.03	73.17	70.51	76.38	71.33	70.62	77.36	73.79	71.37
2,4-D Na+ Carfentrazone	81.37	74.70	73.14	72.52	69.26	66.29	70.90	68.16	66.97	73.29	68.44	65.76	74.55	68.53	67.36	74.53	69.82	67.91
2,4-D E+ Carfentrazone	89.18	85.30	83.75	85.54	82.04	81.53	76.43	73.67	70.54	86.75	85.66	81.13	81.56	77.57	75.14	83.89	80.85	78.42
Halauxifen+ Florasulam+ Carfentrazone + Surfactant	91.76	87.33	84.77	91.17	85.45	86.24	88.54	75.89	73.48	90.16	87.84	83.19	90.44	84.29	82.41	90.42	84.16	82.02
Weedy check	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Weed free	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Weed Index

The data (Table 4) showed that the lowest weed index (2.44 per cent) was achieved by halauxifen + florasulam + polyglycol and it statistically at par with application of halauxifen + florasulam + carfentrazone + surfactant (3.13 %), 2, 4-D E + carfentrazone (3.16 %), metsulfuron +

carfentrazone + surfactant (4.90 %), 2, 4-D Na + carfentrazone (5.03 %) and metsulfuron + surfactant (6.66 %) (Table 4). The data clearly explained that the post-emergence application of halauxifen + florasulam + polyglycol 12.76 g ha^{-1} at 32 DAS gave higher degree of control (2.44 % weed index) of total broad-leaved weeds. This can be reasoned to reduce the weed dry matter under the effect of this herbicide sequence. The results corroborate the findings of Mahmoud *et al.*, (2016) [4] and Progress report, All India Coordinated Research Project on Wheat and Barley Improvement (2017) [5].

Table 4: Effects of herbicides on weed index

Treatments	Weed index (%)
Halauxifen+ Florasulam+ Polyglycol	2.44
Metsulfuron+ Surfactant	6.66
Carfentrazone	13.17
2,4-D Na Salt	12.76
2,4-D Ester	12.45
Metsulfuron+ Carfentrazone + Surfactant	4.90
2,4-D Na+ Carfentrazone	5.03
2,4-D E+ Carfentrazone	3.16
Halauxifen+ Florasulam+ Carfentrazone + Surfactant	3.13
Weedy check	22.42
Weed free	0.00
SEm±	3.35
CD (P = 0.5)	9.88

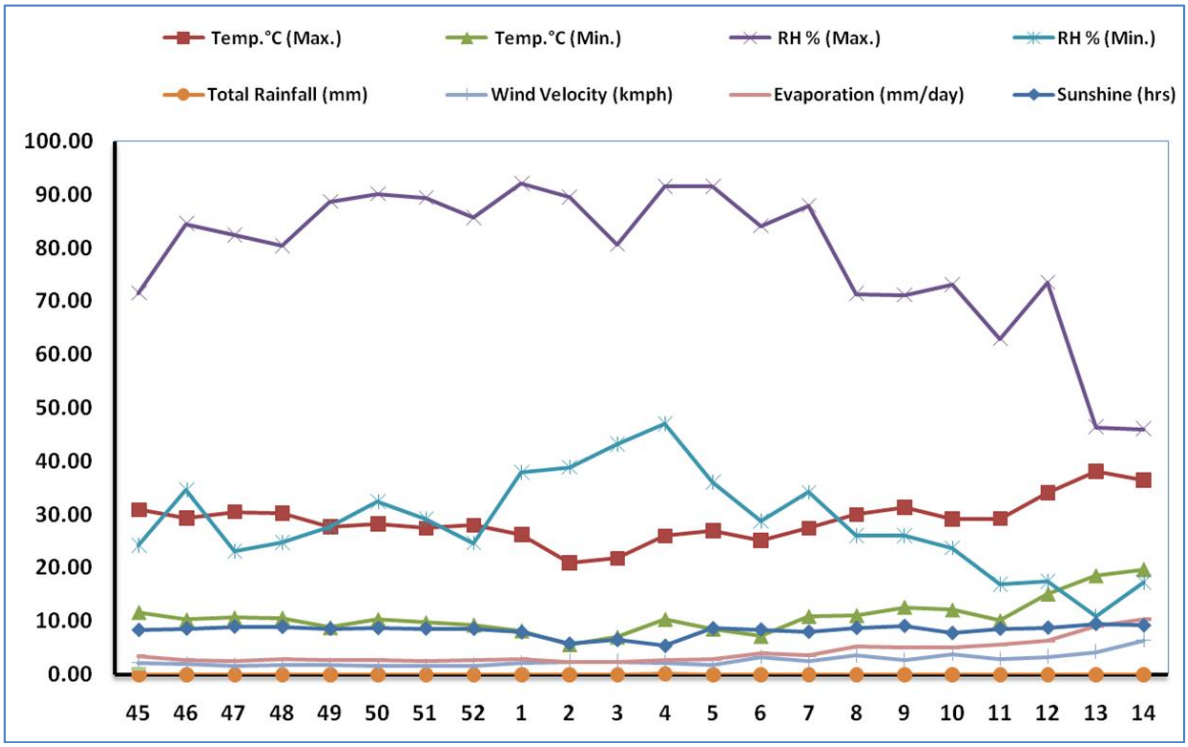

Fig 1: Mean weekly weather parameter during the crop growth period of *Rabi* 2016-17

Yield

The data showed that highest grain yield (5151 kg ha^{-1}) was obtained by halauxifen + florasulam +polyglycol, which was followed by halauxifen + florasulam + carfentrazone + surfactant (5117 kg ha^{-1}). Maximum biological yield (12415kg ha^{-1}) was recorded by controlling weeds through halauxifen + florasulam + polyglycol while maximum straw yield was also obtained by application by halauxifen + florasulam + polyglycol (7264 kg ha^{-1}). Weed control brought down competition and created congenial micro-environment for better establishment and growth of wheat crop. The herbicide sequence comprising halauxifen + florasulam + polyglycol 12.76 g ha^{-1} increased grain, straw and biological yield and its better weed control provided all favourable conditions like increased availability of nutrients, moisture, light and other factors to the crop which in turn resulted in higher dry matter production. The results corroborate the findings of Mahmoud *et al.*, (2016) [4] and Progress report, All India Coordinated Research Project on Wheat and Barley Improvement (2017) [5].

Conclusion

It can be concluded that the ready mix application of halauxifen + florasulam + polyglycolat (12.76 g ha^{-1}), halauxifen methyl ester + florasulam + carfentrazone + surfactant(10.21 g + 20 g ha^{-1}) and tank mix application of 2, 4-D E + carfentrazone, metsulfuron + carfentrazone + surfactant, 2, 4-D Na + carfentrazone and metsulfuron + surfactant at 32 DAS may be used for the effective control of broad-leaved weed in wheat crop as these herbicides resulted in significant reduction in weed density and dry matter along with significantly higher grain yield.

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