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Efficacy of clodinafop propargyl alone and its compatibility with other herbicides on weed indices and productivity of wheat (*Triticum aestivum* L.)

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Abstract
A field experiment was conducted during the *rabi* season of 2021-22 at Research Farm A, College of Agriculture, Ganj Basoda, District Vidisha (M.P.) to evaluate the bio-efficacy of tank-mix herbicides in wheat. The experiment consisting of nine treatments was laid out in randomized block design with three replications. The results revealed that tank-mix application of clodinafop propargyl + metsulfuron methyl @ 60 + 4 g a.i. ha^{-1} reduced significantly the weed density (14.61 No./m^2), dry weight (24.73 g/m^2) and weed index (3.25%) while highest weed control efficiency (85.26%), herbicide efficiency index (3.587), weed persistence index (1.229), crop resistance index (9.368), grain yield (4854 kg ha^{-1}) and crop dry matter yield (12643 kg ha^{-1}) to over all the herbicidal treatments but found at par with clodinafop propargyl + metribuzin @ 60 + 175 and clodinafop propargyl + carfentrazone ethyl @ 60 + 20 g a.i. ha^{-1}.

Keywords: Weed control efficiency, weed index, herbicide efficiency index, weed persistence index, crop resistance index, wheat

Introduction
Wheat (*Triticum aestivum* L.) is the most widely cultivated food grain crop of world playing crucial role in global food security by providing food to billions of people and half of the dietary protein and more than half of the calories (Meena *et al.*, 2017) [12]. Production of the wheat crop is directly impacted by several biotic and abiotic factors. Among these, the most limiting biological constraint is the infestation of weeds. The yield losses of wheat vary between 17-30% annually (Rao and Chauhan, 2015) [16]. The combination of cultural and herbicidal applications is used to manage weeds in wheat crops (Chachar *et al.*, 2009) [1]. Chemical control is majorly used as it is a quick, more effective, time and labour-saving methos for controlling weeds in wheat (Mehmeti *et al.*, 2018) [13]. The constant use of herbicides acting on the same site led to multiple herbicide resistance (Singh *et al.*, 2009) [21]. Weed competition for longer period results into reduction of crop growth and yield attributes over weed free environment (Yadav *et al.*, 2020) [23]. A mixture of more than one herbicide is essential for the effective management of multiple weed flora. Herbicide combinations improve weed control efficacy against weed flora (Singh *et al.*, 2011) [22]. However, continuous use of these herbicides leads to built up of resistance in weeds. To broaden the spectrum of weed, kill and to provide the long-term residual weed control, it is therefore, necessary to combine or change the method and strategies of weed control are advocated. Combined use of herbicide besides providing control of complex weed flora will also help in managing and delaying the herbicide resistance problem.

Materials and Methods
The field experiment was carried out during the *rabi* season of 2021-22 at the Research Farm A, College of Agriculture, Ganj Basoda, District Vidisha (M.P.) (23^0 51’ N, 77^0 55’ E and at 416.66 m above mean sea level). Experimental site is characterized by sub-humid with hot dry summers and cool dry winters. The average annual rainfall in Vidisha district is 1135 mm, with most of it falling between mid-June and the end of September, with a little and occasional rains in the other months of the year.

The soil in the Ganj Basoda district Vidisha region is classed as Vertisol. The depth ranges from medium to deep and the colour is black. Nine treatments *viz.* T_1 - clodinafop propargyl, T_2 - metsulfuron methyl, T_3 - carfentrazone ethyl, T_4 - metribuzin, T_5 - clodinafop propargyl + metsulfuron methyl, T_6 - clodinafop propargyl + carfentrazone ethyl, T_7 - clodinafop propargyl + metribuzin, T_8 - hand weeding at 30 days after sowing (DAS) and T_9 - weedy check were tested in randomized block design with three replications. Wheat variety HI-1544 (Purna) was treated with fungicide (Tebuconazole @ 2.5 g/kg seed) sown on 16th November, 2021 at 20 cm apart using 100 kg seed/ha. The crop was harvested on 21st March, 2022. All the herbicides were applied by knapsack sprayer fitted with flat fan nozzle using spray volume of 500 litre/ha. All the herbicides were sprayed at 25 DAS of wheat crop as post emergence whereas, hand weeding was done at 30 DAS with the help of Khurpi. Weed population was recorded by using 0.25 m^2 quadrate at 30 and 60 DAS in all the treatments. The weeds were dried in oven till a constant weight was observed and then converted in to kg/ha. The data on total weed count was subjected to square root transformation *i.e.*, $\sqrt{(x + 0.5)}$ to normalize their distribution (Gomez and Gomez, 1984) [5]. Weed control efficiency (WCE) was calculated to compare the different treatments of weed control based on dry weight. It indicates the per cent reduction in the dry weight in treated plots compared to weedy check plots. The formula is as follows (Mani *et al.*, 1973; Das 2008) [10, 3]:

$$\text{WCE (\%)} = \frac{\text{Dry weight of weeds in weedy check} - \text{Dry weight of weeds in treated plot}}{\text{Dry weight of weeds in weedy check}} \times 100$$

Weed index (WI) is the per cent reduction in crop yield under a particular treatment due to the presence of weeds in comparison to weed free plot as suggested by Gill and Kumar (1969) [4]. This is used to assess the efficacy of a herbicide. Lesser the weed index, better is the efficiency of a herbicide. It is expressed in percentage and was determined with the help of following formula:

$$\text{Weed index (\%)} = \frac{\text{Yield of weed free plot} - \text{Yield of treated plot}}{\text{Yield of weed free plot}} \times 100$$

The relationship between the crop biomass and weed biomass can be correlated with the help of crop resistance index (CRI) and its shows indirect proportionate relationship to each other. The crop resistance index can be calculated with the help of below mentioned formula given by Misra and Misra (1997) [14] as follows:

$$\text{CRI} = \frac{\text{Dry matter production by crop in treated plot}}{\text{Dry matter production by crop in control plot}} \times \frac{\text{Dry matter production of weed in control plot}}{\text{Dry matter production of weed in treated plot}}$$

Weed persistence index (WPI) indicates the resistance in weeds against the tested treatments and confirms the effectiveness of the selected herbicides and the same was computed using the given formula as suggested by Misra and Misra (1997) [14]:

$$\text{WPI} = \frac{\text{Dry weight of weeds in treated plot}}{\text{Dry weight of weeds in control plot}} \times \frac{\text{Weed density in control plot}}{\text{Weed density in treated plot}}$$

Herbicide efficiency index (HEI) represents the potential of a particular herbicide for controlling the weeds along with their phyto-toxicity effect on the crop. The formula is as follows (Krishnamurthy *et al.*, 1975) [7]:

$$\text{HEI} = \frac{\dfrac{\text{Crop yield from treated plot} - \text{Crop yield from weedy check plot}}{\text{Crop yield from treated plot}} \times 100}{\dfrac{\text{Weed dry matter in treated plot}}{\text{Weed dry matter in weedy check plot}} \times 100}$$

Results and Discussion

Weed flora

The experiment field was infested with grassy, broad-leaf weeds and sedges (Fig. 1). Among the broad-leaf weeds, *Convolvulus arvensis* (23.30%), *Chenopodium album* (16.77%), *Anagallis arvensis* (16.23%) and *Parthenium hysterophorus* (7.14%) were the dominant weeds. Dominant grassy weeds that invade the field were *Phalaris minor* (9.48%) and *Cynodon dactylon* (13.71%). Wheat crop field was also invaded by sedges *i.e.*, *Cyperus rotundus* which had relative density in weedy check 13.38 per cent. Punia *et al.* (2017) [15] reported that the weed flora in all, 21 weed species (4 grassy and 17 broad-leaf) were found to infest wheat fields in Haryana. In grassy weeds like *Phalaris minor, Avena ludoviciana, Poa annua, Polypogon monspliensis* and broad leaf weeds like *Chenopodium album, Chenopodium murale, Rumex dentatus, Rumex spinosus, Coronopus didymus, Anagallis arvensis, Medicago denticulate, Melilotus indica, Malva parviflora, Convolvulus arvensis, Cirsium arvense, Vicia sativa, Trigonella polycerate, Asphodelus tenuifolius, Fumaria parviflora, Pluchea lanceaolata, Carthamus oxycantha*.

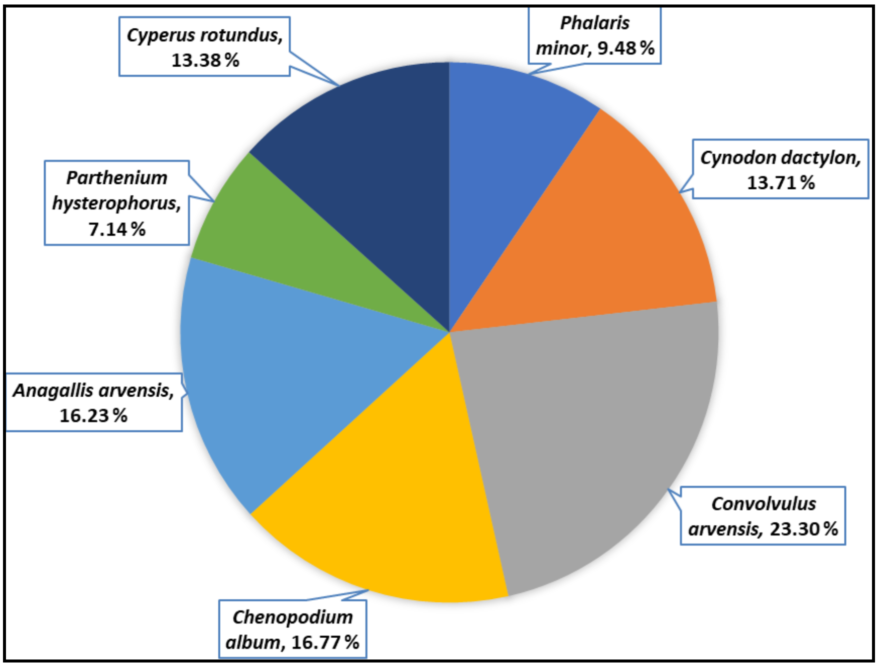

Fig 1: Relative density (%) of dominant weeds under weedy check plot in wheat

Effect on weed indices

The highest value of weed control indices (WCE) was obtained from hand weeding (94.83%) with respect to weedy check and shown in Table 1. Among herbicides, the maximum value of WCE was achieved by clodinafop propargyl + metsulfuron methyl (85.26%) as compared to any other treatments in case of grassy, broad-leaf and sedges weeds which was followed by the application of clodinafop propargyl + metribuzin (85.06%) and clodinafop propargyl + carfentrazone ethyl (82.90%). These tank-mix herbicides significantly reduced the population and dry weight of grassy, broad-leaf and sedges weeds. This was the main cause of higher WCE. These treatments are comparable to hand weeding. The sole application of single herbicide registered less WCE. Similarly, higher index values of HEI, WPI and CRI (3.587, 1.229 and 9.368) under combined application of clodinafop propargyl + metsulfuron methyl which was followed by the application of clodinafop propargyl + metribuzin and clodinafop propargyl + carfentrazone ethyl indicate potential of herbicides for significant control of weed population to increase the per cent yield over the control treatment. Furthermore, the highest value of WI was recorded under weedy check (36.72%) because the weedy check plot resulted in maximum reduction of yield due to presence of weeds throughout the crop growing period as compared to hand weeding. The application of treatments, clodinafop propargyl + metsulfuron methyl resulted in lowest yield reduction (3.25%) which proved to be superior over all the herbicidal treatments. It was tailed by clodinafop propargyl + metribuzin (7.02%). The third-best treatment was clodinafop propargyl + carfentrazone ethyl *i.e.*, 10.66 per cent weed index (Table 1). This was happened due to reduction in weeds because of effective weed management throughout the critical period of crop growth under these treatments. This resulted in minimal decrease in grain yield. These findings are in accordance with those of Meena *et al.* (2019) [11], Sharma *et al.* (2020) [19], Lakra (2021) [9], Sarita *et al.* (2022) [17].

Table 1: Effect of weed control treatments on weed control efficiency, weed index, herbicide efficiency index, weed persistence index and crop resistance index in wheat

Treatment	Weed control efficiency (%)	Weed index (%)	Herbicide efficiency index	Weed persistence index	Crop resistance index
T_1 - Clodinafop propargyl @ 60 g a.i. ha^{-1}	33.36	20.53	0.384	1.001	1.671
T_2 - Metsulfuron methyl @ 4 g a.i. ha^{-1}	53.05	15.29	0.721	1.042	2.519
T_3 - Carfentrazone ethyl @ 20 g a.i. ha^{-1}	50.76	17.10	0.629	1.057	2.327
T_4 - Metribuzin @ 210 g a.i. ha^{-1}	73.65	13.37	1.400	1.025	4.562
T_5 - Clodinafop propargyl + metsulfuron methyl @ 60+4 g a.i. ha^{-1}	85.26	3.25	3.587	1.229	9.368
T_6-Clodinafop propargyl + carfentrazone ethyl @ 60+20 g a.i. ha^{-1}	82.90	10.66	2.408	1.154	7.520
T_7 - Clodinafop propargyl + metribuzin @ 60+175 g a.i. ha^{-1}	85.06	7.02	3.141	1.222	8.904
T_8 - Hand weeding at 30 DAS (Once)	94.83	0.00	11.224	1.298	27.355
T_9 - Weedy check	0.00	36.72	0.000	1.000	1.000

Effect on density and dry weight of weeds

The data revealed significant reduction in all the weed control treatments with respect to weed density and weed dry matter over the weedy check and presented in Table 2. The highest reduction in density and dry matter of weeds were recorded under hand weeding (4.85 No./m^2 and 7.67 g/m^2) due to complete removal of the weeds whereas clodinafop propargyl + metsulfuron methyl found significantly superior among the herbicides treatments in curtailing the density and weed dry weight (14.61 No./m^2 and 24.73 g/m^2) and at par with clodinafop propargyl + metribuzin (14.89 No./m^2 and 25.06 g/m^2) and clodinafop propargyl + carfentrazone ethyl (18.05 No./m^2 and 28.68 g/m^2). Sole application of herbicide was less effective in controlling weeds as compared to their tank-mix application but metsulfuron had significant effects on population of broad-leaf weeds whereas clodinafop propargyl controlled grassy weeds effectively and almost least effective against broad-leaved weeds. The tank mixtures of broad-leaf and grassy weed killing herbicides provided higher order of performance in terms of weed density and intensity of total weeds. Similar findings are also reported by Chand *et al.* (2017) [2], Shaktawat *et al.* (2019) [18], Yadav *et al.* (2022) [24], Kumar *et al.* (2023) [8].

Grain and Crop dry matter yield

The various weed control treatment resulted in significant differences in grain and crop dry matter yield of wheat and presented in Table 2. Weedy check treatment produced the lowest grain and crop dry matter yield (3175 and 9154 kg ha^{-1}) due to weeds were under competitive stress for all resources. In case of herbicidal treatments, clodinafop propargyl + metsulfuron methyl produced highest grain and crop dry matter yield (4854 and 12643 kg ha^{-1}) and proved to be significantly superior to other herbicidal treatments and reduced crop weed competition up to maximum extent and enhanced the availability of various inputs used during crop production. Therefore, higher growth parameters and yield attributing parameters were achieved, resulting in higher grain and crop dry matter yield. Under hand weeded plot, the weed free environment and least crop weed competition was persisted. Consequently, the highest grain yield (5017 kg ha^{-1}) and crop dry matter yield (12943 kg ha^{-1}) was secured. Similar results are also reported by Kaur *et al.* (2015) [6], Shaktawat *et al.* (2019) [18], Singh (2022) [20], Kumar *et al.* (2023) [8].

Table 2: Effect of weed control treatments on weed density, dry weight of weeds, grain yield, and crop dry matter yield in wheat

Treatment	Weed density (No./m^2)	Dry weight of weeds (g/m^2)	Grain yield (kg ha^{-1})	Crop dry matter yield (kg ha^{-1})
T_1 - Clodinafop propargyl @ 60 g a.i. ha^{-1}	81.06	111.78	3987	10196
T_2 - Metsulfuron methyl @ 4 g a.i. ha^{-1}	54.9	78.76	4250	10825
T_3 - Carfentrazone ethyl @ 20 g a.i. ha^{-1}	56.73	82.59	4159	10488
T_4 - Metribuzin @ 210 g a.i. ha^{-1}	31.31	44.20	4346	11004
T_5 - Clodinafop propargyl + metsulfuron methyl @ 60+4 g a.i. ha^{-1}	14.61	24.73	4854	12643
T_6 - Clodinafop propargyl + carfentrazone ethyl @ 60+20 g a.i. ha^{-1}	18.05	28.68	4482	11770
T_7 - Clodinafop propargyl + metribuzin @ 60+175 g a.i. ha^{-1}	14.89	25.06	4665	12177
T_8 - Hand weeding at 30 DAS (Once)	4.85	8.67	5017	12943
T_9 - Weedy check	121.80	167.74	3175	9154
SEm±	4.37	5.41	44.2	90.1
CD at 5%	13.11	16.23	132.6	190.9

Conclusion

In conclusion, the study underscores the pervasive impact of weed flora on wheat crop fields, particularly highlighting the dominance of Convolvulus arvensis, Chenopodium album, Anagallis arvensis, Parthenium hysterophorus, Phalaris minor, and Cynodon dactylon. The efficacy of various weed control treatments, notably hand weeding and herbicide applications, was evaluated through indices such as Weed Control Efficiency (WCE), Herbicide Efficiency Index (HEI), Weed Persistence Index (WPI), and Crop Resistance Index (CRI). Results demonstrate the substantial effectiveness of combined herbicide applications, particularly clodinafop propargyl + metsulfuron methyl, in minimizing weed populations and enhancing crop yields. Furthermore, these treatments exhibited superior performance compared to sole herbicide applications, reflecting the significance of tank-mix formulations in weed management. The profound impact of weed control on weed density, dry matter, and ultimately grain and crop dry matter yield emphasizes the critical role of effective weed management strategies in optimizing wheat production. These findings corroborate previous studies and underscore the importance of adopting integrated weed management approaches to mitigate the adverse effects of weed infestation on crop productivity.

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