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Efficacy of herbicide combinations for suppression of weed density and biomass in wheat (*Triticum aestivum* L.)

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ABSTRACT

An experiment was conducted to evaluate the efficacy of different herbicide treatments for management of complex weed flora in wheat during the Rabi seasons of 2024-25 and 2025-26. The experiment comprised nine weed-management treatments arranged in a randomized block design with three replications. The treatments included pre-emergence and post-emergence application of individual herbicides, herbicide combinations, hand weeding and a weedy check. Total weed density and weed dry weight were recorded at harvest and expressed as weeds m^{-2} and g m^{-2} , respectively. Weed density and dry weight were significantly influenced by the weed-management treatments in both seasons and in pooled analysis. The weedy check recorded the highest pooled total weed density (178.23 m^{-2}) and total weed dry weight (469.47 g m^{-2}). Among herbicidal treatments, clodinafop propargyl + metsulfuron methyl at $60 + 4 \text{ g a.i. ha}^{-1}$ recorded the lowest pooled total weed density (9.69 m^{-2}) and dry weight (26.44 g m^{-2}), resulting in 94.56% reduction in weed density and 94.37% reduction in weed dry weight over the weedy check. Clodinafop propargyl + metribuzin at $54 + 120 \text{ g a.i. ha}^{-1}$ was the next most effective treatment, recording pooled total weed density of 18.78 m^{-2} and dry weight of 52.05 g m^{-2} . The results established that herbicide combinations with complementary activity against both grassy and broad-leaved weeds provided effective suppression of total weed population and biomass. Thus, clodinafop propargyl + metsulfuron methyl ($60 + 4 \text{ g a.i. ha}^{-1}$) proved effective for broad-spectrum weed suppression in wheat under the experimental conditions.

Keywords: Wheat, Herbicide combinations, Weed density, Weed dry weight, Weed management

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most extensively cultivated cereal crops and constitutes a cornerstone of global food and nutritional security. Its broad adaptation, high yield potential, superior processing quality and diverse end uses have established wheat as a major staple food across the world. The crop contributes substantially to human dietary energy and protein requirements, making sustained improvement in wheat productivity essential under increasing population pressure, climate variability and shrinking agricultural resources (CAS, 2020; Mitura *et al.*, 2023) [1]. Globally, wheat is cultivated on about 219.64 million hectares, producing approximately 789.89 million tonnes with an average productivity of 3.60 t ha^{-1} (USDA, 2024). However, the realization of its yield potential is constrained by several biotic and abiotic stresses, among which weeds remain one of the most important and persistent biological constraints.

India is the second-largest producer of wheat, which plays a vital role in national food security and rural livelihoods. During 2024-25, wheat occupied 32.80 million hectares, producing 117.94 million tonnes with an average productivity of $3,595 \text{ kg ha}^{-2}$. Madhya Pradesh contributed substantially, with 5.39 million hectares, 20.76 million tonnes production and $3,852 \text{ kg ha}^{-1}$ productivity (Department of Agriculture and Farmers Welfare, 2025) [2]. However, sustaining wheat productivity requires effective management of weeds, which compete with the crop for nutrients, moisture, light and space, thereby restricting crop growth and yield.

Weed interference depends on weed density, species composition, biomass and duration of competition. Under severe infestation, weeds can cause wheat yield losses of 20-70% or more (Oerke, 2006; Gharde *et al.*, 2018; Gyawali *et al.*, 2022) [4, 3, 5]. Early-season competition is particularly critical, as rapidly emerging weeds compete strongly with young wheat plants. The critical period of crop-weed competition generally occurs between 20 and 45 days after sowing, making timely weed control essential to minimize yield losses (Jat *et al.*, 2003; Saha *et al.*, 2016) [6, 7]. Wheat fields generally harbour a complex mixture of grassy and broad-leaved weeds, with their composition varying according to agro-climatic conditions, soil type, cropping sequence, tillage, irrigation and herbicide-use history. Among grassy weeds, *Phalaris minor* Retz. and *Avena ludoviciana* Durieu are particularly important, whereas *Chenopodium album* L., *Rumex dentatus* L., *Melilotus indica* L., *Medicago denticulata* Willd., *Anagallis arvensis* L., *Vicia sativa* L. and *Convolvulus arvensis* L. constitute important broad-leaved weeds (Chhokar *et al.*, 2012; Ahlawat *et al.*, 2025) [9, 8]. The co

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existence of diverse weed groups complicates management because individual herbicides may not provide satisfactory control across the entire weed spectrum.

From a weed-science perspective, total weed density (m^{-2}) and total weed dry weight (g m^{-2}) are important quantitative indicators for assessing the intensity of weed infestation and the bio-efficacy of weed-management treatments. Assessment of both parameters is therefore more informative than relying solely on weed counts, because reductions in weed number do not necessarily indicate proportional reductions in competitive biomass. Manual and mechanical weed control is constrained by labour scarcity, rising costs and the narrow window for timely weed removal. Although cultural practices contribute to weed suppression, selective pre- and post-emergence herbicides provide rapid and effective control with low labour requirements. Increasing weed diversity has further promoted the use of ready-mix formulations and herbicide combinations to broaden weed control and reduce escapes (Jain *et al.*, 2020; Shah *et al.*, 2025; Ahlawat *et al.*, 2025) [10, 11, 8].

However, repeated dependence on herbicides with similar modes of action can exert selection pressure on weed populations and contribute to herbicide resistance, particularly in *P. minor*. Such changes may result in reduced herbicide efficacy and shifts in weed flora (Singh *et al.*, 2009; 2011) [12, 13]. Therefore, comparative evaluation of herbicide treatments based on their ability to reduce both total weed density and weed dry weight is essential for identifying effective weed-management strategies under specific production environments. Accordingly, the present investigation was undertaken to evaluate the efficacy of different herbicide treatments in suppressing total weed density and total weed dry weight in wheat, thereby providing a quantitative assessment of weed suppression and the potential of these treatments to minimize crop-weed competition.

2. Materials and method

The field experiment was conducted during two consecutive Rabi seasons, i.e., 2024-25 and 2025-26, at the Instructional Farm, Department of Agronomy, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, India ($23^{\circ}10' \text{ N}$, $79^{\circ}57' \text{ E}$; 393 m above mean sea level). The soil was a deep, clayey Vertisol. The experiment was laid out in a Randomized Block Design (RBD) with nine treatments and three replications. Wheat variety GW 451 was sown at 100 kg ha^{-1} with 22.5 cm row spacing. A uniform fertilizer dose of $120:60:40 \text{ kg N:P}_2\text{O}_5:\text{K}_2\text{O ha}^{-1}$ was applied to all treatments.

The weed-management treatments comprised pyroxasulfone 85% WG @ $127.5 \text{ g a.i. ha}^{-1}$ (PE), pinoxaden 5.1% EC @ $40 \text{ g a.i. ha}^{-1}$

(PoE), metsulfuron-methyl 20% WP @ 4 g a.i. ha^{-1} (PoE), clodinafop-propargyl 15% WP @ $60 \text{ g a.i. ha}^{-1}$ (PoE), clodinafop-propargyl 9% + metribuzin 25% WP @ $54 + 120 \text{ g a.i. ha}^{-1}$ (PoE), 2,4-D amine salt 58% SL + carfentrazone 40% WDG @ $500 + 20 \text{ g a.i. ha}^{-1}$ (PoE), clodinafop-propargyl 15% WP + metsulfuron-methyl 20% WP @ $60 + 4 \text{ g a.i. ha}^{-1}$ (PoE), hand weeding at 20 and 40 DAS, and weedy check.

Herbicides were applied using a calibrated knapsack sprayer fitted with a flat-fan nozzle. Pyroxasulfone was applied immediately after sowing, while post-emergence herbicides were applied at the pre-scribed crop and weed growth stages. All other crop-management practices were followed uniformly across treatments.

Weed density was recorded at 20, 40 and 60 DAS using two randomly placed 0.25 m^2 quadrats per plot. Individual weed species were counted and expressed as weeds m^{-2} ; total weed density was calculated by summing all species. For dry-weight estimation, weeds collected from the same quadrats were washed, air-dried and oven-dried at $65 \pm 5^{\circ} \text{ C}$ until constant weight and expressed as g m^{-2} .

Data on total weed density and weed dry weight were subjected to ANOVA appropriate for RBD following Panse *et al.* (1985) [14]. Treatment means were compared using the Critical Difference (CD) at 5% probability, and SE(m), SE(d) and CV were calculated.

3. Results and discussion

The total weed density at harvest was significantly influenced by weed-management practices in both years as well as in the pooled analysis (Table and Fig 1). The weedy check (T_9) recorded the maximum total weed density of 179.70, 176.75 and 178.23 weeds m^{-2} during 2024-25, 2025-26 and pooled analysis, respectively. In contrast, no weed population was recorded under the weed-free treatment (T_8). Among herbicidal treatments, clodinafop-propargyl + metsulfuron-methyl @ $60 + 4 \text{ g a.i. ha}^{-1}$ (T_7) resulted in the lowest total weed density of 10.06, 9.32 and 9.69 weeds m^{-2} , respectively, followed by clodinafop-propargyl + metribuzin @ $54 + 120 \text{ g a.i. ha}^{-1}$ (T_5), which recorded 18.78 weeds m^{-2} in the pooled analysis. Thus, T_7 suppressed the pooled weed population by approximately 94.6% relative to the weedy check.

The pronounced reduction in weed density under T_7 was evident for both monocot and dicot components. Pooled monocot and dicot densities were only 1.04 and 8.65 weeds m^{-2} , respectively, compared with 17.09 and 161.14 weeds m^{-2} under the weedy check. This response can be attributed to the complementary weed spectrum of the two herbicides: clodinafop-propargyl primarily suppresses susceptible grassy weeds, whereas metsulfuron-methyl provides effective post-emergence activity against a broad range of broad-leaved weeds.

Table 4.1. Total weed density at harvest as influenced by various weed management practices

Treatments		Total weed density (m^{-2})								
		Monocot			Dicot			Total		
		2024-25	2025-26	Pooled	2024-25	2025-26	Pooled	2024-25	2025-26	Pooled
T₁	Pyroxasulfone 85% WG @ $127.5 \text{ g a.i. ha}^{-1}$ (PE)	7.73	7.53	7.63	132.60	130.12	131.36	140.34	137.65	138.99
T₂	Pinoxaden 5.1% EC @ $40 \text{ g a.i. ha}^{-1}$ (PoE)	2.60	2.32	2.46	113.20	111.52	112.36	115.79	113.84	114.82
T₃	Metsulfuron methyl 20% WP @ 4 g a.i. ha^{-1} (PoE)	14.69	14.22	14.46	25.45	23.82	24.63	40.14	38.03	39.09
T₄	Clodinafop propargyl 15% WP @ $60 \text{ g a.i. ha}^{-1}$ (PoE)	4.28	4.69	4.48	131.89	130.87	131.38	136.17	135.56	135.86
T₅	Clodinafop Propargyl 9% + Metribuzin 20% WP @ $54+120 \text{ g a.i. ha}^{-1}$ (PoE)	1.77	1.69	1.73	17.48	16.61	17.05	19.25	18.30	18.78
T₆	2,4-D dimethyl ammonium salt 58% SL + Carfentrazone 40% WDG @ $500 + 20 \text{ g a.i. ha}^{-1}$ (PoE)	13.38	12.80	13.09	20.37	20.02	20.19	33.75	32.81	33.28
T₇	Clodinafop propargyl 15% WP + Metsulfuron methyl 20% WP @ $60+4 \text{ g a.i. ha}^{-1}$ (PoE)	1.11	0.97	1.04	8.95	8.34	8.65	10.06	9.32	9.69

(continued on next page)

Treatments		Total weed density (m^{-2})								
		Monocot			Dicot			Total		
		2024-25	2025-26	Pooled	2024-25	2025-26	Pooled	2024-25	2025-26	Pooled
T ₈	Weed free	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T ₉	Weedy check	17.55	16.63	17.09	162.16	160.13	161.14	179.70	176.75	178.23
	S.E.m.(±)	0.52	0.42	0.37	1.89	2.76	2.01	1.86	2.70	2.01
	CD ($P=0.05$)	1.56	1.26	1.11	5.67	8.26	6.02	5.59	8.10	6.03

Consequently, their combined application provided more comprehensive suppression of the mixed weed flora than the respective individual

herbicides.

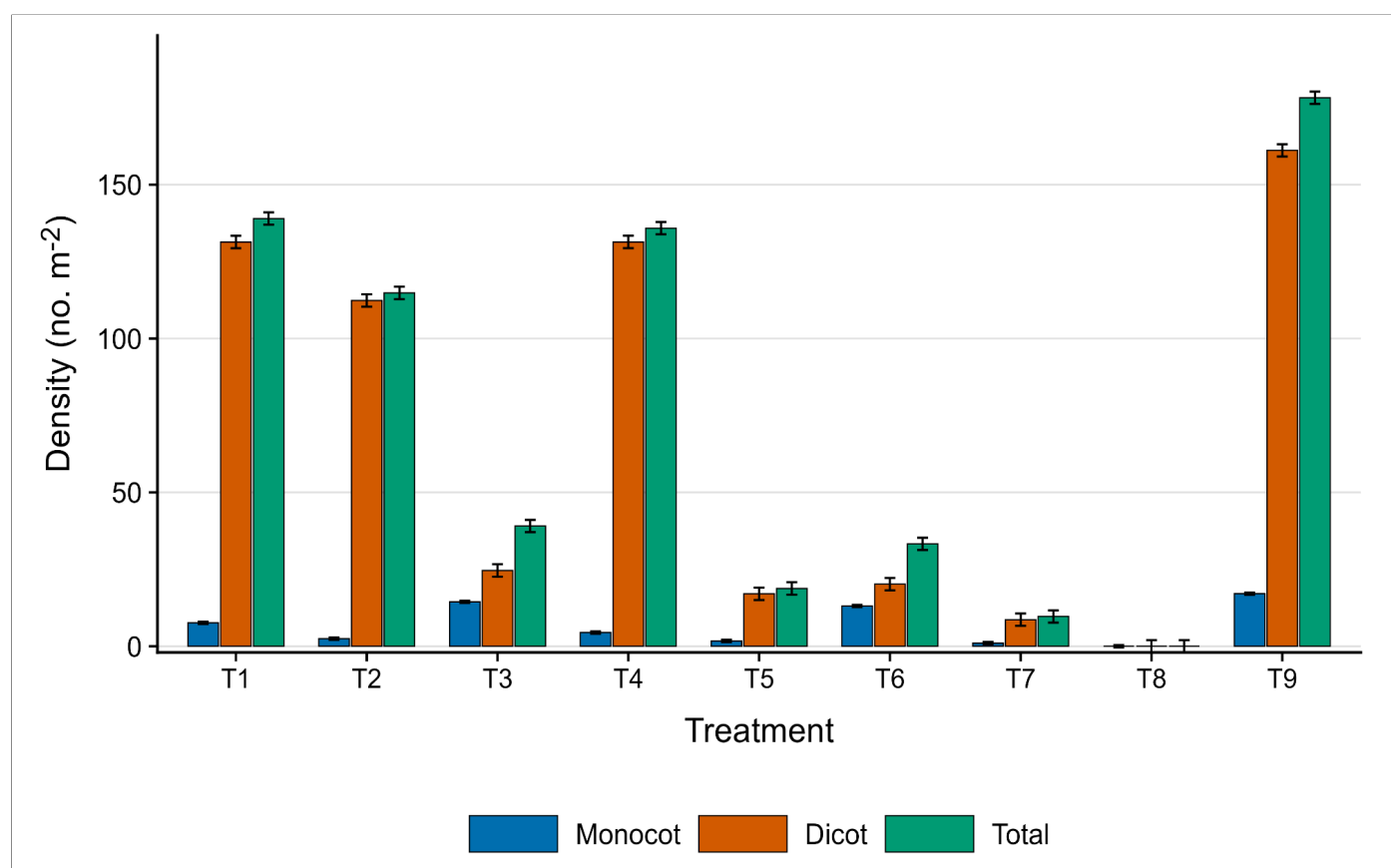


Figure 4.1. Total weed density at harvest as influenced by various weed management practices in pooled analysis

The present results corroborate the findings of Punia *et al.* (2008) [15], who reported that clodinafop + metsulfuron effectively suppressed both grassy and broad-leaved weeds, providing about 97% and 100% control, respectively. Kumar *et al.* (2011) [16] similarly observed substantial reductions in total weed density and dry weight with clodinafop + metsulfuron combinations.

The superiority of T₇ was also consistent with the findings of Deshmukh *et al.* (2020) [17], who reported that clodinafop-propargyl + metsulfuron-methyl @ 60 + 4 g ha⁻¹ reduced pooled weed density to 18.89 plants m⁻², with 89.66% weed-control efficiency. Raj *et al.* (2020) [18] likewise identified this combination as the most effective herbicidal treatment, with 82.02% weed-control efficiency. The present pooled density of 9.69 weeds m⁻² under the same combination was even lower, which may reflect differences in weed flora, environmental conditions, herbicide application conditions and crop-weed competition across experimental environments.

The next effective treatment, T₅, also demonstrated the value of combining herbicides with different weed-control spectra. Earlier, Chand *et al.* (2017) [19] reported that clodinafop + metribuzin was highly effective against complex weed flora, producing low weed density and

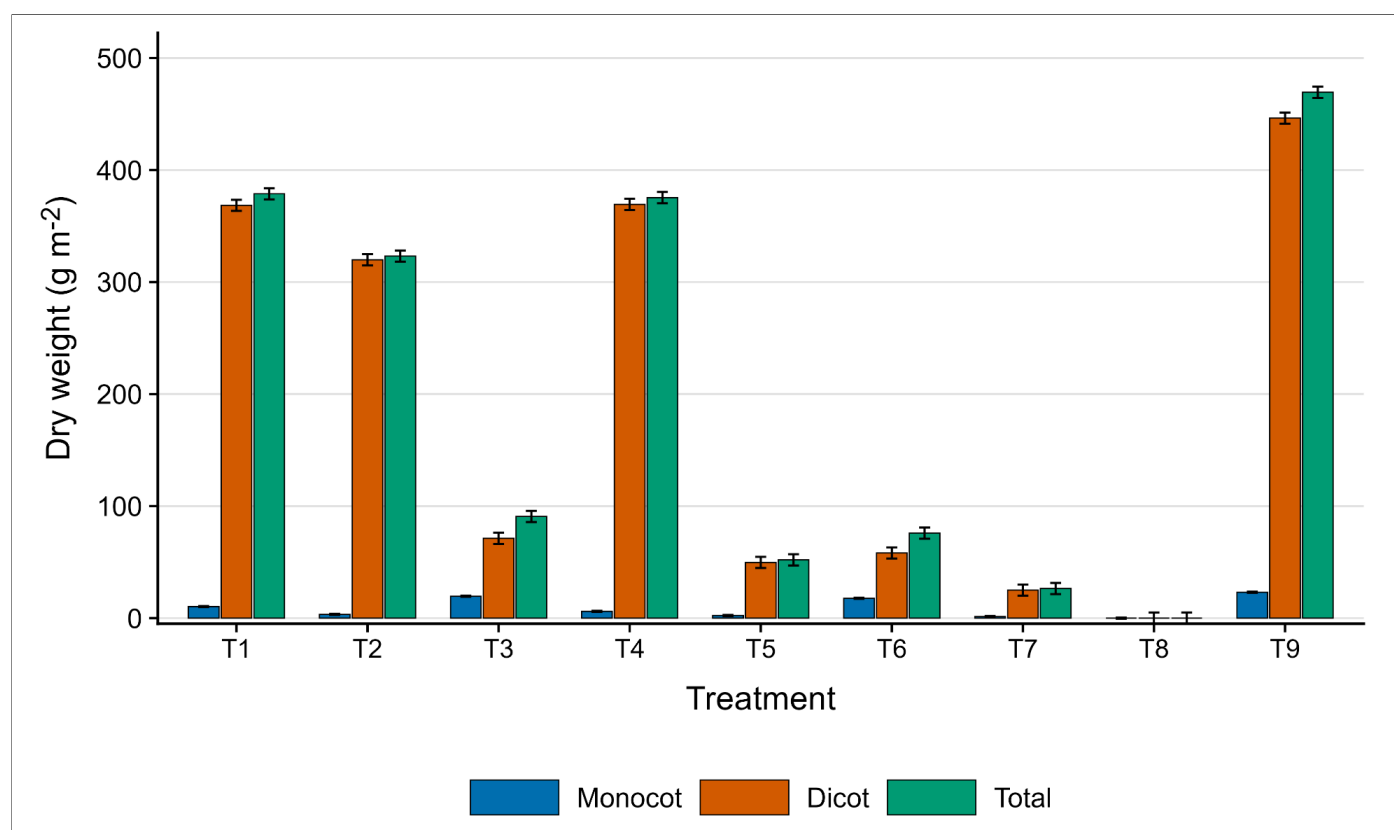
dry matter with more than 92% weed-control efficiency at later crop stages. Choudhary *et al.* (2017) [20] similarly reported substantial suppression of total weed density with clodinafop + metribuzin.

Individual herbicides were comparatively less effective in suppressing the entire weed community. This response emphasizes that the efficacy of a herbicide is strongly influenced by the composition of the weed flora and its spectrum of activity. Yadav *et al.* (2024) [21] also reported greater weed suppression with herbicide combinations than with individual herbicide applications. Similar broad-spectrum responses have been reported for pinoxaden and pyroxasulfone against predominantly grassy weeds, although their performance can vary with species composition and application timing.

The total weed dry weight exhibited a response pattern broadly similar to weed density and was significantly affected by weed-management treatments in both years and in the pooled analysis (Table and Fig 2). The weedy check (T₉) accumulated the maximum weed dry weight of 494.41, 444.53 and 469.47 g m⁻², whereas weed-free plots recorded no weed biomass. Among herbicidal treatments, T₇ recorded the minimum total weed dry weight of 28.38, 24.49

Table 4.2. Total weed dry weight at harvest as influenced by various weed management practices

Treatments	Total weed dry weight (g m ⁻²)								
	Monocot			Dicot			Total		
	2024-25	2025-26	Pooled	2024-25	2025-26	Pooled	2024-25	2025-26	Pooled
T₁ Pyroxasulfone 85% WG @ 127.5 g a.i. ha ⁻¹ (PE)	10.83	9.79	10.31	388.60	348.34	368.47	399.43	358.13	378.78
T₂ Pinoxaden 5.1% EC @ 40 g a.i. ha ⁻¹ (PoE)	3.64	3.01	3.33	336.66	303.09	319.88	340.30	306.11	323.20
T₃ Metsulfuron methyl 20% WP @ 4 g a.i. ha ⁻¹ (PoE)	20.58	18.49	19.53	76.07	66.46	71.27	96.65	84.95	90.80
T₄ Clodinafop propargyl 15% WP @ 60 g a.i. ha ⁻¹ (PoE)	5.99	6.10	6.05	387.81	350.87	369.34	393.81	356.96	375.38
T₅ Clodinafop Propargyl 9% + Metribuzin 20% WP @ 54+120 g a.i. ha ⁻¹ (PoE)	2.48	2.20	2.34	52.71	46.73	49.72	55.18	48.93	52.05
T₆ 2,4-D dimethyl ammonium salt 58% SL + Carfentrazone 40% WDG @ 500 + 20 g a.i. ha ⁻¹ (PoE)	18.73	16.64	17.69	60.92	55.48	58.20	79.65	72.13	75.89
T₇ Clodinafop propargyl 15% WP + Metsulfuron methyl 20% WP @ 60+4 g a.i. ha ⁻¹ (PoE)	1.55	1.27	1.41	26.83	23.23	25.03	28.38	24.49	26.44
T₈ Weed free	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T₉ Weedy check	24.57	21.62	23.10	469.84	422.91	446.37	494.41	444.53	469.47
S.Em (±)	0.74	0.55	0.51	5.49	6.39	4.99	5.42	6.36	5.01
CD (P=0.05)	2.21	1.64	1.52	16.47	19.15	14.97	16.24	19.08	15.01

**Figure 4.2.** Total weed dry weight at harvest as influenced by various weed management practices in pooled analysis

and 26.44 g m⁻² during 2024-25, 2025-26 and pooled analysis, respectively. T₅ ranked next with 52.05 g m⁻² in the pooled analysis. Thus, T₇ reduced weed biomass by approximately 94.4% compared with the weedy check.

The reduction in weed biomass under T₇ was associated with its strong suppression of both components of the weed flora. Pooled monocot and dicot dry weights were only 1.41 and 25.03 g m⁻², respectively, compared with 23.10 and 446.37 g m⁻² under the weedy check. The substantially lower biomass indicates that the treatment restricted not only weed establishment but also subsequent growth and dry-matter accumulation. In agronomic terms, reduced weed biomass represents lower competitive demand for soil moisture, nutri-

ents, light and growing space, thereby reducing the intensity and duration of crop-weed interference.

The present findings are in close agreement with [Deshmukh et al. \(2020\) \[17\]](#), who recorded only 24.66 g m⁻² weed biomass with clodinafop-propargyl + metsulfuron-methyl @ 60 + 4 g ha⁻¹. Similarly, [Yadav et al. \(2019\) \[22\]](#) reported approximately 89% reduction in weed dry matter with clodinafop-propargyl + metsulfuron-methyl compared with the weedy check.

The effectiveness of herbicide mixtures in restricting weed biomass has also been demonstrated by [Jain et al. \(2020\) \[10\]](#), who reported substantially lower weed dry matter with broad-spectrum herbicide combinations. Likewise, [Sahana et al. \(2021\) \[23\]](#) observed markedly

lower weed density with metsulfuron-methyl + carfentrazone, attributing the response to complementary activity against mixed weed flora.

The relatively good performance of T₅ in the present study is also supported by Goyal *et al.* (2025) [24], who reported that metribuzin + clodinafop-propargyl substantially reduced total weed density and biomass compared with the unsprayed control. Similarly, Chhokar *et al.* (2023) [25] reported that pre-emergence pyroxasulfone at 85-127.5 g a.i. ha⁻¹ reduced total weed dry weight by 75.9-95.6%, demonstrating its strong activity against wheat weed flora.

The higher weed density and biomass under the weedy check indicate unrestricted weed emergence and continuous biomass accumulation throughout the crop period. Such persistent weed interference can intensify competition for essential growth resources and consequently reduce crop productivity. Conversely, the substantial reduction in both weed population and biomass under T₇ demonstrates effective and sustained suppression of the weed community.

Overall, the results establish that clodinafop-propargyl + metsulfuron-methyl @ 60 + 4 g a.i. ha⁻¹ was the most effective herbicidal treatment for suppressing the mixed weed flora, as reflected by the lowest total weed density (9.69 weeds m⁻²) and total weed dry weight (26.44 g m⁻²) in pooled analysis. The consistency of this response across both experimental years indicates that combining herbicides with complementary modes and spectra of activity can provide more reliable control of complex weed flora in wheat than reliance on individual herbicides.

4. Conclusion

The study demonstrated that herbicide-based weed management markedly influenced total weed density and weed dry weight in wheat. Among the herbicidal treatments, clodinafop propargyl + metsulfuron methyl (60 + 4 g a.i. ha⁻¹) was the most effective treatment, recording the lowest pooled total weed density (9.69 m⁻²) and weed dry weight (26.44 g m⁻²), representing reductions of 94.56 and 94.37%, respectively, over the weedy check. The superior performance of this combination was associated with effective suppression of both monocot and dicot weeds. The clodinafop + metribuzin combination was the next most effective treatment. Overall, the results indicated that herbicide combinations with complementary weed-control spectra provided more consistent suppression of the complex weed flora than individual herbicides, thereby reducing weed competition and improving the weed-management efficiency in wheat.

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