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Bio-efficacy evaluation of herbicides and their mixtures on broad leaf weeds in wheat

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Abstract
A field experiment was conducted during *Rabi* 2016-17 at Agronomy Research Farm of CCS Haryana Agricultural University, Hisar. The experiment comprised of five post emergence herbicides (metsulfuron, carfentrazone, 2, 4-D Ester, pyroxsulam and halauxifen) and their mixtures at different doses along with weedy check and weed free treatment. Major weed flora in experiment includes *Anagallis arvensis, Chenopodium album, Melilotus indicus, Medicago denticulata, Rumex dentatus* etc. Application of the herbicides halauxifen + pyroxsulam at 23.96 g/ha, metsulfuron + 2, 4-D Ester at (3 + 500 g/ha) and halauxifen + pyroxsulam at 19.17 g/ha significantly increased the dry matter accumulation of wheat and plant height at harvest compared to weedy check. Application of halauxifen + pyroxsulam at 23.96 kg/ha, metsulfuron + 2, 4-D Ester at 3 + 500 g/ha and carfentrazone + 2, 4-D Ester at 15 + 500 g/ha resulted into higher number of tillers per meter row length. Application of halauxifen + pyroxsulam sprayed at 23.96 g/ha at 35 days after sowing was the most effective treatment to control the weeds in wheat with higher grain yield of 5395 kg/ha, straw yield of 8466 kg/ha and biological yield of 13861 kg/ha with highest weed control efficiency followed by metsulfuron + 2, 4-D Ester at 3 + 500 g/ha and carfentrazone + 2, 4-D Ester at 15 + 500 g/ha.

Keywords: Wheat, herbicide efficacy, broad leaf weeds, carfentrazone, halauxifen, metsulfuron, pyroxosulam, weed control efficiency

Introduction
Wheat (*Triticum aestivum* L.) is one of the most important cereal crop and staple food in India after rice. For food security, its assured production and supply are necessary. The annual wheat production has been estimated at 103.60 million tonnes from 29.32 million hectare (13.43% of global area) registering an all-time highest crop productivity of 3533 kg ha^{-1} (ICAR-IIWBR 2019 [5], Director's Report of AICRP on wheat and barley). In Haryana, it is grown over an area of about 2.56 million hectares with production of 12.4 million tonnes and a productivity of 4841 kg/ha (Anonymous, 2018) [1]. There is hardly any scope for expansion of area under wheat and the main emphasis would be on increasing the productivity of wheat by adopting the improved cultivation practices. The productivity of wheat in most of the northern states i.e. Punjab, Haryana and U.P. etc. has stagnated. There are number of factors responsible for the stagnation of wheat productivity, among these weeds contribution is maximum. If agronomic practices are fine tuned and weeds are managed properly, the wheat productivity can be enhanced further.

Weeds are one of the major constraints in achieving potential yield of wheat. The losses caused by weeds vary with the weed species, their density and environmental factors. Wheat is generally infested with both grassy and broadleaf weeds depending upon environmental conditions like humidity, temperature and moisture availability, type of soil, cultural practices and crop rotation adopted. Several grassy and broadleaf weeds infest wheat causing severe competition for essential nutrients, moisture and space thus reducing wheat yield and also its quality significantly. Among broadleaf weeds, toothed dock (*Rumex dentatus*) and field bindweed (*Convolvulus arvensis*) are also a major problem in wheat crop. Adoption of high yielding dwarf wheat varieties combined with increased use of chemical fertilizers and improved irrigation facilities have resulted in shifts in weed flora in wheat crop. Broadleaf weeds are becoming a problem in area where grassy herbicides (clodinafop, fenoxaprop and pinoxaden) without supplementing with broadleaf weed herbicides are used continuously.

Weed management is one of the major input costs of crop production. In wheat, the earlier period up to 30-40 days is critical period for weed control. Weeds can be controlled by adopting different methods; however, each weed control method has its limitations. Mechanical methods are laborious and time consuming, besides weeds with similar morphological characters like crops are likely to be escaped. Because of higher economic cost of labour for manual weeding and its lower efficacy, farmers are relying heavily on herbicides for effective weed control in different crops including wheat. Generally, a herbicide is more effective against some of the weeds and less or not effective against others. Herbicides have benefited the agricultural community in many ways; however, heavy reliance on herbicides creates an environment favourable for weed resistance to herbicides, weed population shifts and off-site movements of herbicides (Rao and Nagmani, 2010) [12]. A number of weed species that were once susceptible to and easily managed by certain herbicides have developed resistance with time. These weeds are no longer controlled by application of previously effective herbicides. As a result the repeated use of a specific type of a herbicide on a same land has developed resistance in some type of weeds to these chemicals. Extensive use of isoproturon over many years has led to the evolution of resistance in *Phalaris minor* in north-west India. Therefore, continued use of isoproturon after the development of resistance resulted in heavy build-up of *Phalaris minor* population and caused heavy yield losses in wheat (Chhokar and Malik, 2002) [2]. The control of weeds through chemicals is considered more suitable as they cover more area during short period of time. Keeping the importance of these circumstances in view, it is necessary to select suitable chemicals capable of controlling effectively and economically all the weeds present in wheat field. Nowadays, herbicides such as pendimethalin, metribuzin, 2, 4-D etc, are used for weed control in wheat along with cultural and mechanical methods.

For control of broadleaf weeds in wheat, three major herbicides used in India are metsulfuron, 2, 4-D and carfentrazone (Chhokar *et al*., 2007) [4]. Also, some of the post-emergent contact herbicides like carfentrazone-ethyl, are less effective on weeds having advanced stage, as well as, unable to control the subsequent weeds emerging after application due to its lack of residual activity (half-life of carfentrazone is 2-5 days) in soil (Lyon *et al*., 2007, Willis *et al*., 2007) [7, 16]. However, the sole dependence on herbicide of single mode of action is also not advisable as it has contributed to shift towards difficult-to-control weeds and the rapid evolution of multiple herbicide resistance, which is a threat to wheat production (Malik and Singh, 1995; Singh, 2007) [9, 13]. As the introduction of herbicides with new mode of action has slowed down, therefore, there is need to use mixture of existing herbicides in a way to lower the load on environment and improve weed control efficacy without any adverse effect on crop. Also, the cost of application is increased in sequential application and efforts should be made to use a suitable combination of more than one herbicide to combat noxious weeds like *Phalaris minor* along with broadleaf weeds by lowering the cost of herbicide without losing weed control efficacy (Singh, 2009; Singh *et al*., 2011) [14, 15]. The benefits and consequences of herbicides mixtures are apparent and should be adhered to while recommending a mixture of more than one herbicide (Singh, 2009; Singh *et al*., 2011) [14, 15]. To broaden the spectrum of weed kill and to provide the long term residual weed control, use of herbicide mixture combinations is advisable. Herbicide mixture besides providing control of complex weed flora will also help in managing and delaying the herbicide resistance problem. Greater knowledge of herbicide mixtures against weeds in wheat crops may allow a better understanding of differences occurred among various studies and would aid in development of weed management strategies as components of more comprehensive integrated weed management programs. Since, limited information is available on herbicide mixtures to control broad leaf weeds in wheat, the present study was carried out to evaluate the bio-efficacy of some herbicides and their mixtures on broad leaf weeds in wheat.

Materials and Methods

A field experiment was conducted during *Rabi* season of 2016-17 at Agronomy Research Farm of CCS Haryana Agricultural University, Hisar. The experimental site is located at 29°16’N latitude and 75°7’E longitude at the mean sea elevation of 215.2 m in north-west part of India. The climate of the area is semiarid type, with very hot summers and relatively cool winters. The main characteristics of climate in Hisar are dryness, extremes of temperature, and scanty rainfall. The maximum daytime temperature during the summer varies between 40 and 46 °C (104 and 115 °F). During winter, its ranges between 1.5 and 4 °C. Relative humidity varies from 5 to 100%. Hisar is located on the outer margins of the south-west monsoon region. The average annual rainfall is around 429 mm (16.9 in), most of which occurs during July and August. The texture of the surface soil of the experimental field was sandy loam, that was low in organic carbon and nitrogen, medium in available phosphorus, high in potassium and slightly alkaline (pH 7.73) in reaction. Sowing of wheat variety WH 1105 was done on 04.11.2016 by seed-cum-fertilizer drill with a spacing of 20 cm from line to line at 5-6 cm depth using 100 kg seed ha^{-1} and the crop was harvested on 11.04.2017. The experiment comprised of five post emergence herbicides (metsulfuron, carfentrazone, 2, 4-D Ester, pyroxsulam and halauxifen) and their mixtures at different doses along with weedy check and weed free treatment (Table 1). All the herbicides and their mixtures were applied at 35 days after sowing of the crop by using flat fan nozzle mounted on a knapsack sprayer with a spray discharge of 375 liter/ha. The experiment was laid in randomized block design with three replications. Observations for total weed density were recorded by randomly placing quadrate (0.25 m^2) in each plot at different intervals. Major weed flora in experiment includes *Anagallis arvensis*, *Chenopodium album*, *Melilotus indicus*, *Medicago denticulata*, *Rumex dentatus* and other miscellaneous weeds (*Lathyrus aphaca, Convolvulus arevensis*, *Cirsium arvense* etc.). For calculating dry matter accumulation (g/m^2) of weeds, the weeds taken with a quadrate were dried in oven at 65 ± 5 ^{0}C. The dried samples were weighed and expressed as g/m^2. Weed control efficiency was calculated with the help of formula:

$$WCE\ (\%) = \frac{W_2 - W_1}{W_2} \times 100$$

Where,
W_2 = Dry weight of weeds in weedy check plot
W_1 = Dry weight of weeds in treatment plot

The experimental data were statistically analyzed by the methods of analysis of variance (ANOVA) as described by Panse and Sukhatme (1985) [10].

Results and Discussion

Efficacy of herbicides on broad leaf weeds

The population of weeds was significantly lower in the treatments of weed free (0/m^2) followed by 2, 4-D Ester at 500 g/ha and pyroxsulam at 18.75 g/ha (Table 1, 2 & 3). *Chenopodium album* population was observed to significantly reduced in all the treatments where the herbicides were sprayed in mixture forms as compared to sole application of metsulfuron, carfentrazone, pyroxsulam and halauxifen in wheat at 60 and 120 days after sowing. At 60 and 120 days after sowing, *Medicago denticulate*, *Anagallis arvensis* and *Melilotus indicus* along with miscellaneous weeds were successfully controlled by the herbicide mixture sprayed at 35 days after sowing (Table 1, 2 & 3). The herbicide mixtures, halauxifen + pyroxsulam (23.96 g/ha); metsulfuron + carfentrazone (4+20 g/ha), metusulfuron + 2, 4-D Ester (3+500 g/ha) and carfentrazone + 2, 4-D Ester (15 + 500 g/ha) were at par with weed free (0 plant/m^2). The significant of herbicide mixture haluxifen + pyroxsulam at 23.96 g/ha sprayed at 35 days after sowing was observed to control the population of *Rumex dentatus* at 60 days after sowing and was found at par with the weed free treatment.

The dry weight of the broad leaf weeds at 60 and 120 days after sowing was significantly reduced by the post emergence herbicides and their mixture and the most prominent herbicides mixtures treatment which reduced the dry matter (2.6 g/m^2) of the broad leaf weeds was halauxifen + pyroxulam at 23.96 g/ha as compared to weed check (10.96 g/m^2). Highest weed control efficiency was estimated under weed free conditions (100.0%) at 60 and 120 days after sowing followed by halauxifen + pyroxsulam at 23.96 g/ha, carfentrazone + 2, 4-D Ester at 15 + 500 g/ha, metsulfuron + 2, 4-D Ester at 3 + 500 g/ha and metsulfuron + carfentrazone at 4 + 20 g/ha and lowest among the herbicides pyroxsulam at 18.75 g/ha as compared to weedy check (Table 4). The herbicides like metsulfuron, carfentrazone, 2, 4-D Ester, pyroxasulam and halauxifen all were systemic and can control the weeds efficiently. However, halauxifen + pyroxsulam at 23.96 g/ha resulted into maximum weed control efficiency than the other herbicides and their mixtures. The reason may be the synergistic effect of the herbicides to control the associated weeds in wheat. Similar results have been reported by Mahamoud *et al*. (2016) [8].

Table 1: Effect of herbicides and their mixtures on population of *Anagallis arvensis* and *Chenopodium album* weeds in wheat

Treatments	Dose	*Anagallis arvensis* population (No./m^2)			*Chenopodium album* population (No./m^2)		
		30 DAS	60 DAS	120 DAS	30 DAS	60 DAS	120 DAS
T_1: Metsulfuron	4 g/ha	4.90 (23.0)	2.37 (4.6)	1.92 (2.6)	6.48 (41.0)	1.97 (2.9)	1.73 (2.0)
T_2: Carfentrazone	20 g/ha	4.69 (21.0)	3.91 (14.3)	3.21 (9.3)	6.40 (40.0)	2.30 (4.3)	2.00 (3.0)
T_3: 2,4-D Ester	500 g/ha	4.90 (23.0)	1.92 (2.6)	1.73 (2.0)	6.16 (37.0)	1.00 (0.0)	1.00 (0.0)
T_4: Metsulfuron + carfentrazone	4+20 g/ha	4.81 (22.0)	2.07 (3.3)	1.70 (1.9)	6.32 (39.0)	1.00 (0.0)	1.00 (0.0)
T_5: Metsulfuron+ 2,4-D Ester	3+400 g/ha	5.00 (24.0)	1.00 (0.0)	1.00 (0.0)	6.63 (43.0)	1.00 (0.0)	1.00 (0.0)
T_6: Metsulfuron+ 2,4-D Ester	3+500 g/ha	4.69 (21.0)	1.00 (0.0)	1.00 (0.0)	6.56 (42.0)	1.00 (0.0)	1.00 (0.0)
T_7: Carfentrazone + 2,4-D Ester	15+400 g/ha	4.90 (23.0)	1.92 (2.6)	1.73 (2.0)	6.40 (40.0)	1.00 (0.0)	1.00 (0.0)
T_8: Carfentrazone + 2,4-D Ester	15+500 g/ha	5.09 (25.0)	1.00 (0.0)	1.00 (0.0)	6.40 (40.0)	1.00 (0.0)	1.00 (0.0)
T_9: Halauxifen + pyroxsulam	19.17 g/ha	4.81 (22.0)	2.51 (5.3)	2.07 (3.3)	6.56 (42.0)	1.00 (0.0)	1.00 (0.0)
T_{10}: Halauxifen + pyroxsulam	23.96 g/ha	4.81 (22.0)	1.00 (0.0)	1.00 (0.0)	6.32 (39.0)	1.00 (0.0)	1.00 (0.0)
T_{11}: Pyroxsulam	18.75 g/ha	5.00 (24.0)	2.81 (6.9)	2.37 (4.6)	6.16 (37.0)	2.70 (6.3)	2.30 (4.3)
T_{12}: Halauxifen	5.21 g/ha	4.90 (23.0)	2.14 (3.6)	1.73 (2.0)	6.48 (41.0)	1.73 (2.0)	1.73 (2.0)
T_{13}: Weed free	--	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)
T_{14}: Weedy check		5.00 (24.0)	7.35 (53)	5.74 (32.0)	6.56 (42.0)	5.19 (26.0)	4.57 (19.9)
SEm±		0.14	0.11	0.07	0.15	0.08	0.06
C.D.at 5%		0.41	0.31	0.22	0.46	0.26	0.19

Original data given in parenthesis were subjected to square root($\sqrt{x+1}$) transformation before analysis

Table 2: Effect of herbicides and their mixtures on population of *Melilotus indicus* and *Medicago denticulata* weeds in wheat

Treatments	Dose	*Melilotus indicus* population (No./m^2)			*Medicago denticulata* population (No./m^2)		
		30 DAS	**60 DAS**	**120 DAS**	**30 DAS**	**60 DAS**	**120 DAS**
T_1: Metsulfuron	4 g/ha	5.74 (32.0)	1.82 (2.3)	1.73 (2.0)	4.47 (19.0)	3.05 (8.3)	2.83 (7.0)
T_2: Carfentrazone	20 g/ha	5.48 (29.0)	3.41 (10.6)	3.05 (8.3)	4.81 (22.0)	2.76 (6.6)	2.63 (5.9)
T_3: 2,4-D Ester	500 g/ha	5.66 (31.0)	2.07 (3.3)	1.82 (2.3)	4.69 (21.0)	3.26 (9.6)	3.05 (8.3)
T_4: Metsulfuron + carfentrazone	4+20 g/ha	5.57 (30.0)	1.00 (0.0)	1.00 (0.0)	4.58 (20.0)	1.00 (0.0)	1.00 (0.0)
T_5: Metsulfuron+ 2,4-D Ester	3+400 g/ha	5.66 (31.0)	1.00 (0.0)	1.00 (0.0)	4.90 (23.0)	1.82 (2.3)	1.61 (1.6)
T_6: Metsulfuron+ 2,4-D Ester	3+500 g/ha	5.74 (32.0)	1.00 (0.0)	1.00 (0.0)	4.58 (20.0)	1.00 (0.0)	1.00 (0.0)
T_7: Carfentrazone + 2,4-D Ester	15+400 g/ha	5.48 (29.0)	2.30 (4.3)	2.07 (3.3)	4.80 (22.0)	2.30 (4.3)	2.07 (3.3)
T_8: Carfentrazone + 2,4-D Ester	15+500 g/ha	5.83 (33.0)	1.00 (0.0)	1.00 (0.0)	4.47 (19.0)	1.00 (0.0)	1.00 (0.0)
T_9: Halauxifen + pyroxsulam	19.17 g/ha	5.74 (32.0)	1.82 (2.3)	1.70 (1.9)	4.58 (20.0)	2.24 (4.0)	2.00 (3.0)
T_{10}: Halauxifen + pyroxsulam	23.96 g/ha	5.57 (30.0)	1.00 (0.0)	1.00 (0.0)	4.90 (23.0)	1.00 (0.0)	1.00 (0.0)
T_{11}: Pyroxsulam	18.75 g/ha	5.66 (31.0)	3.10 (8.6)	2.83 (7.0)	4.58 (20.0)	3.61 (12.0)	3.16 (9.0)
T_{12}: Halauxifen	5.21 g/ha	5.57 (30.0)	2.37 (4.6)	2.07 (3.3)	4.47 (19.0)	3.26 (9.6)	3.05 (8.3)
T_{13}: Weed free	--	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)
T_{14}: Weedy check		5.74 (32.0)	5.92 (34.0)	4.90 (23.0)	4.80 (22.0)	5.48 (29.0)	5.00 (24.0)
SEm±		0.12	0.11	0.07	0.13	0.91	0.07
C.D.at 5%		0.38	0.31	0.21	0.40	0.28	0.20

Original data given in parenthesis were subjected to square root($\sqrt{x+1}$) transformation before analysis

Table 3: Effect of herbicides and their mixtures on population of *Rumex dentatus* and other miscellaneous weeds in wheat

Treatments	Dose	*Rumex dentatus* population (No./m^2)			Miscellaneous weed population (No./m^2)		
		30 DAS	60 DAS	120 DAS	30 DAS	60 DAS	120 DAS
T_1: Metsulfuron	4 g/ha	4.00 (15.0)	3.26 (9.6)	3.00 (8.0)	4.12 (16.0)	4.12 (16.0)	3.74 (13.0)
T_2: Carfentrazone	20 g/ha	3.74 (13.0)	3.05 (8.3)	2.93 (7.6)	4.07 (15.6)	3.61 (12.0)	3.16 (9.0)
T_3: 2,4-D Ester	500 g/ha	4.12 (16.0)	3.78 (13.3)	3.51 (11.3)	4.24 (17.0)	3.74 (13.0)	3.32 (10.0)
T_4: Metsulfuron + carfentrazone	4+20 g/ha	3.87 (14.0)	2.57 (5.6)	2.37 (4.6)	3.87 (14.0)	2.76 (6.6)	2.43 (4.9)
T_5: Metsulfuron+ 2,4-D Ester	3+400 g/ha	3.87 (14.0)	3.16 (9.0)	3.16 (9.0)	4.24 (17.0)	4.04 (15.3)	3.63 (12.3)
T_6: Metsulfuron+ 2,4-D Ester	3+500 g/ha	4.12 (16.0)	1.82 (2.3)	1.73 (2.0)	4.00 (15.0)	3.05 (8.3)	2.70 (6.3)
T_7: Carfentrazone + 2,4-D Ester	15+400 g/ha	4.24 (17.0)	3.26 (9.6)	3.09 (8.6)	4.12 (16.0)	3.74 (13.0)	3.32 (10.0)
T_8: Carfentrazone + 2,4-D Ester	15+500 g/ha	4.00 (15.0)	2.07 (3.3)	1.97 (2.9)	3.87 (14.0)	2.57 (5.6)	2.24 (4.0)
T_9: Halauxifen + pyroxsulam	19.17 g/ha	3.87 (14.0)	3.21 (9.3)	3.05 (8.3)	3.75 (13.1)	4.11 (15.9)	3.65 (12.3)
T_{10}: Halauxifen + pyroxsulam	23.96 g/ha	4.00 (15.0)	1.00 (0.0)	1.00 (0.0)	4.12 (16.0)	2.30 (4.3)	2.00 (3.0)
T_{11}: Pyroxsulam	18.75 g/ha	4.12 (16.0)	3.46 (11.0)	3.21 (9.3)	4.00 (15.0)	4.47 (19.0)	4.04 (15.3)
T_{12}: Halauxifen	5.21 g/ha	3.87 (14.0)	2.70 (6.3)	2.51 (5.3)	3.74 (13.0)	3.74 (13.0)	3.21 (9.3)
T_{13}: Weed free	--	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)
T_{14}: Weedy check		4.00 (15.0)	4.47 (19.0)	4.58 (20)	3.87 (14.0)	6.00 (35.0)	5.39 (28)
SEm±		0.17	0.09	0.07	0.17	0.14	0.11
C.D.at 5%		0.52	0.26	0.22	0.51	0.41	0.34

Original data given in parenthesis were subjected to square root $(\sqrt{x+1})$ transformation before analysis

Table 4: Effect of herbicides and their mixtures on dry weight of weeds and on weed control efficiency in wheat crop

Treatments	Dose	Dry weight (g/m^2) of different BLW		Weed control efficiency (%)	
		60 DAS	120 DAS	60 DAS	120 DAS
T_1: Metsulfuron	4 g/ha	5.25 (26.5)	8.61 (72.9)	77.7	76.3
T_2: Carfentrazone	20 g/ha	5.92 (34.0)	9.59 (90.8)	71.4	70.5
T_3: 2,4-D Ester	500 g/ha	5.14 (25.3)	8.51 (71.4)	78.7	76.8
T_4: Metsulfuron + carfentrazone	4+20 g/ha	3.23 (9.4)	5.00 (24.0)	92.1	92.2
T_5: Metsulfuron+ 2,4-D Ester	3+400 g/ha	4.14 (16.1)	7.02 (48.2)	86.5	84.3
T_6: Metsulfuron+ 2,4-D Ester	3+500 g/ha	2.73 (6.4)	4.32 (17.5)	94.6	94.3
T_7: Carfentrazone + 2,4-D Ester	15+400 g/ha	4.64 (20.5)	7.64 (57.3)	82.8	81.4
T_8: Carfentrazone + 2,4-D Ester	15+500 g/ha	2.53 (5.4)	3.94 (14.5)	95.5	95.3
T_9: Halauxifen + pyroxsulam	19.17 g/ha	4.83 (22.3)	7.86 (60.7)	81.3	80.3
T_{10}: Halauxifen + pyroxsulam	23.96 g/ha	1.91 (2.6)	2.71 (6.3)	97.8	97.9
T_{11}: Pyroxsulam	18.75 g/ha	6.31 (38.7)	10.27 (104.4)	67.5	66.1
T_{12}: Halauxifen	5.21 g/ha	4.97 (23.7)	8.04 (63.6)	80.1	79.3
T_{13}: Weed free	--	1.00 (0)	1.00 (0)	100.0	100.0
T_{14}: Weedy check		10.96 (119.2)	17.57 (307.8)	0.0	0.0
SEm±		0.3	0.5	--	--
C.D.at 5%		0.8	1.3	--	--

Original data given in parenthesis were subjected to square root $(\sqrt{x+1})$ transformation before analysis

Table 5: Effect of herbicides and their mixtures on plant height, number of tillers, crop yield and harvest index of wheat

Treatments	Dose	Plant height at harvest (cm)	No. of tillers at harvest (No./mrl)	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
T_1: Metsulfuron	4 g/ha	93.0	72.3	4,622	7,900	12,522	36.91
T_2: Carfentrazone	20 g/ha	92.0	71.4	4,560	7,831	12,391	36.80
T_3: 2,4-D Ester	500 g/ha	92.3	73.4	4,696	7,918	12,614	37.23
T_4: Metsulfuron + carfentrazone	4+20 g/ha	97.9	77.8	4,971	8,248	13,219	37.60
T_5: Metsulfuron+ 2,4-D Ester	3+400 g/ha	98.0	78.1	4,992	8,266	13,258	37.65
T_6: Metsulfuron+ 2,4-D Ester	3+500 g/ha	98.6	82.8	5,290	8,379	13,669	38.70
T_7: Carfentrazone + 2,4-D Ester	15+400 g/ha	93.2	73.7	4,714	7,817	12,531	37.62
T_8: Carfentrazone + 2,4-D Ester	15+500 g/ha	98.5	82.0	5,243	8,335	13,578	38.61
T_9: Halauxifen + pyroxsulam	19.17 g/ha	98.3	78.1	4,991	8,256	13,247	37.68
T_{10}: Halauxifen + pyroxsulam	23.96 g/ha	99.2	84.4	5,395	8,466	13,861	38.92
T_{11}: Pyroxsulam	18.75 g/ha	91.9	70.6	4,510	7,421	11,931	37.80
T_{12}: Halauxifen	5.21 g/ha	93.4	76.4	4,883	7,916	12,799	38.15
T_{13}: Weed free	--	99.5	85.6	5,475	8,552	14,027	39.03
T_{14}: Weedy check	--	87.3	65.2	3,162	5,907	9,069	34.87
SEm±		1.6	1.3	86	110	141	0.04
C.D.at 5%		4.4	3.8	247	329	418	0.12

Effect of herbicides on plant height, number of tillers and wheat yield

Weed free condition in wheat resulted into taller plants and higher number of tillers as compared to all other treatments (Table 5). But to see the alternate of weed free condition in practical due to higher labour costs, chemical control were felt necessary. Post emergence herbicides were the best alternate to curb the growth of the broad leaf weeds which fetch most of the nutrients in wheat. Plant heights of wheat at harvest was significantly improved after the application of the herbicides halauxifen + pyroxsulam at 23.96 g/ha (99.2 cm), followed by metsulfuron + 2, 4-D Ester at 3 + 500 g/ha) (98.6 cm) and halauxifen + pyroxsulam at 19.17 g/ha (98.3 cm), respectively. Application of these herbicides also increased the number of tillers/mrl. Halauxifen is a systemic herbicide belongs to phenoxyalkanoic acids family and its mode of action as synthetic auxins and auxin transport inhibitor. Hence in combination of pyroxsulam, this herbicide inhibits the growth of the broad leaf weeds in the plots where they were applied. In addition to this, because auxins are responsible for cell division, elongation, apical dominance and many more functions in the plants. Use of auxin inhibitor herbicide like halauxifen resulted into inhibition of this plant growth hormone leading to death of the plant in case of weeds especially. Further, use of pyroxsulam along with halauxifen resulted into inhibition of ALS enzyme. Halauxifen herbicide binds to different sites on the ALS enzyme and stops its activity for the synthesis of different kinds of amino acids leading to death of the plant. Both the herbicides in mixtures performed well to reduce the weed intensity. Thus, less competition of weeds led to more plant height and higher number of tillers in wheat. Moreover, herbicides used in mixtures may create synergistic effects and may alter the balance of the ecosystem. Similar results have been obtained by Khan *et al*. (2003) [6].

Significantly higher wheat yields (grain, straw and biological yield) were observed in weed free plots of wheat followed by halauxifen + pyroxsulam at 23.96 g/ha which resulted into highest grain yield 5395 kg/ha, straw yield 8466 kg/ha, biological yield 13861 kg/ha (Table 5). The harvest index (%) of weed free treatment and halauxifen + pyroxsulam were at par with each other but were significantly higher than all other treatments. Halauxifen + pyroxsulam at 23.96 g/ha was found to be most suitable treatment in terms of grain, straw and biological yield and the harvest index (%) of wheat (Table 5). Biological yield meant for all over biomass production which is a function of initial growth and biomass production of a crop. Weeds compete for the applied inputs but in wheat especially the broad leaf weeds are the main problem which use mostly the available input and space and resulted into significant loss in the economic yield. The mixtures of the above herbicides significantly controlled the weeds after their spray at 35 days after sowing, resulting in increased in biological yield, grain yield and straw yield. Similar results have been confirmed by Pratap *et al.* (2010) [11] where they applied pyroxsulam (12 to 30 g) in wheat which increased the grain yield in both the concentration (3.0 and 3.6% O.D.). Similarly, Mahamoud *et al.* (2016) [8] also reported that application of herbicides halauxifen-methyl + florasulam (paradigm) gave 100% reduction in fresh weight of broad leaf weeds at both locations.

So, it is concluded that application of halauxifen + pyroxsulam sprayed at 23.96 g/ha at 35 days after sowing was the most effective treatment to control the weeds in wheat with higher grain yield of 5395 kg/ha, straw yield of 8466 kg/ha and biological yield of 13861 kg/ha with highest weed control efficiency followed by metsulfuron + 2, 4-D Ester (3 + 500 g/ha) and carfentrazone + 2, 4-D Ester (15 + 500 g/ha). Application of herbicide mixtures was found more effective in controlling the weeds as compared to their sole application.

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