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Research Article

Broad-leaved Weed Control with Combination of Halauxifen-Methyl with Florasulam or Fluroxypyr in Wheat

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Abstract

Field experiments were conducted to determine the effectiveness of combination of halauxifen-methyl with either florasulam or fluroxypyr-methyl for control of diverse broad-leaved weed flora in wheat (*Triticum aestivum* L.). In first experiment, the bio-efficacy of a premix of halauxifen-methyl + florasulam at 7.66 (3.91+3.75), 10.21 (5.21+5.00) and 12.76 (5.51+6.25) g/ha, applied with and without surfactant, was evaluated and compared with carfentrazone (20 g/ha) and metsulfuron (4 g/ha). In second experiment, premix of halauxifen-methyl + fluroxypyr methyl at 160.4 (4.8+156.6), 200.6 (6.1+194.5) and 240.66 (7.3+233.4) g/ha, along with halauxifen-methyl (7.3 g/ha), fluroxypyr (233.4 g/ha), metsulfuron (4 g/ha), metsulfuron + carfentrazone (5+20 g/ha), hand weeding, and an untreated control were evaluated. Halauxifen-methyl alone was poor for control of *Rumex dentatus*. However, combination of halauxifen-methyl and florasulam at 10.21-12.76 g/ha and halauxifen-methyl and fluroxypyr at 200.6-240.66 g/ha effectively controlled the diverse broad-leaved weed flora (*Rumex dentatus, Medicago denticulata* and *Coronopus didymus*). The efficacy of halauxifen-methyl + florasulam was better when applied along with surfactant. Halauxifen-methyl + florasulam at 10.21 g/ha along with surfactant was superior to metsulfuron methyl 4 g/ha and carfentrazone 20 g/ha. Halauxifen methyl + fluroxypyr methyl had similar efficacy as the standard treatment metsulfuron + carfentrazone combination at 5+20 g/ha. Studies clearly indicated effectiveness of halauxifen-methyl + florasulam and halauxifen-methyl + fluroxypyr-methyl for control of diverse broad-leaved weed flora in wheat and these treatments resulted in 30.9-77.9% higher wheat grain yields compared to weedy control.

Keywords: Carfentrazone, *Medicago denticulata*, Metsulfuron, Ready mixture, *Rumex dentatus*

1. Introduction

Wheat (*Triticum aestivum* L. emend. Fiori and Paol) is a staple food crop, supporting the nutritional requirements of billions of people globally. Among cereal crops, wheat occupies the largest cultivated area, estimated at 220.4 million hectares worldwide (FAO, 2025). Ensuring the consistent production and supply of wheat is essential for global food security. However, weed infestation remains one of the most significant biotic constraints limiting wheat productivity. The magnitude of yield losses attributable to weeds is influenced by weed species composition, density, and prevailing environmental conditions (Chhokar *et al.*, 2012). Globally, yield losses due to weed competition in wheat have been estimated to range from 7.7% to 23.9%, varying by region (Oerke, 2006; Kosina *et al.*, 2007). In India, weeds cause annual economic losses of USD 3376 million in wheat (Gharde *et al.*, 2018) and actual yield loss to the tune of 7.5–41.0% were observed in the farmers' fields.

Wheat is cultivated under a broad spectrum of agro-climatic conditions, cropping sequences, tillage, and irrigation regimes, resulting in a diverse and dynamic weed flora (Chhokar *et al*., 2012). Agronomic practices, such as crop rotation, tillage intensity, and herbicide usage, exert substantial influence on the composition and prevalence of weed species (Anderson and Beck, 2007; Chhokar *et al*., 2007a). For example, reduced or zero-tillage practices in rice-wheat systems, particularly under high soil moisture, have been shown to favor the proliferation of *Rumex dentatus* L. (toothed dock) and *Malva parviflora* L. (little mallow) (Chhokar *et al*., 2007a). In certain regions of eastern India, *Solanum nigrum* L. (black nightshade) and *Physalis minima* (groundcherry) have emerged as problematic weeds, where reliance on 2,4-D has proven inadequate for effective control (Chhokar *et al*., 2012). The persistent use of selective grassy weed herbicides, such as clodinafop, fenoxaprop, and pinoxaden, without concurrent application of broadleaf herbicides, has led to a shift in weed flora, with an increasing prevalence of broadleaf weeds. In India, the principal herbicides employed for broadleaf weed control in wheat include metsulfuron, 2,4-D, and carfentrazone (Chhokar *et al*., 2007b). However, herbicide efficacy is often species-specific, and certain post-emergent contact herbicides, such as carfentrazone-ethyl, exhibit limited effectiveness against weeds at advanced growth stages and lack residual soil activity (half-life: 2–5 days), failing to control subsequent weed flushes (Lyon *et al*., 2007; Willis *et al.,* 2007). Moreover, carfentrazone is poor against *Lathyrus aphaca* and metsulfuron is poor against *Malva parviflora* and *Solanum nigrum* (Chhokar *et al*., 2015).

Florasulam, a acetolactate synthase inhibiting herbicide belong to triazolopyridine sulfonamides group, is commonly utilized in mixtures with herbicides of differing modes of action to manage broadleaf weeds post-emergence. Florasulam is absorbed via both roots and shoots and is translocated through the xylem and phloem. Synthetic auxins, a class of plant hormone analogues, are also widely employed as herbicides. Halauxifen-methyl, a novel arylpicolinate, represents a new generation of synthetic auxin herbicides (Epp *et al*., 2016). It is rapidly absorbed and translocated within the plant, accumulating in meristematic tissues, and is characterized by rapid degradation in soil, providing effective control of several broadleaf weed species in cereals (EFSA, 2014). It is also used as a preplant application for corn and soybean (McCauley *et al*., 2018). Fluroxypyr, another important synthetic auxin, is notable for its stability in plants and its ability to induce auxin-like responses, such as leaf curling, epinasty, deformation, necrosis, and uncontrolled cell division leading to plant death (Epp *et al*., 2016).

The repeated use of herbicides with a single mode of action, such as metsulfuron, has resulted in the evolution of resistant weeds (*Rumex dentatus* and *Chenopodium album*) in wheat fields (Chhokar *et al*., 2018). To mitigate resistance evolution and broaden the spectrum of weed control, the use of herbicide mixtures with heterogeneous modes of action is advocated. Such mixtures not only improve control of complex weed flora but also delay the onset of herbicide resistance. The efficacy of these herbicide mixtures can be further enhanced by the inclusion of surfactants (Chhokar *et al*., 2011).

In light of these challenges, the present study was designed with the objective to evaluate the bio-efficacy of a ready-mix combination of halauxifen methyl 20.8% w/w + florasulam 20% w/w WG and halauxifen-methyl 1.21% + fluroxypyr methyl 38.9% w/w EC against major broadleaf weeds in wheat.

2. Materials and methods

Two sets of field experiments were conducted at Resource Management Block, ICAR- Indian Institute of Wheat and Barley Research, Karnal, Haryana, India to evaluate the efficacy of pre-mix combination of halauxifen methyl 20.8% w/w + florasulam 20% w/w WG and halauxifen-methyl 1.21% + fluroxypyr methyl 38.9% w/w EC against broad-leaf weeds in wheat.

2.1 Experiment 1: Efficacy of pre-mix combination of halauxifen methyl 20.8% + florasulam 20% w/w WG

An experiment involving 9 weed control treatments (Table 1) was conducted for two *Rabi* seasons of 2013-14 and 2014-15 keeping three replications in randomized block design. The soil of the experimental field was sandy clay loam with pH of 8.0 and organic carbon content of 0.37%. Wheat cultivar 'DPW-621-50' was sown in first week of November during first and second year, respectively, at 20 cm row spacing using a seed rate of 100 kg/ha. Herbicide treatments included three rates of the ready-mix combination halauxifen methyl 20.8% + Florasulam 20% w/w WG (7.66, 10.21 and 12.76 g a.i./ha), each with and without surfactant. Additional standard treatments comprised an untreated control, carfentrazone (Affinity 40 DF) at 20 g a.i./ha, and metsulfuron (Algrip 20 WP) at 4 g a.i./ha. Non-ionic surfactant (Iso-Octyl-phenoxy-polyethanol 12.5%) was used with metsulfuron, and a polyglycol surfactant @ 750 ml/ha was applied with the halauxifen methyl + florasulam mixture. Herbicide application was performed at 40-42 Days After Sowing (DAS) using a knapsack sprayer equipped with a flat fan nozzles, delivering 375 L water/ha. Irrigation and fertilization were done as per the standard recommendations. At 115-120 DAS, the enclosed weeds within quadrats placed at two spots in each plot were harvested for recording dry biomass. The crop was manually harvested using sickles in second week of April and threshed using small plot thresher.

2.2 Experiment 2: Efficacy of pre-mix combination of halauxifen + fluroxypyr

An experiment involving 9 weed control treatments (Table 2) was conducted for two *Rabi* seasons of 2017-18 and 2018-19 keeping three replications in randomized block design. The soil of the experimental field was sandy clay loam with pH of 8.2 and organic carbon content 0.40%. Wheat cultivar 'HD-2967' was sown on last week of November during first and second year, respectively, at 20 cm row spacing using a seed rate of 100 kg/ha. Herbicide treatments consisted of three rates of the ready-mix combination halauxifen-methyl 1.21% + fluroxypyr methyl 38.9% w/w EC [160.4 (4.8+156.6), 200.6 (6.1+194.5) and 240.66 (7.3+233.4) g *a.i.*/ha], alongside an untreated control, two hand weeding, halauxifen-methyl 10.42% WG at 7.3 g *a.i.*/ha along with Polyglycol 26-2N surfactant 750 ml/ha, fluroxypyr methyl 48% EC at 233.4 g *a.i.*/ha, metsulfuron (Algrip 20 WP) at 4 g *a.i.*/ha, and metsulfuron methyl 10% + carfentrazone ethyl 40% DF + surfactant at 5+20 g *a.i.*/ha. Non-ionic surfactant was used with metsulfuron and the metsulfuron methyl + carfentrazone ethyl mixture, while polyglycol surfactant was used with halauxifen-methyl. Herbicide application was made at about 45 DAS using a knapsack sprayer with flat fan nozzles at 375 L water/ha. Irrigation and fertilization were done as per the standard recommendations. Broadleaf weed dry biomass was measured at approximately 9 weeks after herbicide spraying**.** For weed dry biomass determination, all weeds within the quadrat were harvested, dried, and weighed. The crop was manually harvested during fourth week of April and threshed using small plot thresher.

2.3 Statistical analysis

Field experimental data were statistically analyzed in randomized block design using the Statistical Analysis System (SAS, version 9.2) software. Weed and crop data were subjected to an analysis of variance and treatment means were compared using Tukey's Honest Significant Difference (HSD) test at a significance level of $p = 0.05$. The weed dry weight data were transformed to square root $\{\sqrt{(x + 1)}\}$ prior to analysis. The original weed data are presented in the results tables with a comparison of means for significant differences with letter based on the transformed data analysis.

3. Results and discussion

Two sets of field experiments were conducted to determine the efficacy of halauxifen methyl applied in combination with either florasulam or fluroxypyr methyl as post emergence options in wheat.

3.1 Efficacy of halauxifen methyl + florasulam

In this experiment, the major weeds infested the experimental plots during both the years of study were *Rumex dentatus, Medicago denticulata*, *Coronopus didymus, Lathyrus aphaca* and *Malva parviflora.* Among these, the most dominant weed species during both the years was *Rumex dentatus* followed by *Medicago denticulata*.

Field studies showed that halauxifen + florasulam applied as Post Emergence (POE) was very effective for control of broadleaf weeds namely *Rumex dentatus, Medicago denticulata,* and *Coronopus didymus* (Table 1). Similar to our findings, earlier workers have reported the effectiveness of halauxifen + florasulam against many broadleaf weeds *Coronopus didymus, Malva parviflora, Lathyrus aphaca, Medicago denticulata, Medicago hispida, Polygonum spp., Rumex spp., Chenopodium album, Melilotus spp., Vicia hirusuta, Papaver rhoeas, Sinapsis arvensis, Galium aparine, Convulvulus arvensis, Solanum nigrum, Anagallis arvensis, Vicia sativa, Fumaria parviflora, Cirsium arvense, Trachyspermum spp., Fumaria officinalis, Polygonum convolvulus, Stellaria media, Veronica spp., Cichorium intybu*s, *Conyza canadensis*

Table 1: Effect of Halauxifen + florasulam (Premix) on weed dry weight in wheat (Two years pooled data)

Treatments	Dose/ha (g a.i.)	*Weed dry wt, g/m^2					Weed control efficiency (%)	Grain Yield q/ha
		Rumex dentatus	*Coronopus didymus*	*Medicago denticulata*	Other weeds	Total weeds		
Halauxifen + florasulam	7.66(3.91+3.75)	4.5c	0.6b	13.2b	16.7a	34.6b	89.0	49.22c
Halauxifen + florasulam	10.21(5.21+5.00)	0.8cd	0.2b	8.5bc	10.7ab	19.9cde	93.7	53.41ab
Halauxifen + florasulam	12.76(6.51+6.25)	0.2d	0.1b	0.9c	6.6bc	7.7ef	97.5	54.76ab
Halauxifen + florasulam + S**	7.66(3.91+3.75)	0.4d	0.1b	3.8bc	6.6bc	10.8def	96.6	51.22bc
Halauxifen + florasulam + S	10.21(5.21+5.00)	0.2d	0.1b	0.6c	3.3cd	4.1fg	98.7	54.97ab
Halauxifen + florasulam + S	12.76(6.51+6.25)	0.0d	0.0b	0.4c	0.5d	0.9g	99.7	55.75a
Metsulfuron methyl +S	4	0.2d	0.2b	1.4c	16.8a	18.4cd	94.2	53.22ab
Carfentrazone	20	12.3b	1.0b	6.6bc	14.6a	33.7bc	89.3	48.57c
Untreated Check		193.9a	3.8a	108.0a	11.3ab	314.5a	0.0	31.46d
p-value		<0.001	<0.001	<0.001	<0.001	<0.001		<0.001

* Original values were square root transformed (√x+1) for statistical analysis and based on which the lower-case letters have been mentioned with original values for interpretation. Treatment means within column having at least one common letter are not significantly different at 5% level of significance according to Tukey's Honest Significant Difference test

**S= Surfactant Polyglycol 26-2N @750 ml/ha

Table 2: Effect of halauxifen methyl + fluroxypyr methyl (Premix) on weed dry weight at 9 weeks after herbicide spraying in wheat (Two years pooled data)

Treatments	Dose/ha (g a.i.)	*Weed dry wt, g/m^2			Weed control efficiency (%)	Grain Yield q/ha
		Rumex dentatus	Other weeds	Total weeds		
Halauxifen + Fluroxypyr	160.4(4.8+156.6)	1.2d	3.0cd	4.2de	98.0	56.69a
Halauxifen + Fluroxypyr	200.6(6.1+194.5)	0.0d	0.5d	0.5de	99.8	59.28a
Halauxifen + Fluroxypyr	240.7(7.3+233.4)	0.0d	0.1d	0.1e	100.0	59.10a
Halauxifen methyl + S**	7.3	70.0b	2.5cd	72.5b	66.2	52.14b
Fluroxypyr	233.4	0.0d	5.6bc	5.6d	97.4	56.94a
Metsulfuron methyl + S**	4	5.3cd	12.1b	17.4c	91.9	57.29a
Metsulfuron + Carfentrazone + S**	5+20	0.0d	0.4d	0.4e	99.8	60.15a
Hand Weeding-2	-	9.9c	4.9bc	14.8c	93.1	57.86a
Untreated Check	-	161.6a	53.2a	214.7a	0.0	45.17c
p-value		<0.001	<0.001	<0.001		<0.001

*Original values were square root transformed (√x+1) for statistical analysis and based on which the lower-case letters have been mentioned with original values for interpretation. Means within column having at least one letter common are not significantly different according to Tukey's Honest Significant Difference test at 5% level of significance

**S= surfactant

and *Ambrosia artemisiifolia* (Mitra *et al.*, 2019; Mukherjee *et al.*, 2020; Pala and Mennan, 2019; Ram and Kaur, 2020; Mahmoud *et al.*, 2016; Hayyat *et al.* 2016; Zimmer *et al.*, 2018; Dwivedi *et al.*, 2023; Jackson *et al.*, 2018; Kaur *et al.*, 2023; Tomar *et al.*, 2023).

The dry biomass accumulated by total weeds in untreated control was 314.5 g/m^2 (Table 1). Compared to weedy check, all the herbicide treatments caused significant reduction in weed dry biomass. Among herbicide treatments, the lowest weed biomass was recorded with application of halauxifen + florasulam at 12.76 g/ha with surfactant and it was followed by halauxifen + florasulam at 10.21 g/ha with surfactant and both of these treatments were statistically not different. The broadleaved weed control with halauxifen + florasulam without surfactant was poor compared to with surfactant application. The weed control efficiency (99.7%) was maximum when ready mix combination halauxifen + florasulam at 12.76 g/ha with surfactant was applied. Among different weeds, *Rumex dentatus* control by halauxifen + florasulam at ≥ 7.66 g/ha with surfactant was similar and these treatments were superior to the lowest dose of mixture without surfactant. The effect of various herbicides against *Coronopus didymus* was similar. Halauxifen + florasulam at 10.21 and 12.76 g/ha with surfactant provided > 99.6% control of *Medicago denticulata* and treatments were statistically not different compared to other herbicide treatments except the lowest dose of ready mixture without surfactant. The biomass of other weeds, which consisted of *Lathyrus aphaca*, *Malva parviflora* and *Melilotus indica* was the lowest (0.5 g/m^2) in treatment halauxifen + florasulam at 12.76 g/ha with surfactant and this treatment was at par with ready mixture at 10.21 g/ha with surfactant and significantly superior to rest of the treatments. Ready mix at ≥ 7.66 g/ha with surfactant and 12.76 g/ha without surfactant were superior to standard treatments i.e. metsulfuron 4 g/ha and carfentrazone 20 g/ha. The advantage of combination of Halauxifen + florasulam over metsulfuron and carfentrazone will be in situations having the diverse infestation of broad-leaved weeds particularly the *Malva parviflora* and *Lathyrus aphaca*. Metsulfuron is not effective against *Malva parviflora*, whereas, carfentrazone is not effective against *Lathyrus aphaca* (Chhokar *et al.*, 2015). The ready mix combination of Halauxifen + florasulam provides the effective control of these weeds. Similarly, the wide window of application and robust control of broad-leaved weeds in cereals with halauxifen+ florasulam have been reported by various research workers (Jackson *et al.*, 2018; Mitra *et al.,* 2019; Tomar *et al.*, 2023). Crose *et al.* (2019) also observed the effectiveness of halauxifen plus florasulam for control of broadleaf weeds in winter wheat.

This strategy of herbicide mixtures besides providing broad spectrum weed control will also help in delaying the evolution of herbicide resistance in weeds along with providing the sustainability of wheat production. Application of mixed herbicides can prevent evolution of herbicide-resistant weeds because of using more than one mechanism of action active ingredient (Galon *et al.* 2018).

The presence of weeds throughout the crop season reduced the grain yield by 43.6% and as a result among various weed control treatments, the lowest yield (31.46 q/ha) was recorded in weedy control (Table 1). Compared to weedy control, all the weed control treatments resulted in significant wheat grain yield improvement due to the effective control of the broad-leaf weeds. The yield in halauxifen + florasulam (Premix) at 10.21-12.76 g a.i/ha without surfactant was inferior (1.8-3.9%) to its application with surfactant. The ready mixture applied at 10.21 and 12.76 g/ha with surfactant had statistically similar yields. The application of mixture at 10.21-12.76 g a.i/ha had numerical yield advantage over lower dose of mixture without and with surfactant. The application of ready mixture at 10.21-12.76 g a.i/ha with surfactant (3.3-12%) produced more grain yield compared to alone application of metsulfuron and carfentrazone. The application of mixture at 10.21-12.76 g a.i/ha with surfactant yielded significantly better (13.2-14.8%) over application of carfentrazone 20 g/ha. The improvement in wheat grain yield under various weed control treatments was as a result of effective weed control. The results show that for better efficacy of the ready-mix combination of halauxifen + florasulam its application with a surfactant is must.

3.2 Effect of ready-mix combination of halauxifen-methyl + fluroxypyr-methyl

Field studies showed that halauxifen +fluroxypyr applied as POE was very effective for control of broadleaf weeds namely *Rumex dentatus* (Table 2). Similar to our findings, earlier workers have reported the effectiveness of halauxifen + fluroxypyr against many broadleaf weeds *Chenopodium album, Chenopodium murale, Malva parviflora, Malva neglect, Argemone mexicana, Lamium amplexicaule,* *Conyza bonariensis, Fumaria densiflora, Papaver somniferum, Sonchus oleraceous, Fallopia convolvulus, Convulvulus arvensis, Euphorbia helioscopia, Fumaria indica, Conyza canadensis, Ambrosia artemisiifolia, Ageratum houstonianum, Biden pilosa, Emilia sonchifolia, Scorpiurus muricatus, Polygonum aviculare, Bifora testiculata* and *Bassia scoparia* (Love *et al.*, 2019; Hayyat *et al.*, 2016; Zimmer *et al.*, 2018; Mekonnen, 2022; Moeini *et al.*, 2022; Dhanda *et al.*, 2023).

Compared to weedy check, all the herbicide treatments caused significant reduction in total dry biomass of weeds. The dry biomass accumulated by broad-leaved weeds in untreated control was 214.7 g/m^2 (Table 2). Among different weeds, *Rumex dentatus* showed good sensitivity to various herbicides tested and its dry weight was drastically reduced with metsulfuron, metsulfuron + carfentrazone, fluroxypyr methyl, and halauxifen methyl + fluroxypyr methyl. Love *et al.* (2019) reported that halauxifen + fluroxypyr combines the weed spectrum of halauxifen and fluroxypyr to allow wide window of application in cereals. The best weed control strategy in wheat field with broadleaf weed flora dominated by *Chenopodium album*, *C. murale*, *Convolvulus arvensis, Euphrobia helioscopia* and *Fumaria indica* is the use of postemergence application of fluroxypyr + MCPA (Hayyat *et al.*, 2016). Significant reduction in density and biomass of diverse broadleaf weed flora by application of fluroxypyr + MCPA herbicides compared with weedy check in wheat was also reported by Abbas *et al.* (2009). Dicamba in mixtures with halauxifen/fluroxypyr + 2,4-D, halauxifen/fluroxypyr + dichlorprop-p resulted in ≥85% shoot dry weight reduction of multiple herbicide resistant kochia populations (Dhanda *et al.*, 2023). In another study, at 30 days after application, halauxifen + fluroxypyr at 200.6 and 240.66 g/ha recorded effective control of *Rumex dentatus*, *Medicago denticulata* and *Coronopus didymus* (Kaur *et al.*, 2023).

The weed dry matter accumulation reduced as the dose of halauxifen methyl + fluroxypyr methyl (Premix) increased from 160.4 to 240.7 g/ha. However, all the rates of this ready mixture did not differ among themselves for the total weed dry biomass accumulation. The reduction in dry biomass of broadleaf weeds was more with pre-mix combination of halauxifen methyl + fluroxypyr methyl and pre-mix combination of metsulfuron + carfentrazone (5 + 20 g/ha). More than 99% weed control efficiency was achieved with application of halauxifen methyl + fluroxypyr at 200.6 and 240.7 g/ha and metsulfuron + carfentrazone at 5 + 20 g/ha. Pre-mix halauxifen methyl + fluroxypyr had significantly lesser weed dry weight compared to application of halauxifen methyl alone, metsulfuron and two hand weedings treatments.

The advantage of combination of halauxifen methyl + fluroxypyr methyl over metsulfuron and halauxifen methyl will be in situations having the diverse infestation of broad-leaved weeds particularly the *Malva parviflora and Rumex dentatus*. Metsulfuron is not effective against *Malva parviflora*, whereas, halauxifen methyl is poor against *Rumex dentatus.* In earlier studies also, halauxifen-methyl applied alone resulted in poor giant ragweed and redroot pigweed control; however, mixtures of halauxifen-methyl with dicamba and 2,4-D effectively controlled these weeds (Zimmer *et al.*, 2018). Also recently, the *Rumex dentatus* has also evolved resistance against ALS inhibitor herbicides such as metsulfuron in Haryana and Punjab. The ready-mix combination of halauxifen methyl + fluroxypyr methyl will provide the control of these weeds.

The presence of weeds throughout the crop season reduced the grain yield by 24.9% and as a result among various weed control treatments, the lowest yield (45.17 q/ha) was recorded in weedy control (Table 2). Compared to weedy control, all the weed control treatments resulted in significant wheat grain yield improvement due to the effective control of the broad-leaf weeds. The yield in halauxifen methyl + fluroxypyr methyl (Premix) at 200.6 g/ha (59.28 q/ha) and 240.7 g/ha (59.10 q/ha) was statistically similar, but had numerical yield advantage over lower dose of mixture (160.4 g/ha) (56.69 q/ha). The application of mixture at 200.6-240.7 g/ha yielded significantly better over application of halauxifen methyl 7.3 g/ha (52.14 q/ha). The improvement in wheat grain yield under various weed control treatments was as a result of effective weed control. The results showed the better weed control efficacy with the ready-mix combination of halauxifen methyl + fluroxypyr methyl. In earlier studies also the halauxifen at 7.3 g/ha and fluroxypyr at 233.4 g/ha recorded less grain yield as compared to pre-mix halauxifen + fluroxypyr (Kaur *et al.*, 2023).

4. Conclusion

Results showed that halauxifen methyl alone was poor against *Rumex dentatus.* However, halauxifen methyl in combination with either florasulam or fluroxypyr provided effective control of diverse broadleaved weed flora (*Rumex* *dentatus*, *Medicago denticulata* and *Coronopus didymus*) in wheat. Moreover, as *R. dentatus* has evolved resistance against ALS inhibitor herbicides such as metsulfuron and florasulam (Chhokar *et al.*, 2019), whereas, fluroxypyr is effective against resistant populations. Therefore, halauxifen-methyl + fluroxypyr at 200.6–240.7 g/ha can be alternative option for broadleaved weeds control in resistant prone area having ALS herbicide resistant weeds (*R. dentatus* and *Chenopodium album*) (Chhokar *et al.*, 2018). The application of a mixture containing two or more herbicide site of actions as a constituent of integrated weed management is usually recommended to control or delay the evolution of herbicide resistance in weeds (Beckie and Reboud 2009; Green, 1991).

Further studies are also required to determine the compatibility of these pre-mix combinations of broadleaved herbicides with grass herbicides for control of broad spectrum weed flora.

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Author Contributions

RSC conducted experiments, performed statistical analysis and wrote manuscript draft; CC wrote the first manuscript draft; SCG conducted the experiments; NK edited the manuscript; RKS overall supervision; SK helped in conduct of experiments; AKK reviewed the manuscript.

Declarations of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Conflict of Interest

The authors declare no conflict of interest.

Ethical Approval

The article doesn't contain any study involving ethical approval.

Use of Generative AI or AI assisted technologies

Authors declare that no Generative AI or AI assisted technologies have been used in preparation of this manuscript.

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