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Enhancing profitability and sustainability through herbicides on weed control in wheat-greengram cropping system in Punjab, India

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ABSTRACT

A field study was conducted during the two successive years of Rabi, 2020–21, 2021–22 and Kharif, 2020–21, 2021–22 at the research farm of Lovely Professional University, Jalandhar, Punjab (India) in a RBD (randomized block design) with eight weed-controlling treatments with three replications. In wheat, seed yield, straw yield, and minimum total weed population and dry weight of weed in subsequent wheat were noted with Pyroxasulfone, with at equality Pyroxasulfone as (PE), followed by HW twice (20 and 40 days after sowing), and 2,4-D sodium salt with a combination of 1 HW (60 DAS). The minimum weed population and dry weight of weeds, maximum weed control efficiency and Greengram growth characteristics, number of pods per plant, number of seeds per pod, test weight, seed and straw yields were noted with Pendimethalin at 2 DAS (PE) and Imazethapyr at 30 DAS (PE), which was at par with Imazethapyr as (PE), followed by (fb) Pendimethalin as (PoE), and HW twice at 20 and 40 days after sowing. It can be used for extremely active weed control to increase the output of Greengram.

Key words: *Herbicides, Cropping system, Greengram, Weed population and weed biomass*

Introduction

Wheat (*Triticum aestivum* L.) is the next most significant cereal crop after rice. Wheat is the best and most widespread cereal crop for human consumption. The wheat crop is largely grown in the Northern States of India and Uttar Pradesh is at the top with a total production of 25.22 million tonnes, followed by Punjab with 15.78 MT. But the production of wheat crops is highest in Punjab. Wheat is grown from November to December in a number of states in India, and harvesting is completed from April to May. The production of wheat is 99.70 M.T. of wheat grown in an area of 29.58 million hectares in India. The production of wheat in India is about 3371 kg ha^{-1} (Anonymous, 2018a). In Punjab, wheat is grown in a range of 3480 hectares with a product of 16360 thousand tonnes. The productivity of wheat in Punjab is about 4700 kg ha^{-1} Anonymous, (2018b). Weeds are a major impediment to irrigated wheat productivity because some monocot and dicot weeds infest wheat, causing a severe struggle for sunlight, important nutrients, moisture, and space, resulting in a severe reduction in wheat production and its superiority (Chhokar *et al*., 2012; DAS *et al*. (2012). Post-emergence of herbicide use of sulfosulfuron + metsulfuron-methyl remained identical against monocot and dicot weeds, and they noted expressively lower weed population and weed dry weight of these weeds and maximum seed yield at 60 DAS Sasode *et al*. (2020). Farmers in India are adopting chemical weed control methods that are very effective, ideal and practical.

Mungbean (*Vigna radiata* L.), normally identified as "Greengram", is one of the most significant and widely grown pulse crops in India. It contains approximately 25% protein, 62.6 percent carbohydrate, 1.1% fat, total dietary fiber, 16.3% and a variety of essential amino acids, including lysine, which is commonly lacking in cereals, and provides a protein-rich diet to the country's vegan population IIPR, (2019).

The occurrence of weeds not only disturbs grain yield, but it also correspondingly impacts the superiority of seed. Weed invasion and strength in the early stages are a significant biotic constraint in irrigated mungbean and have been shown to reduce yield by 50-80% under Greengram (Singh *et al*., 2017, and Verma and Chaoudhary, (2020). Pendimethalin effectively controls monocot and dicot weeds at the 3 to 4 leaf stage of crop growth.Imazethapyr has also been noted to offer active weed switch in Greengram after 30 days after sowing Singh *et al*. (2014). Imazethapyr is a wide-ranging herbicide. It stays in the soil for a long time and has a less toxic effect on soil health Tamang *et al*. (2015). For active managing of difficult weed flora, there is a necessity to use a combination of different new herbicides Devi *et al.* (2017), which would have a wide range of weed control without crop damage and low residual impact on the next crop and increase production of the crop Devi *et al*., (2017).

Materials and Methods

Area of the field

The experiment was conducted with wheat in Rabi of 2020–2022 and Greengram in kharif of 2020–22. Two years of a cropping system have been completed at the research farm, Lovely Professional University, Jalandhar (Punjab). The study was carried out in sandy loam soil with low organic matter content.

Climatic Conditions during Cropping Seasons

Figure 1 depicts monthly data on the maximum and minimum temperatures of the experimental date (Source: Punjab Agriculture University, Ludhiana, and Punjab, India).

Experiments, Treatments, and Design

In wheat, the performance of four herbicides (Pyroxasulfone as preemergence and Sulfosulfuron + Metsulfuron, Clodinafop-propargyl and 2, 4-D sodium salt as post-emergence) was evaluated by comparing with the 'hand weeding and 'weedy check' treatments as a check to observe the efficacy and economic of herbicide(s).

The study considered eight treatment such as T_1= Pyroxasulfone 85 % WP @ 120 g ha^{-1} (PE), T_2= Pyroxasulfone 85 % WP @ 110 g ha^{-1} (PE), T_3= Sulfosulfuron 75 % + Metsulfuron 5% WG @ 40 g ha^{-1} (PoE), T_4= Two hand weeding (30 and 60 DAS), T_5= Sulfosulfuron 75 % + Metsulfuron 5% WG @ 35 g ha^{-1} 35 (PoE), T_6= Clodinafop-propargyl 15 % WP @ 400 g ha^{-1} (PoE) + One hand weeding at 60 DAS, T_7= 2, 4-D sodium salt 80 % WP @ 750 g ha^{-1} (PoE) + One hand weeding at 60 DAS, T_8= Weedy check (Control). The wheat trial was led by a randomized block design (RBD) with three repetitions. The net pot extent of the wheat trial was 8 meters in length and 7 meters in width.

For kharif Greengram, the evaluation of five herbicides (Imazethapyr as (PE & PoE), Pendimethalin

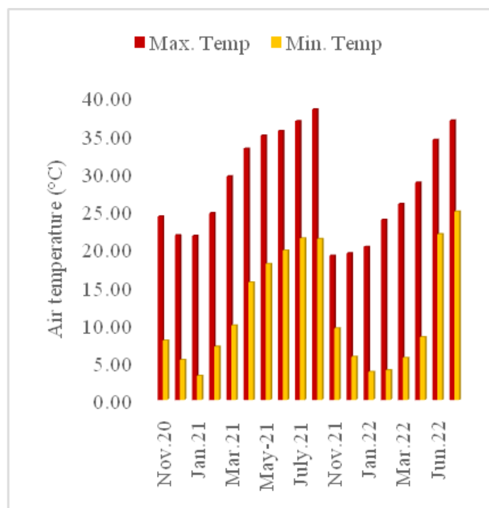

Fig. 1. Monthly average of maximum and minimum temperatures at the experimental site from November 2020 to August 2022

as (PE) and following herbicides are use at (PoE) Quizalofop-p-ethyl, Imazethapyr + Imazamax and Sodium Acifulourfen and Clodinafop-propargyl) was study with comparing weedy check. The study considered eight treatment such as T_1= Imazethapyr 10 % SL @ 60 g ha^{-1} (PE), T_2= Pendimethalin 30 % EC @ 1 kg ha^{-1} (PE), (PE) as + Imazethapyr @ 50 g ha^{-1} (PoE), T4= Hand weeding twice (20 and 40 DAS), T5= Quizalofop-p-ethyl 5 % EC @ 75 g ha^{-1} (PoE), T6= Imazethapyr 35 % + Imazamax 35 % WG @ 75 g ha^{-1} (PoE), T7= Sodium Acifulourfen 16.5 % and Clodinafop- propargyl 8 % EC @ 180 g ha-1 (PoE), T8= Unweeded check (Control). The Greengram trial was led by a randomized block design (RBD) with three repetitions. The net pot extent of the wheat trial was 8 meters in length and 7 meters in width.

Results and Discussion

Effect of herbicides on weeds in karif wheat

There were seven weed species in wheat during the winters of 2020–21 and 2021–22, including two grasses, *Phalaris minor* Retz., *Cynodon dactylon* (L.), sedges such as *Cyperus rotundus* (L.), and four broadleaf weeds, *Cannabis sativa* (L.), *Chenopodium album* (L.), *Medicago denticulate* Willd., and *Parthenium hysterophorus*. Similar weed species were also reported by the Singh *et al*. (2015) and Osari *et al*. (2020).

The species-wise and total weed population (density) of both monocot, sedges and dicot weeds were meaningfully regulated by Pyroxasulfone (120 g ha^{-1}) as PE at par with Pyroxasulfone (110 g ha^{-1}) as PE (Table 1). Hand weeding, on the other hand, significantly reduces the weed population when compared to control. The herbicides with the combination of one-handed weeding after 60 DAS show better performance. The weedy check plot had the highest plant population as compared to other herbicidal treatments. The outcomes are near conformism with Malik *et al*. (2013) and Katara *et al*. (2015).

Weed treatment had a significant effect on the reduction of weed biomass during both the years of the study (Table 2). Weed species and total minimum dry biomass of weeds remained recorded using Pyroxasulfone (120 g ha^{-1}) as PE and Pyroxasulfone vapour (110 g ha^{-1}) as PE fb 2, 4-D sodium salt (750 g ha^{-1}). This outcome revealed that Kaur and Kaur *et al*., (2019) had found. The weedy check plot was observed to have the highest weed dry biomass over the remaining herbicidal treatment. But, all herbicides cause an important lessening in total weed dry biomass as compared to the control.

Weed control efficiency (WCE) and weed index (WI) are dynamic factors to evaluate the performance of several weed management treatments. The weed control efficacy data showed that all treatments generally provided greater than 64% weed control efficacy over the weed control. Maximum

Table 1. Influence of herbicides on weed species and total weed density (no. m^{-2}) at 60 days after sowing of wheat by weed management treatments (Cumulative data for two years 2020-21 to 2021-22)

Treatments	Grasses		Sedges	Broadleaf				Total weed density
	P. minor	*C. dactylon*	*C. rotundus*	*C. sativa*	*C. album*	*M. denticulate*	*P. hysterophorus*	
Pyroxasulfone (120 g ha^{-1})	1.18 (1.41)	1.29 (1.67)	1.23 (1.53)	0.98 (1.00)	1.05 (1.11)	0.98 (0.97)	0.99 (0.99)	2.94 (8.67)
Pyroxasulfone (110 g ha^{-1})	1.22 (1.51)	1.33 (1.79)	1.29 (1.67)	1.08 (1.17)	1.10 (1.21)	1.01 (1.03)	1.01 (1.03)	3.14 (9.89)
Sulfosulfuron + Metsulfuron (40 g ha^{-1})	1.86 (3.49)	1.79 (3.22)	1.99 (3.96)	1.40 (1.96)	1.37 (1.88)	1.44 (2.08)	1.39 (1.93)	4.30 (18.52)
HW twice (20 and 40 DAS)	1.08 (1.18)	1.07 (1.15)	1.05 (1.10)	1.05 (1.11)	1.02 (1.05)	1.01 (1.09)	1.02 (1.05)	2.80 (7.82)
Sulfosulfuron + Metsulfuron (35 g ha^{-1})	1.88 (3.57)	1.63 (2.68)	1.98 (3.94)	1.45 (2.11)	1.44 (2.08)	1.48 (2.20)	1.40 (1.97)	4.30 (18.53)
Clodinafop-propargyl 400 g ha^{-1} + 1 HW (60 DAS)	1.75 (3.09)	1.67 (2.79)	1.84 (3.39)	1.36 (1.86)	1.36 (1.86)	1.37 (1.88)	1.34 (1.82)	4.10 (16.84)
2, 4-D sodium salt 750 g ha^{-1} + 1 HW (60 DAS)	1.55 (2.42)	1.58 (2.51)	1.76 (3.08)	1.25 (1.58)	1.35 (1.82)	1.34 (1.81)	1.03 (1.06)	3.77 (14.27)
Unweeded check (Control)	2.62 (6.91)	2.15 (4.63)	2.22 (4.90)	1.70 (2.89)	1.57 (2.47)	1.50 (2.26)	1.63 (2.67)	5.16 (26.71)
SE (m±)	0.08	0.13	0.11	0.12	0.11	0.11	0.14	0.08
CD (P = 0.05)	0.25	0.39	0.33	0.36	0.31	0.34	0.41	0.24

All Numbers are exposed to converted values to square root ($\sqrt{x+0.5}$).

(90%) weed control efficiency and minimum weed index were observed with pre-emergent use of Pyroxasulfone (120 g ha^{-1}) as PE, which was similar to Pyroxasulfone (110 g ha^{-1}) as PE fb 2, 4-D sodium salt (750 g ha^{-1}) PoE + One-hand weeding at 60 DAS (Table 3). Among herbicides, the minimum weed control efficiency was noted as Sulfosulfuron + Metsulfuron (40 g ha^{-1}) as PoE. Pyroxasulfone (110 g ha^{-1}) was used as a pre-emergent control of Phalaris minor (91.78%) at 60 days after sowing (Figures 5 and 6). Similar results were also found in Bayat and Zarger*et al*., (2020). A minimum weed control efficiency and a higher weed index were detected in control.

Herbicide effect on Rabi wheat growth character

Plant population was observed to be highest with Pyroxasulfone (120 g ha^{-1}) pre-emergence applica-

Table 2. Influence of herbicides on weed species and total weed biomass (no. m^{-2}) at 60 days after sowing of Wheat by weed controller treatments (cumulative data of two years 2020-21 to 2021-22)

Treatments	Grasses		Sedges	Broadleaf				Total
	P. minor	*C. dactylon*	*C. rotundus*	*C. sativa*	*C. album*	*M. denticulate*	*P. hysterophorus*	weed density
Pyroxasulfone (120 g ha^{-1})	0.42 (0.17)	0.35 (0.13)	0.37 (0.138)	0.20 (0.042)	0.32 (0.101)	0.22 (0.049)	0.22 (0.048)	0.82 (0.68)
Pyroxasulfone (110 g ha^{-1})	0.41 (0.10)	0.36 (0.13)	0.38 (0.144)	0.22 (0.047)	0.33 (0.125)	0.23 (0.054)	0.24 (0.056)	0.84 (0.71)
Sulfosulfuron + Metsulfuron (40 g ha^{-1})	0.66 (0.44)	0.57 (0.33)	0.53 (0.283)	0.31 (0.097)	0.47 (0.219)	0.26 (0.070)	0.91 (0.820)	1.50 (2.26)
HW twice (20 and 40 DAS)	0.38 (0.14)	0.41 (0.17)	0.30 (0.092)	0.19 (0.038)	0.30 (0.090)	0.20 (0.040)	0.20 (0.039)	1.79 (0.62)
Sulfosulfuron + Metsulfuron (35 g ha^{-1})	0.67 (0.44)	0.54 (0.29)	0.55 (0.305)	0.33 (0.111)	0.50 (0.253)	0.27 (0.074)	0.69 (0.481)	1.25 (1.57)
Clodinafop-propargyl 400 g ha^{-1} + 1 HW (60 DAS)	0.60 (0.36)	0.51 (0.26)	0.48 (0.234)	0.28 (0.080)	0.38 (0.146)	0.30 (0.091)	0.66 (0.434)	1.27 (1.61)
2, 4-D sodium salt 750 g ha^{-1} + 1 HW (60 DAS)	0.50 (0.25)	0.48 (0.23)	0.49 (0.244)	0.25 (0.062)	0.37 (0.135)	0.30 (0.088)	0.28 (0.077)	1.23 (1.52)
Unweeded check (Control)	1.42 (2.01)	1.20 (1.43)	1.03 (1.065)	0.55 (0.301)	0.95 (0.910)	0.58 (0.340)	0.60 (0.360)	2.45 (5.98)
SE (m±)	0.04	0.06	0.04	0.02	0.06	0.03	0.04	0.10
CD (P = 0.05)	0.12	0.17	0.11	0.06	0.18	0.09	0.122	0.30

All Numbers are expressed as converted values to square root ($\sqrt{x+0.5}$).

Table 3. Influence of herbicides on weed species, total weed control efficiency (no. m^{-2}) at 60 days after sowing and WI (%) of Wheat by weed controller treatments (cumulative data of two years 2020-21 to 2021-22)

Treatments	Grasses		Sedges	Broadleaf				Total	Weed
	P. minor	*C. dactylon*	*C. rotundus*	*C. sativa*	*C. album*	*M. denticulate*	*P. hysterophorus*	WCE (%)	Index (%)
Pyroxasulfone (120 g ha^{-1})	91.37	91.07	87.06	86.23	88.94	85.60	86.82	90.00	0.00
Pyroxasulfone (110 g ha^{-1})	91.78	91.06	86.50	84.41	86.30	84.29	84.61	88.87	3.41
Sulfosulfuron + Metsulfuron (40 g ha^{-1})	78.20	76.81	73.35	67.76	75.97	79.45	77.22	64.76	16.21
HW twice (20 and 40 DAS)	92.85	87.90	91.35	87.40	90.16	88.41	89.17	90.41	6.54
Sulfosulfuron + Metsulfuron (35 g ha^{-1})	77.92	79.39	71.29	63.21	72.20	78.41	75.28	69.14	17.10
Clodinafop-propargyl 400 g ha^{-1} + 1 HW (60 DAS)	81.90	82.08	78.02	73.57	83.94	73.39	76.97	68.28	13.53
2, 4-D sodium salt 750 g ha^{-1} + 1 HW (60 DAS)	87.37	84.19	78.53	79.41	85.20	74.13	78.62	77.58	7.20
Unweeded check (Control)	00.00	00.00	00.00	00.00	00.00	00.00	00.00	00.00	50.43
SE (m±)	-	-	-	-	-	-	-	-	0.49
CD (P = 0.05)	-	-	-	-	-	-	-	-	1.47

tion as compared to PE, which was on the same level as Pyroxasulfone (110 g ha^{-1}) as PE after hand weeding (30 and 60 DAS). It shows better results as compared to weed check (Table 4). The herbicides with the combination of one-handed weeding after 60 DAS show better performance.

A significant lessening in plant height was observed in the no-weed control, which may have been due to competition between the crop and the weed for soil moisture, plant nutrients, sunlight, and space during the active growth period (Table 4). These results were consistent with those reported by Pradhan and Chakraborti, (2010) and Punia *et al*. (2017).

These results were in agreement with the consequences stated by Pradhan and Chakraborti, (2010) and Punia *et al*., (2017). Higher plant heights were recorded for the application of Pyroxasulfone (120 g ha^{-1}) as PE, which was on the same level as Pyroxasulfone (110 g ha^{-1}) as PE as likened to weedy check. The data presented 60 days after sowing (Table 5) showed that weed controller treatments subsantially changes the active tillers in wheat. Pre-emergent use of Pyroxasulfone (120 g ha^{-1}) as PE, which was on the same level as PE (110 g ha^{-1}) and post-emergence application of 2,4-D sodium salt (750 g ha^{-1}) PoE + One-hand weeding at 60 DAS produced a higher number of viable tillers than the other herbicide treatments and remained at the same level as the no-weed control, this result close agreement with Kumar *et al.,* (2011). This can be attributed to viable weed control, leading to fewer weed problems.

Impact of herbicides on yield and yield characteristics and economics of rabi wheat

The higher stature of yield characteristics, viz., No. of spike m^{-2}, spike length (cm), No. of grains spike^{-1},

Table 4. Herbicide effects on growth characteristics of kharif greengram 60 days after sowing by weed controller treatments (Cumulative data from 2020-21 to 2021-22)

Treatments	Plant population (no. m^{-2})	Plant height (cm)	No. of tillers m^{-2}
Pyroxasulfone (120 g ha^{-1})	179.72	47.99	97.87
Pyroxasulfone (110 g ha^{-1})	178.72	47.47	97.56
Sulfosulfuron + Metsulfuron (40 g ha^{-1})	172.94	46.00	92.43
HW twice (20 and 40 DAS)	177.70	46.39	94.82
Sulfosulfuron + Metsulfuron (35 g ha^{-1})	171.83	45.55	91.79
Clodinafop-propargyl 400 g ha^{-1} + 1 HW (60 DAS)	176.82	46.16	93.95
2, 4-D sodium salt 750 g ha^{-1} + 1 HW (60 DAS)	177.82	46.71	95.94
Unweeded check (Control)	165.01	38.75	77.05
SE (m±)	0.85	0.69	0.69
CD (P = 0.05)	**2.57**	**2.09**	**2.10**

Table 5. Impact of herbicides on wheat yield and yield characteristics, as well as the wheat economy (Current data 2020-21 and 2021-22)

Treatments	No. of spike m^{-2}	Spike length (cm)	No. of grains/ spike	Test weight (g)	Seed yield t ha^{-1}	Straw yield (t ha^{-1})	Gross return (ha^{-1})	Net return (ha^{-1})	B:C ratio
Pyroxasulfone (120 g ha^{-1})	340.69	11.48	32.59	38.69	3251	3794	78555	53038	1.77
Pyroxasulfone (110 g ha^{-1})	337.78	11.43	32.14	37.69	3140	3772	75980	31869	1.73
Sulfosulfuron + Metsulfuron (40 g ha^{-1})	331.02	11.20	31.62	36.30	2724	3268	65909	24425	1.59
HW twice (20 and 40 DAS)	335.67	11.37	31.87	36.38	3038	3611	73481	36444	1.69
Sulfosulfuron + Metsulfuron (35 g ha^{-1})	330.93	11.16	31.55	36.04	2695	3234	65207	23862	1.58
Clodinafop-propargyl 400 g ha^{-1} + 1 HW (60 DAS)	335.26	11.24	31.74	36.18	2811	3250	67892	23957	1.59
2, 4-D sodium salt 750 g ha^{-1} + 1 HW (60 DAS)	336.23	11.55	32.45	38.87	3017	3154	72533	26002	1.67
Unweeded check (Control)	320.81	10.77	30.18	34.78	1611	2441	39494	317	1.01
SE (m±)	0.70	0.56	0.43	0.37	49.47	53.63	-	-	-
CD (P = 0.05)	2.12	1.69	1.32	1.12	150.04	162.79	-	-	-

and test weight (g) for the use of Pyroxasulfone (120 g ha^{-1}) as PE, which was on par with Pyroxasulfone (110 g ha^{-1}) as PE fb post-emergent use of 2,4-D sodium salt (750 g ha^{-1}) PoE + one hand weeding as similar results were also found in Bhoir *et al*. (2016) and Kaur *et al*. (2019).

Herbicide use had a significant impact on wheat grain and straw yield (Table 5).This may be due to the good seed yield obtained in these treatments due to better weed management. The highest wheat grain yield was noted through Pyroxasulfon (120 g ha^{-1}) as PE, which was comparable to Pyroxasulfon (110 g ha^{-1}) because in PE almost identical results were found by Johnson *et al*. (2018). The herbicides Sulfosulfuron + Metsulfuron (35 g ha^{-1}) applied post-emergence yielded a grain yield of 2.6 tonnes ha^{-1}, which is the lowest wheat grain yield associated with the control (Table 10).

Maximum values of gross return (78,555 ha^{-1}) and net monetary returns (53038 ha^{-1}) remained noted through Pyroxasulfone (120 g ha^{-1}) as PE, which was on par with Pyroxasulfone (110 g ha^{-1}) as PE. The minimum net monetary returns and benefit cost ratio were detected by weedy check practice throughout the year (Table 10). The variation in benefit cost ratio is due to the price of chemical weed control and the return of the crop. The same results were observed by Osari *et al*. (2019).

Influence of herbicides on weeds in kharif Greengram

Both monocot and dicot weeds were observed, but the dominance of both weeds was greater in the entire field. Among the five weed species mentioned in the winter of 2020–21 and 2021–22 were two grasses, *Commelina benghalensis* L., *Digitaria sanguinalis* L., sedges *Cyperus rotundus* L., and two broadleaf weeds such as *Cassia tora* L., *Celosia argentea* L. Weed flora was also observed in Sasode *et al*. (2020) and Singh *et al*. (2019).

Weed-free treatment results show fewer weed species, total weed population, and weed dry weight. Herbicidal treatments significantly influenced the weed population and dry weight of the weeds. The density and biomass of both monocot and dicot weeds were suggestively lowest by all weed controller treatments likened to control, though, weed free (two hand weeding) noted minimum count of dicot, monocot and total weeds than the remaining of the treatments. The lowest weed population and dry weight of weeds were seen for the use of pendimethalin (1 kg ha^{-1}) as (PE) followed by Imazethapyr (50 g ha^{-1}) as (PoE) at 40 days after sowing (Table 6 and 7). Higher weed populations were counted under weedy check as compared to herbicidal treatment. Similar outcomes were detected by Yadav *et al*., (2019).

Weed control efficiency (WCE) shows the true magnitude of weed dry weight reduction by different weed treatments. Weed control efficiency (WCE) varied with different weed control methods at 40 days after sowing (Table 8). In the WCE, the total dry weight of the weeds, which consists of different weed species with different proportions, was taken into account. At 40 DAS, the maximum weed control efficiency (86.94%) and weeding index (0.00) of

Table 6. Influence of herbicides on different species and total weed density (no. m^{-2}) at 40 days after sowing of kharif greengram by weed controlled treatments (Cumulative data for two years 2020-21 to 2021-22)

Treatments	Grasses		Sedges	Broadleaf		Total weed density
	C. benghalensis	*D. sanguinalis*	*C. rotundus*	*C. tora*	*C. argentea*	
Imazethapyr (60 g ha^{-1})	1.53(2.35)	1.80(3.23)	2.41(5.83)	1.17(1.37)	1.23(1.52)	4.01(16.07)
Pendimethalin (1 kg ha^{-1})	1.36(1.84)	1.59(2.53)	1.85(3.42)	1.14(1.31)	1.05(1.11)	3.56(12.64)
Pendimethalin (1 kg ha^{-1}) fb Imazethapyr(50 g ha^{-1})	1.21(1.59)	1.31(1.72)	1.08(1.17)	1.07(1.15)	1.12(1.25)	2.64(6.96)
HW twice (20 and 40 DAS)	1.031.06	1.07(1.14)	1.88(3.53)	1.10(1.20)	1.42(2.03)	2.98(8.90)
Quizalofop-p-ethyl (75 g ha^{-1})	1.57(2.45)	1.79(3.21)	3.68(13.54)	1.39(1.93)	1.49(2.23)	4.73(22.34)
Imazethapyr + Imazamax (75 g ha^{-1})	1.642.69	1.69(2.54)	3.40(11.55)	1.65(2.74)	1.77(3.14)	4.64(21.58)
Sodium Acifulourfen and Clodinafop- propargyl (180 g ha^{-1})	1.51(2.28)	1.68(2.82)	3.32(11.03)	1.20(1.45)	1.39(1.94)	4.41(19.48)
Unweeded check (Control)	3.19(10.16)	3.32(11.03)	4.70(22.05)	2.84(8.08)	3.48(12.12)	7.97(63.45)
SE (m±)	0.12	0.12	0.14	0.15	0.16	0.11
CD (P = 0.05)	0.37	0.32	0.41	0.45	0.47	0.32

All Numbers are exposed to converted values to square root (√x+0.5).

grasses, sedges and broadleaf weeds were recorded with the combined application of Pendimethalin (1 kg g ha^{-1}) + Imazethapyr (50 g ha^{-1}) fb HW twice (20 and 40 DAS), Figure 3 and 4. Both the lowest weed control efficiency and the highest weed index were recorded in weed control in both the years. This result was in close agreement with Singh *et al*., (2019).

Herbicide Effects on Kharif Greengram

The collected data (Table 9) revealed that all weed treatments significantly increased plant population after 40 days after sowing, with the best observed when applying Pendimethalin (1 kg ha^{-1}) + Imazethapyr (50 g ha^{-1}) + Imazethapyr (60 g ha^{-1}) as PE compared to control.

A significant reduction in plant height was observed in the no-weed control, which may have been due to competition between the crop and the weed for soil moisture, plant nutrients, sunlight, and space during the active growth period. Greengram growth characters were significantly affected by weed treatments. Hand weeding twice at 15 and 30 DAS rather than other herbicide treatments. However, the combination of pre-emergence and post-emergence application of Pendimethalin (1 kg ha^{-1}) + Imazetapyr (50 g ha^{-1}) produced significantly taller

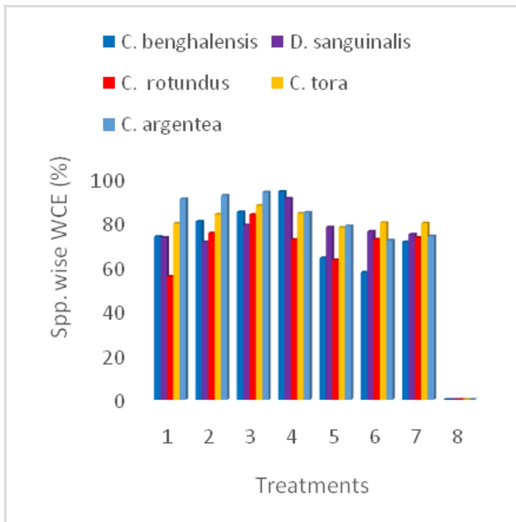

Fig. 3. Impact of different weed management treatment control on weed count in Greengram

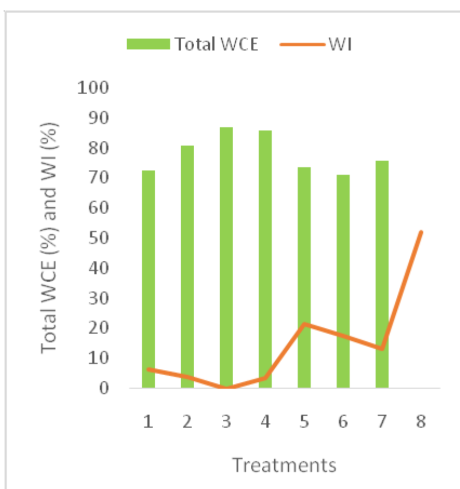

Fig. 4. Impact of different weed management treatment efficiency in wheat control on weed

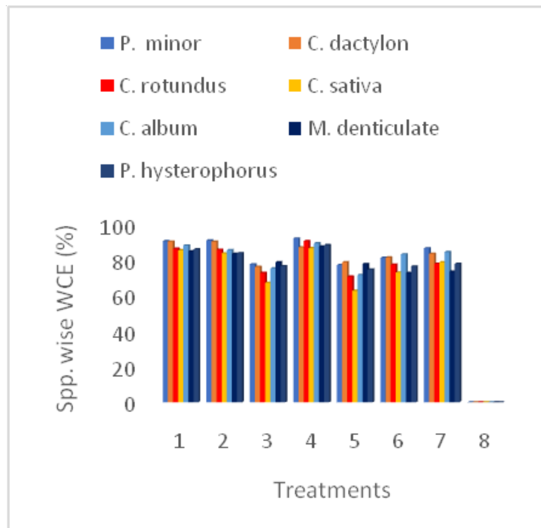

Fig. 5. Impact of altered herbicides on Spp. weed efficiency in wheat field

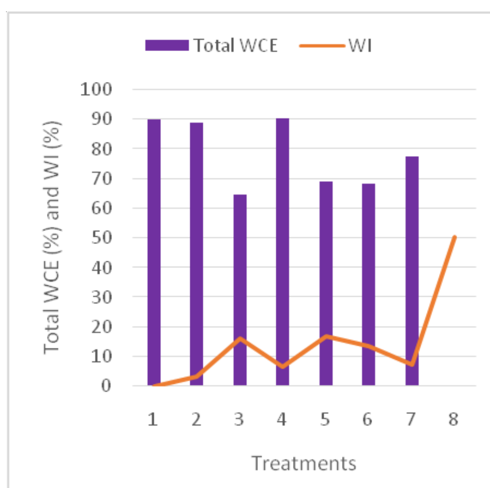

Fig. 6. Impact of altered herbicides on total weed control efficiency and weed index in Greengram

plants (32.62 cm). The plant height of greengram under different herbicide combinations was comparable.

The consecutive use of pre-emergence and post-emergence herbicide Pendimethalin (1 kg ha^{-1}) with a combination of Imazethapyr (50 gha^{-1}) resulted in a higher number of branches per plant. Different weed control methods significantly affected the number of branches per plant as compared to weedy check. Similar findings were found in Osari *et al*. (2019).

Herbicide impact on yield, yield attributes, and economics of kharif Greengram

With respect to yield characteristics, a significantly higher number of pods per plant, grains per pod, and test weight were recorded when Pendimethalin (1 kg ha^{-1}) + Imazetapyr (50 g ha^{-1}) was applied (Table 10). Pre-emergence applications of Imazetapyr (60 g ha^{-1}), Pendimethalin (1 kg ha^{-1}) and HW twice (20 and 40 DAS) produced comparable results in terms of number of pods per plant and seeds per pod. Improved weed control in these treatments would promote increased resource-relatedness, resulting in more yield-attributing traits Kaur *et al.*, (2016) and Muthuram *et el.* (2018). The lowest number of pods per plant was noted during the control.

Seed yield and straw yield of greengram improved meaningfully with the absence of crop weed competition due to the use of Pendimethalin (1 kg ha^{-1}) and Imazethapyr (50 g ha^{-1}) noted for meaning-

Table 7. Effect of herbicides on weed species and total dry biomass in greengram (g m^{-2}) (Data for the two years 2020-21 to 2021-22)

Treatments	Grasses		Sedges	Broadleaf		Total weed density
	C. benghalensis	*D. sanguinalis*	*C. rotundus*	*C. tora*	*C. argentea*	
Imazethapyr (60 g ha^{-1})	0.35(0.12)	0.026(0.068)	0.40(0.157)	0.30(0.087)	0.17(0.03)	0.77(0.60)
Pendimethalin (1 kg ha^{-1})	0.29(0.08)	0.027(0.073)	0.29(0.087)	0.29(0.069)	0.15(0.025)	0.58(0.34)
Pendimethalin (1 kg ha^{-1}) *fb* Imazethapyr (50 g ha^{-1})	0.25(0.06)	0.23(0.054)	0.24(0.057)	0.23(0.052)	0.14(0.02)	0.48(0.23)
HW twice (20 and 40 DAS)	0.16(0.02)	0.15(0.023)	0.31(0.098)	0.26(0.067)	0.23(0.054)	0.50(0.25)
Quizalofop-p-ethyl (75 g ha^{-1})	0.39(0.15)	0.24(0.056)	0.35(0.125)	0.31(0.095)	0.29(0.089)	0.72(0.52)
Imazethapyr + Imazamax (75 gha^{-1})	0.43(0.18)	0.25(0.060)	0.32(0.097)	0.29(0.085)	0.30(0.093)	0.72(0.51)
Sodium Acifulourfen and Clodinafop-propargyl (180 gha^{-1})	0.35(0.12)	0.25(0.064)	0.30(0.094)	0.32(0.077)	0.27(0.078)	0.66(0.43)
Unweeded check (Control)	0.66(0.43)	0.51(0.260)	0.59(0.355)	0.69(0.43)	0.57(0.33)	1.34(1.80)
SE (m±)	0.02	0.02	0.03	0.03	0.02	0.07
CD (P = 0.05)	0.06	0.05	0.08	0.09	0.05	0.21

All Numbers are exposed to converted values to square root ($\sqrt{x+0.5}$)

Table 8. Effect of herbicides on species, total weed control efficiency 40 days after sowing and WI (%) of kharif greengram by anti-weed management treatment (cumulative data for two years 2020-21 to 2021-22)

Treatments	Grasses		Sedges	Broadleaf		Total weed density(%)	Weed Index (%)
	C. benghalensis	*D. sanguinalis*	*C. rotundus*	*C. tora*	*C. argentea*		
Imazethapyr (60 g ha^{-1})	73.81	73.33	55.79	79.76	90.91	72.63	6.49
Pendimethalin (1 kg ha^{-1})	80.68	71.42	75.36	83.93	92.45	80.90	3.86
Pendimethalin (1 kg ha^{-1}) *fb* Imazethapyr (50 g ha^{-1})	85.01	78.97	83.81	87.91	93.95	86.94	0.00
HW twice (20 and 40 DAS)	94.18	91.12	72.40	84.28	84.74	86.03	3.45
Quizalofop-p-ethyl (75 g ha^{-1})	64.14	78.00	63.26	77.90	78.65	73.78	21.53
Imazethapyr + Imazamax (75 g ha^{-1})	57.60	76.17	72.63	80.11	72.13	71.25	17.73
Sodium Acifulourfen and Clodinafop- propargyl (180 g ha^{-1})	71.36	74.83	73.39	79.86	74.02	75.79	13.18
Unweeded check (Control)	0.00	0.00	0.00	0.00	0.00	0.00	52.11
SE (m±)	-	-	-	-	-	-	0.54
CD (P = 0.05)	-	-	-	-	-	-	1.63

Table 9. Herbicide effects on growth characteristics of kharif greengram 40 days after sowing (Cumulative data for two years 2020-21 to 2021-22)

Treatments	Plant population (No. m^{-2})	Plant height (cm)	No. of branches plant^{-1}
Imazethapyr (60 g ha^{-1})	29	31.64	2.95
Pendimethalin (1 kg ha^{-1})	28	32.36	3.05
Pendimethalin (1 kg ha^{-1}) *fb* Imazethapyr (50 g ha^{-1})	29	32.62	3.12
HW twice (20 and 40 DAS)	28	31.85	2.84
Quizalofop-p-ethyl (75 g ha^{-1})	27	30.68	2.66
Imazethapyr + Imazamax (75 g ha^{-1})	28	31.14	2.73
Sodium Acifulourfen and Clodinafop- propargyl (180 g ha^{-1})	29	31.62	2.82
Unweeded check (Control)	28	29.86	2.54
SE (m±)	0.72	0.77	0.23
CD (P = 0.05)	2.19	2.33	0.69

Table 10. Effects of herbicides on the yield, yield characteristics, and economics of kharif greengram

Treatments	No. of pods/ plant	No. of grains/ pod	Test weight (g)	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Gross return (ha^{-1})	Net return (ha^{-1})	B:C ratio
Imazethapyr (60 g ha^{-1})	20.15	10.47	31.88	678	2277	46342	18879	1.69
Pendimethalin (1 kg ha^{-1})	21.00	11.36	32.65	697	2372	47661	19533	1.70
Pendimethalin (1 kg ha^{-1}) *fb* Imazethapyr (50 g ha^{-1})	21.26	11.99	32.86	725	2448	49559	21393	1.76
HW twice (20 and 40 DAS)	15.76	9.75	30.99	700	2366	47854	19935	1.72
Quizalofop-p-ethyl (75 g ha^{-1})	15.98	8.26	28.79	569	2051	39020	11435	1.42
Imazethapyr + Imazamax (75 g ha^{-1})	16.35	8.77	29.48	596	2075	40822	13227	1.48
Sodium Acifulourfen and Clodinafop-propargyl (180 g ha^{-1})	18.96	9.57	30.46	629	2118	43021	15123	1.55
Unweeded check (Control)	14.35	7.76	26.60	347	1222	23798	-2437	0.91
SE (m±)	0.54	0.50	0.83	49.47	53.63	-	-	-
CD (p = 0.05)	1.63	1.52	2.52	150.04	162.79	-	-	-

fully higher mean grain yield and straw yield over other treatments (Table 5). The lower seed and straw yield was observed in weedy conditions as compared to the rest of the treatment. Similar consequences were also detected in Patel *et al.* (2020).

Among the herbicidal treatments, the maximum net returns were recorded with Pendimethalin 1 kg ha^{-1}*fb* Imazethapyr 50 g ha^{-1}(Table 5) *fb* Imazethapyr (60 g ha^{-1}) and the minimum Quizalofop-p-ethyl 75 g ha^{-1}. The highest benefit:cost ratio was achieved with Pendimethalin 1 kg ha^{-1}+ Imazethapyr 50 g ha^{-1}and the lowest with Quizalofop-p-ethyl (75 g ha^{-1}) as compared to control. The maximum net return for the pre-emergent use of Pendimethalin (1 kg ha^{-1}) fb Imazethapyr (50 g ha^{-1}) is similar findings were reported by Sasode *et al*. (2020).

Conclusion

It can be concluded that all types of weeds such as grasses, sedges, and broadleaf in wheat, the use of Pyroxasulfon (120 g ha^{-1}) as pre-emergent was comparable to that of Pyroxasulfon (110 g ha^{-1}) as PE, and the post-emergent use of 2,4-D sodium salt (750 g ha^{-1}) They were the most effective after emergence, controlling all types of weeds and yielding potential and monetary benefits. In kharif Greengram were controlled by consecutive use of Pendimethalin (1 kg ha^{-1}) as a pre-emergent followed by Imazethapyr (50 g ha^{-1}) as a post-emergence as they provide higher seed yield and benefit cost ratio with better weed control efficiency without detrimental effect on subsequent wheat crop. The use of premix herbicides can be beneficial for operational and environmentally friendly weed control in wheat.

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Conflict of Interest

All authors declare no conflicts of interest in this paper

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