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RESEARCH ARTICLE

Efficacy of pre-emergent herbicides against diverse weed flora in wheat crop in Northern Transition Zone of Karnataka in South India

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ABSTRACT

A field experiment was carried out at All India Coordinated Wheat and Barley Improvement Project (AICW&BIP), Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka during *Rabi* season of 2021-22 and 2022-23. The weed free plot recorded significantly, higher growth and yield attributes, *viz.* plant height, lower lodging score, higher number of effective tillers, number of grains per spike, thousand grain weight, grain, straw and biological yields followed by pendimethalin + metribuzin 1250 + 280 g/ha PE tank mix. The pendimethalin + metribuzin 1250 + 280 g/ha PE tank mix recorded significantly lower total number of weeds (5.66, 6.96 and 4.57/m^2), total dry weight of weeds (2.26, 6.24 and 10.38 g/m^2), higher weed control efficiency (74.68, 62.48 and 61.07%) at 30, 60 and 90 DAS, respectively and lower weed index (2.64%) as compared to weedy check plot.

Key words: Economics, Pre-tank mix herbicides, Weed control efficiency, South India, Wheat, Yield

INTRODUCTION

Wheat (*Triticum aestivum* L.) holds the position of the second most crucial cereal crop in India, playing a vital role in ensuring food and nutritional security. Being widely cultivated worldwide, wheat stands out as the most popular staple food among grain crops, contributing significantly to human consumption. In India, diverse environmental conditions and dietary preferences support the cultivation of bread, durum and dicoccum wheat varieties. Bread wheat dominates production with a substantial 95%, followed by durum wheat at four percent and dicoccum at nearly one percent. Wheat serves as a vital carbohydrate source and is globally recognized as the primary source of vegetable protein in human diets, boasting a protein content of around 13%. This protein, gluten, is crucial for the baking process.

Globally, wheat is cultivated in an area of 222 Mha with a production of 779 Mt and having the productivity of 3510 kg/ha (Anon. 2022). In India, the estimated area 31.61 Mha with production of 109.52 Mt and productivity of 3464 kg/ha (Anon. 2021). Uttar Pradesh has the highest area (9.85 M ha) and production (35.50 Mt) followed by Madhya Pradesh (6.39 Mha, 17.62 Mt). Punjab has the highest average productivity of 4.86 t/ha followed by Haryana with 4.84 t/ha (Anon. 2021). Karnataka is unique in cultivation of three species, namely, bread, durum and dicoccum wheat. In Karnataka, the area under wheat is 1.67 lakh ha with annual production of 1.79 Mt and productivity of 1.20 t/ha.

Wheat is a key component of various cropping systems in different regions worldwide. Globally, the rice-wheat and cotton-wheat cropping systems collectively occupy 60% of the cultivated wheat area. In the state of Karnataka, groundnut-wheat, greengram-wheat and soybean-wheat cropping systems play a crucial role, where wheat is cultivated as either a rainfed or irrigated crop during the *Rabi* season. Weeds emerge as major contributors to decreasing crop productivity in these wheat-based cropping systems. They disrupt crop production practices and result in substantial yield and quality losses. The composition of weed flora is strongly influenced by factors such as soil types, cultivation systems and agronomic practices in different cropping systems.

Continuous growing of same crop in a cropping system results in the prevalence of the best-suited weeds. For instance, rice-wheat cropping system favoured *Phalaris minor, Chenopodium album,*

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Avena fatua, Rumex dentatus. Moreover, soybean-wheat-greengram cropping system favoured *Medicago denticulata, Chenopodium album* and *Phalaris minor,* whereas, *Echinochloa crus-galli, Eleusine indica, Commelina benghalensis, Amaranthus viridis, Abutilon indicum* were favoured by maize–wheat cropping system (Singh *et al.* 2017a). Similarly, groundnut-wheat cropping system favoured *Cynodon dactylon, Echinochloa colonum, Euphorbia hirta, Commelina benghalensis, Alternanthera sessilis* and *Cyperus rotundus* weeds (Agasimani *et al.* 2010).

At present, global pesticide consumption stands at approximately 2 million metric tons, with herbicides accounting for 47.5%, insecticides for 29.5%, fungicides for 17.5% and other pesticides for 5.5% of the total usage (Pathak *et al.* 2022). The leading countries in pesticide consumption worldwide are China, the USA, Argentina, Thailand, Brazil, Italy, France, Canada, Japan and India. Specifically, India reported a pesticide usage of 62,193 metric tons in the 2020-21 period, with insecticides comprising 51%, herbicides 16%, fungicides 32% and others 1% of the total (Shekhawat *et al.* 2022).

In India, herbicides are employed on more than 20 million hectares, constituting approximately 10% of the total cropped area in the country. Notably, wheat, rice, soybean and sugarcane are the major crops where herbicides find extensive use, accounting for approximately 28%, 20%, 9% and 7% of herbicide application, respectively. According to Rao *et al.* (2018), the highest consumed herbicides in India were Butachlor (6032 tons) and Glyphosate (6003 tons), followed by Paraquat (2068 tons), Pretilachlor (2418 tons) and Pendimethalin (1444 tons). The states with the highest herbicide consumption were reported to be Punjab, followed by Uttar Pradesh, Andhra Pradesh, Maharashtra and West Bengal.

Weeds pose a substantial threat to wheat cultivation in India, leading to significant annual productivity losses in various regions (Harrington *et al.* 1992). Weed infestation stands out as a major factor that hampers crop productivity. To unlock the full genetic yield potential of the crop, proper weed control becomes an indispensable component. Weeds not only diminish the overall yield but also complicate the harvesting process. Therefore, to sustain food grain production and meet the needs of the ever-growing population, effective weed management is crucial in wheat cultivation.

The primary objective of this study was to evaluate the efficacy of pre-emergent herbicides against diverse weed flora in wheat crop in Northern Transition Zone of Karnataka.

MATERIALS AND METHODS

Experimental site and design

A field experiment was conducted at All India Coordinated Wheat and Barley Improvement Project (AICW&BIP), Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka during *Rabi* season of 2021-22 and 2022-23 to assess the efficacy of pre-emergent herbicides against diverse weed flora in wheat crop in Northern Transition Zone of Karnataka. The soil type of experimental site was medium deep black with clay loam texture. Soil was neutral in reaction (pH 7.6) with normal electrical conductivity (EC 0.27 dS/m), medium in organic carbon content (0.58%), low in available nitrogen (174.23 kg/ha) and higher in available phosphorous (31.17 kg/ha) and potassium (291.14 kg/ha) content. The experiment was laid out in randomized block design with three replications. The experiment consists of twelve treatments, *viz.* pendimethalin 1000 g/ha PE, pendimethalin 1500 g/ha PE, pyroxasulfone 127.5 g/ha PE, pendimethalin + pyroxasulfone 1250 + 127.5 g/ha PE tank mix, pyroxasulfone 127.5 g/ha + metsulfuron 4 g/ha PE, pyroxasulfone 127.5 g/ha EPoE, pyroxasulfone + metsulfuron 127.5 + 4 g/ha EPoE tank mix, metribuzin 300 g/ha PE, pendimethalin + metribuzin 1250 + 280 g/ha PE tank mix, pendimethalin + metribuzin 127.5 + 280 g/ha PE tank mix, weedy check and weed free. Each experimental plot had dimensions of 8.0 × 1.80 = 14.40 square meter in size. The sowing process utilized a seeding rate of 150 kg/ha, with a row spacing of 20 cm. The recommended doses of fertilizer (RDF) at 150: 75: 50 kg N:P:K /ha were applied. Nitrogen was applied in two equal splits, *i.e.* at sowing as basal application and 30 days after sowing. Entire quantity of phosphorus and potassium was applied as basal dose at the time of sowing along with $1/2^{rd}$ nitrogen and the remaining was applying $1/3^{rd}$ and $2/3^{rd}$ nitrogen as $1/3^{rd}$ at first irrigation and $2/3^{rd}$ at second irrigation. The other package of practices was adopted to raise the wheat as for University of Agricultural Science, Dharwad. Irrigation was administered in accordance with the crop's water requirements using the check basin method. Pre-emergent herbicides were administered immediately after sowing on adequately moistened soil, while early post-emergence (EPoE) herbicides were administered at 21 days after sowing (DAS). Spraying was done by manually operated knapsack sprayer.

Crop sampling

Five plants were selected and harvested for subsequent analysis. The grains were then carefully separated from the spikes and enumerated. The average number of grains per spike was calculated for each treatment. Average value of number of effective tillers m^{-2} were counted from each net plot at harvest. The wheat crop was harvested manually, leaving two border rows unharvested in both directions and 0.5 m in the longitudinal direction. The harvested wheat grain was collected and then oven-dried at 65–70°C for 48 h. The dried grain was weighed to determine the economic yield. The crop harvesting was done from net plot and the yield was expressed in kg/hectare.

Lodging score

To score lodging the per cent area of plant that lodged was estimated and the angle of stem lodging was estimated (Wiersma *et al.* 2011).

$$Lodging\ score = \frac{\%\ area\ lodging\ \times Angle\ of\ lodging\ from\ vertical}{90}$$

Weed count

The number of weeds present in one m^2 area in each plot was counted at 30, 60 and 90 DAS.

Dry weight of weeds (g/m²)

Dry weight of weeds was recorded at 30, 60 and 90 DAS. The weeds were uprooted from the sampling area of 0.5 m^2 each time and oven dried to a constant weight 60 to 70°C and the dry weight of weeds was expressed as g/m^2.

Weed control efficiency (%)

Weed control efficiency (WCE) = [(X-Y)/X] × 100

Where,

X = Dry weight of weeds in weedy check

Y = Dry weight of weeds in the treatment

Weed index (%)

Weed index (Wp!) = [(X-Y)/X] × 100

Where,

X = Yield of weed free plot.

Y = Yield of treated plot.

Statistical analysis

All the data recorded were processed in Microsoft excel 2016 and analysed with ANOVA at 5% level of significance.

RESULTS AND DISCUSSION

Weed flora

The predominant weed flora observed in the experimental plots during the period of experimentation consisted of grassy weeds, sedges and broad-leaved weeds. Among the grassy weeds, *Echinochloa colona, Dinebra retroflexa, Digitaria sanguinalis, Brachiaria eruciformis* and *Cynodon dactylon.* Among broad-leaved weeds, *Lagascea mollis, Euphorbia geniculata, Ageratum houstonianum, Convolvulus arvensis, Alternanthera sessilis, Parthenium hysterophorus, Amaranthus viridis, Physalis minima, Phyllanthus niruri, Commelina diffusa, Portulaca oleracea.* Among sedges, *Cyperus rotundus* was noticed.

Effect on plant height and lodging score

Plant height of wheat as influenced by various weed management practices is illustrated in (**Table 1**). There are significant differences in plant height of wheat were identified as a result of various weed management practices through different herbicides application. Though the weed free plot has shown significantly higher plant height (80.33 cm). The weedy check treatment recorded significantly lowest plant height (69.93 cm). Improved weed control in the mentioned treatments likely led to more efficient utilization of light, water and nutrients compared to other treatments. The decreased plant height observed in the weedy check can be attributed to the suppressive impact of weeds on crop plants, as noted by Chander *et al.* (1997). The substantial competition from weeds resulted in reduced nutrient uptake by the crop, as evidenced by the lowest plant height observed in the weedy check, as reported by Balasubramanian (1985).

Significantly lower lodging score was recorded in weed free check (2.47%) followed by pendimethalin 1250 g/ha + metribuzin 280 g/ha PE tank mix (2.75%) and pendimethalin 1500 g/ha PE (2.77%). The weedy check recorded significantly higher lodging score (3.93%) (**Table 1**). This might be due to better weed control in the above treatments which resulted in weed-free plot supports lodging control in wheat by minimizing competition for resources, enhancing air circulation, facilitating effective fungicide application, preventing host plants for pests, optimizing plant density, improving nutrient utilization and eliminating lodging-prone weed species. These results in similarity with the findings of Chaudhari *et al.* (2017).

There is no significant difference was recorded in number of days taken for maturity of wheat were identified as a result of various weed management practices through different herbicides application. Though, the weed free check has shown numerically lower number of days take for maturity of wheat (105.67 days) followed by pendimethalin 1250 g/ha + metribuzin 280 g/ha PE tank mix (105.83 days). The weedy check recorded higher number of days taken for maturity of wheat (112.33 days) (**Table 1**). This might be due to better weed control in the above treatments which resulted in weed-free plot supports early maturity in wheat by minimizing competition for resources, enhancing nutrient availability, improving water use efficiency, reducing allelopathic effects, optimizing light exposure, preventing weed-induced stress, promoting crop uniformity and facilitating easier harvesting.

Effects on yield and yield attributes

The significantly, higher number of effective tillers and number of grains per ear head was recorded in weed free check (396.33/m^2 and 54.00) followed by pendimethalin 1250 g/ha + metribuzin 280 g/ha PE tank mix (385.33/m^2 and 52.00) and pendimethalin 127.5 g/ha + metribuzin 280 g/ha PE tank mix (375.00 m^2 and 51.47) (**Table 1**). The weedy check recorded significantly, lowest number of effective tillers and number of grains per ear head (303.83/m^2 and 43.43). The observed increase in the number of ear head productions per square meter in crops under effective weed control treatments could be attributed to reduced competition between the crop and weeds, leading to better conservation of soil moisture, nutrients and space. These findings align with the results reported by Chaudhari *et al.* 2017.

The statistically higher thousand grain weight (47.38 g) was recorded in weed free check followed by pendimethalin 1250 g/ha + metribuzin 280 g/ha PE tank mix (46.31 g). While, significantly lowest thousand grain weight was recorded in weed check plot (37.91 g) (**Table 2**). Improved weed control in the aforementioned treatments likely led to a more efficient utilization of light, water and nutrients compared to the other treatments. These outcomes align with the discoveries made by (Meena and Singh 2011).

The significantly, higher grain, straw and biological yields of wheat (4.74, 8.55 and 13.30 t/ha, respectively) were recorded in weed free plot than other treatments. The next best treatment was pendimethalin 1250 g/ha + metribuzin 280 g/ha PE tank mix (4.62, 8.51 and 13.13 t/ha, respectively) closely followed by pendimethalin 127.5 g/ha + metribuzin 280 g/ha PE tank mix (4.50, 8.34 and 12.85 t/ha, respectively). The weedy check recorded significantly lower grain, straw and biological yields of wheat (2.978 5.99 and 8.97 t/ha, respectively) among all the treatments as shown in (**Table 2**). The observed higher yield and associated attributes, such as the number of ear heads, number of grains per ear head and thousand grain weight, in the aforementioned treatments suggest improved

Table 1. Growth and yield attributes of wheat as influenced by different pre- and early pre-emergence tank mix herbicides application

Treatment	Plant height (cm) at 80 DAS			Lodging score (%)			No. of days taken for maturity			No. of effective tillers per m^2			No. of grains per ear head		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Pendimethalin 1000 g/ha PE	73.0	72.3	72.7	3.07	2.77	2.92	111.0	102.7	106.8	257.7	368.0	312.8	44.4	48.3	46.4
Pendimethalin 1500 g/ha PE	77.0	78.7	77.8	2.80	2.73	2.77	111.3	104.0	107.7	301.3	351.7	326.5	48.0	48.7	48.3
Pyroxasulfone 127.5 g/ha PE	73.9	77.5	75.7	3.13	2.80	2.97	108.0	104.7	106.3	295.0	384.3	339.7	44.8	49.3	47.1
Pendimethalin + pyroxasulfone 1250 + 127.5 g/ha PE tank mix	71.8	78.7	75.2	4.20	3.60	3.90	110.7	104.0	107.3	287.7	401.0	334.3	48.8	51.0	49.9
Pyroxasulfone 127.5 g/ha + metsulfuron 4 g/ha PE	74.5	80.0	77.2	3.07	2.77	2.92	109.7	103.0	106.3	291.3	407.0	349.7	46.0	49.3	47.7
Pyroxasulfone 127.5 g/ha EPoE	74.5	81.4	78.0	3.03	3.17	3.10	110.0	102.7	106.3	309.7	390.7	350.7	44.6	45.7	45.1
Pyroxasulfone + metsulfuron 127.5 + 4 g/ha EPoE tank mix	75.1	79.5	77.3	3.43	2.73	3.08	109.0	104.0	106.5	307.7	416.3	362.0	45.6	51.3	48.5
Metribuzin 300 g/ha PE	73.5	80.8	77.1	3.67	3.03	3.35	110.3	104.7	107.5	310.0	394.0	352.0	44.4	50.7	47.5
Pendimethalin + metribuzin 1250 + 280 g/ha PE tank mix	74.3	79.8	77.0	2.83	2.67	2.75	108.3	103.3	105.8	324.7	446.0	385.3	50.0	54.0	52.0
Pendimethalin + metribuzin 127.5 + 280 g/ha PE tank mix	75.2	81.1	78.2	3.50	3.33	3.42	110.0	104.7	107.3	316.0	434.0	375.0	49.6	53.3	51.5
Weedy check	64.9	75.0	69.9	4.30	3.57	3.93	117.0	107.7	112.3	286.7	321.0	303.8	39.2	47.7	43.4
Weed free	78.8	81.9	80.3	2.70	2.23	2.47	109.3	102.0	105.7	330.0	462.7	396.3	51.3	56.7	54.0
LSD (p=0.05)	8.6	11.5	7.9	0.72	0.78	0.68	2.0	2.0	1.3	42.0	96.1	50.1	8.2	8.8	4.7

PE: pre-emergence; EPoE: early post-emergence; DAS: day after sowing performance compared to other treatments. These findings closely align with the results reported by Pisal and Sagarka (2013).

Harvest index of wheat as influenced by various weed management practices through different herbicide application is shown in (**Table 2**). Though the weed free check and pendimethalin 1250 g/ha + metribuzin 280 g/ha PE tank mix has shown higher harvest index (37 and 37%, respectively). While, lower harvest index was recorded in weedy check plot (33%). This might be due to support higher harvest index in wheat, allowing the crop to utilize resources efficient and reach its full potential. These results are in agreement with (Meena and Singh, 2011)

Effects on weeds

The treatment with effective weed control exhibited significantly lower total weed population and total weed dry weight, along with higher weed control efficiency and a lower weed index across all stages, compared to the other treatments. Among other weed management practices through different herbicides application, pendimethalin + metribuzin 1250 + 280 g/ha PE tank mix recorded significantly lower weed population (5.66, 6.96 and 4.57 no./m), total weed dry weight (2.26, 6.24 and 10.38 g/m), higher weed control efficiency (76.84, 64.18 and 61.85) at 30, 60 and 90 DAS, respectively and lower weed index (2.64%) than other treatments and it was on par with pendimethalin + metribuzin 127.5 + 280 g/ha PE tank mix. However, weedy check plot recorded significantly higher total weed population (52.38, 63.86 and 56.91 no./m), total weed dry weight (8.91, 16.62 and 26.68 g/m) at 30, 60 and 90 DAS, respectively and weed index (37.23%) (**Table 3** and **4**). The observed effects are likely attributed to the herbicidal properties of pendimethalin, which specifically targets annual grass and small-seeded broadleaf weeds. Pendimethalin's mode of action involves entering grasses through the coleoptile and shoot of the seedling below the ground, as described by Vencill (2002). This herbicide effectively reduces weed competition in the initial stage and controls late-emerged weeds through sequential spray applications, leading to lower weed density and reduced weed dry matter. The efficacy of pendimethalin in controlling grasses is further supported by its pre-emergent action against annual grass weeds and small-seeded dicot weeds for approximately a month, as highlighted by Byrd and York, 1987. The rapid depletion of carbohydrate reserves in weeds through accelerated respiration, as proposed by Prakash *et al.* 1999, may contribute to the overall effectiveness of pendimethalin in weed control. The weed management practices in these treatments have controlled weeds efficiently throughout the growing season ultimately improving the yield of crop, which resulted in lower weed index. This resulted into satisfactory control over both broad-leaf as well and grassy weeds, respectively and ultimately reducing total weed count in respective treatments. The better performance of these herbicides might be due to the effective control of all type of weeds. This study provides further evidence to support the conclusions of Veeraputhiran and Srinivasan (2015) and Gnanavel and Babu (2008).

Table 2. Yield and yield attributes of wheat as influenced by different pre- and early pre-emergence tank mix herbicides application

Treatment	Thousand grain weight (g)			Grain yield (t/ha)			Straw yield (t/ha)			Biological yield (t/ha)			Harvest index (%)		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Pendimethalin 1000 g/ha PE	41.83	43.20	42.52	3.53	3.91	3.72	6.53	7.56	7.05	10.06	11.47	10.77	33	34	35
Pendimethalin 1500 g/ha PE	42.11	43.70	42.90	3.65	4.09	3.87	6.41	8.41	7.41	10.06	12.50	11.28	36	33	34
Pyroxasulfone 127.5 g/ha PE	42.53	43.42	42.97	3.76	4.15	3.95	6.19	9.18	7.69	9.95	13.33	11.64	38	31	34
Pendimethalin + pyroxasulfone 1250 + 127.5 g/ha PE TM	43.92	45.80	44.86	3.91	4.91	4.41	6.28	9.06	7.67	10.19	13.97	12.08	36	35	35
Pyroxasulfone 127.5 g/ha + metsulfuron 4 g/ha PE	43.05	43.74	43.40	3.97	4.78	4.38	6.51	9.23	7.87	10.48	14.01	12.25	38	34	36
Pyroxasulfone 127.5 g/ha EPoE	42.19	46.78	44.48	3.70	4.20	3.95	7.01	9.12	8.06	10.72	13.32	12.02	35	32	33
Pyroxasulfone + metsulfuron 127.5 + 4 g/ha EPoE TM	43.35	45.49	44.42	3.97	4.77	4.37	6.75	8.35	7.55	10.72	13.12	11.92	36	35	35
Metribuzin 300 g/ha PE	44.20	44.86	44.53	3.73	4.65	4.19	7.29	8.50	7.90	11.02	13.15	12.08	34	35	35
Pendimethalin + metribuzin 1250 + 280 g/ha PE TM	45.14	47.48	46.31	4.01	5.23	4.62	7.50	9.52	8.51	11.51	14.75	13.13	35	35	35
Pendimethalin + metribuzin 127.5 + 280 g/ha PE TM	42.90	46.46	44.68	4.00	5.01	4.50	7.23	9.46	8.34	11.23	14.46	12.85	37	36	37
Weedy check	37.72	38.09	37.91	2.77	3.18	2.98	5.34	6.65	5.99	8.11	9.83	8.97	34	32	33
Weed free	46.21	48.55	47.38	4.26	5.23	4.74	7.56	9.54	8.55	11.82	14.77	13.30	38	35	37
LSD (p=0.05)	6.02	6.74	4.57	0.73	1.06	0.72	1.44	1.98	1.05	1.44	1.85	1.67	0.3	0.3	0.2

*Note: PE: pre-emergence; EPoE: early post-emergence; DAS: day after sowing; TM: tank mix

Table 3. Mean weed count and total weed dry weight at different growth stages of wheat as influenced by different pre- and early pre-emergence tank mix herbicides application

Treatment	Mean weed count (no./m)									Total weed dry weight (g/m^2)					
	2021-22			2022-23			Pooled			2021-22			2022-23		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Pendimethalin 1000 g/ha PE	4.16 (16.3)	4.41 (18.5)	4.59 (20.1)	3.90 (14.2)	4.41 (18.4)	4.80 (22.0)	4.03 (15.3)	4.41 (18.4)	4.70 (21.1)	2.83 (7.0)	3.89 (14.1)	4.69 (21.0)	2.77 (6.7)	3.85 (13.8)	4.63 (20.4)
Pendimethalin 1500 g/ha PE	3.33 (10.1)	3.91 (14.3)	3.88 (14.1)	3.64 (12.2)	3.96 (14.7)	4.03 (15.2)	3.49 (11.1)	3.93 (14.5)	3.96 (14.7)	2.79 (6.8)	3.80 (13.4)	4.52 (19.4)	2.75 (6.6)	3.74 (13.0)	4.48 (19.1)
Pyroxasulfone 127.5 g/ha PE	3.30 (9.9)	3.55 (11.6)	3.70 (12.7)	3.07 (8.4)	3.59 (11.9)	3.59 (11.9)	3.19 (9.2)	3.57 (11.7)	3.65 (12.3)	2.69 (6.2)	3.76 (13.1)	4.42 (18.6)	2.64 (6.0)	3.72 (12.9)	4.37 (18.1)
Pendimethalin + pyroxasulfone 1250 + 127.5 g/ha PE TM	2.85 (7.1)	3.20 (9.2)	2.65 (6.0)	3.00 (8.0)	3.29 (9.8)	2.82 (6.9)	2.93 (7.6)	3.25 (9.5)	2.73 (6.5)	2.19 (3.8)	2.93 (7.6)	3.61 (12.0)	2.07 (3.3)	2.86 (7.2)	3.56 (11.7)
Pyroxasulfone 127.5 g/ha + metsulfuron 4 g/ha PE	2.92 (7.5)	3.30 (9.9)	2.74 (6.5)	2.98 (7.9)	3.35 (10.2)	2.83 (7.0)	2.95 (7.7)	3.33 (10.1)	2.79 (6.8)	2.37 (4.6)	3.35 (10.2)	3.83 (13.6)	2.30 (4.3)	3.27 (9.7)	3.76 (13.2)
Pyroxasulfone 127.5 g/ha EPoE	3.21 (9.3)	3.39 (10.5)	2.88 (7.3)	3.35 (10.2)	3.45 (10.9)	3.01 (8.1)	3.28 (9.8)	3.42 (10.7)	2.94 (7.7)	2.75 (6.6)	3.64 (12.3)	4.27 (17.2)	2.72 (6.4)	3.59 (11.9)	4.24 (17.0)
Pyroxasulfone + metsulfuron 127.5 + 4 g/ha EPoE TM	2.78 (6.7)	3.00 (8.0)	2.62 (5.9)	2.85 (7.1)	3.08 (8.5)	2.65 (6.0)	2.82 (6.9)	3.04 (8.24)	2.63 (5.9)	2.47 (5.1)	3.58 (11.8)	4.09 (15.8)	2.42 (4.9)	3.50 (11.2)	4.04 (15.3)
Metribuzin 300 g/ha PE	2.98 (7.9)	3.18 (9.1)	3.06 (8.3)	3.01 (8.0)	2.85 (7.1)	3.13 (8.8)	2.99 (7.9)	3.02 (8.1)	3.09 (8.6)	2.63 (5.9)	3.49 (11.2)	3.95 (14.6)	2.50 (5.2)	3.44 (10.9)	3.91 (14.3)
Pendimethalin + metribuzin 1250 + 280 g/ha PE TM	2.50 (5.2)	2.79 (6.8)	2.26 (4.1)	2.66 (6.1)	2.85 (7.1)	2.46 (5.0)	2.58 (5.7)	2.82 (7.0)	2.36 (4.6)	1.84 (2.4)	2.73 (6.5)	3.39 (10.5)	1.77 (2.1)	2.65 (6.0)	3.36 (10.3)
Pendimethalin + metribuzin 127.5 + 280 g/ha PE TM	2.68 (6.2)	2.82 (7.0)	2.53 (5.4)	2.78 (6.7)	3.00 (8.0)	2.58 (5.7)	2.73 (6.5)	2.91 (7.5)	2.56 (5.5)	1.94 (2.8)	2.80 (6.8)	3.57 (11.7)	1.92 (2.7)	2.75 (6.5)	3.53 (11.5)
Weedy check	7.84 (60.5)	8.68 (74.3)	8.13 (65.1)	6.72 (44.2)	7.38 (53.4)	7.05 (48.7)	7.31 (52.4)	8.06 (63.9)	7.61 (56.9)	3.09 (8.6)	4.18 (16.4)	5.23 (26.3)	3.20 (9.2)	4.22 (16.8)	5.29 (27.0)
Weed free	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)
LSD (p=0.05)	2.56	2.83	2.75	2.49	2.89	2.87	1.98	1.96	2.28	1.59	2.85	2.72	1.84	1.88	2.62

PE-Pre-emergence; EPoE-Early post emergence; DAS- Day after sowing *Figures in the parentheses represent original values Data subjected for transformation using ($\sqrt{x+1}$), where x is weed count

Table 4. Total weed dry weight, WCE and weed index at different growth stages of wheat as influenced by different pre- and early pre-emergence tank mix herbicides application

Treatment	Total weed dry weight (g/m^2) Pooled			Weed control efficiency (%)									Weed index (%)		
				2021-22			2022-23			Pooled					
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	2021-22	2022-23	Pooled
Pendimethalin 1000 g/ha PE	2.80 (6.8)	3.87 (14.0)	4.66 (20.7)	18.4	13.6	20.4	28.1	17.5	24.5	23.2	15.6	22.5	17.1	25.2	21.6
Pendimethalin 1500 g/ha PE	2.77 (6.7)	3.77 (13.2)	4.50 (19.3)	20.5	17.9	26.2	28.9	22.4	29.3	24.8	20.2	27.8	14.3	21.8	18.5
Pyroxasulfone 127.5 g/ha PE	2.66 (6.1)	3.74 (13.0)	4.40 (18.3)	27.9	20.1	29.6	35.3	23.3	32.8	31.7	21.7	31.2	11.6	20.7	16.7
Pendimethalin + pyroxasulfone 1250 + 127.5 g/ha PE TM	2.13 (3.5)	2.90 (7.4)	3.59 (11.9)	55.8	54.0	54.2	64.8	57.3	56.7	60.2	55.7	55.5	8.2	6.2	7.1
Pyroxasulfone 127.5 g/ha + metsulfuron 4 g/ha PE	2.33 (4.4)	3.31 (10.0)	3.80 (13.4)	46.3	37.7	48.1	54.0	42.5	51.2	50.2	40.1	49.7	6.8	8.5	7.8
Pyroxasulfone 127.5 g/ha EPoE	2.73 (6.5)	3.62 (12.1)	4.26 (17.1)	23.3	25.3	34.5	31.1	29.3	36.9	27.3	27.3	35.7	13.0	19.7	16.7
Pyroxasulfone + metsulfuron 127.5 + 4 g/ha EPoE TM	2.45 (5.0)	3.54 (11.5)	4.07 (15.5)	40.5	28.0	40.1	47.7	33.0	43.3	44.1	30.6	41.7	6.6	8.8	7.8
Metribuzin 300 g/ha PE	2.57 (5.6)	3.47 (11.0)	3.93 (14.4)	30.9	31.9	44.6	43.3	35.2	47.1	37.3	33.6	45.9	12.4	11.1	11.7
Pendimethalin + metribuzin 1250 + 280 g/ha PE TM	1.80 (2.3)	2.69 (6.2)	3.37 (10.4)	72.3	60.7	60.3	76.8	64.2	61.8	74.7	62.5	61.1	5.8	0.1	2.6
Pendimethalin + metribuzin 127.5 + 280 g/ha PE TM	1.93 (2.7)	2.77 (6.7)	3.55 (11.6)	67.5	58.5	55.5	71.1	61.0	57.5	69.4	59.7	56.5	6.1	4.3	5.1
Weedy check	3.15 (8.9)	4.20 (16.6)	5.26 (26.7)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.9	39.1	37.2
Weed free	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0.0
LSD (p=0.05)	1.30	1.96	2.59	18.5	17.6	9.9	19.7	11.2	9.5	14.49	12.1	9.37	2.11	2.35	3.25

PE: pre-emergence; EPoE: early post-emergence; DAS- day after sowing; TM: tank mix; Figures in the parenthesis represent original values; Data subjected for transformation using ($\sqrt{x+1}$), where x is weed count

Table 5. Relative economics of wheat as influenced by different pre- and early pre-emergence tank mix herbicides application

Treatment	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
Pendimethalin 1000 g/ha PE	48895	137917	89022	2.82
Pendimethalin 1500 g/ha PE	49145	143535	94390	2.92
Pyroxasulfone 127.5 g/ha PE	48945	146880	97935	3.00
Pendimethalin + pyroxasulfone 1250 + 127.5 g/ha PE tank mix	49545	162752	113207	3.28
Pyroxasulfone 127.5 g/ha + metsulfuron 4 g/ha PE	49095	161852	112757	3.30
Pyroxasulfone 127.5 g/ha EPoE	48945	147192	98247	3.01
Pyroxasulfone + metsulfuron 127.5 + 4 g/ha EPoE tank mix	49095	161393	112298	3.29
Metribuzin 300 g/ha PE	48745	155267	106522	3.19
Pendimethalin + metribuzin 1250 + 280 g/ha PE tank mix	49345	171027	121682	3.47
Pendimethalin + metribuzin 127.5 + 280 g/ha PE tank mix	48805	166785	117981	3.42
Weedy check	48445	110857	62412	2.29
Weed free	53770	175482	121712	3.26
LSD (p=0.05)	-	6820	4766	-

PE-Pre-emergence & EPoE-Early post emergence

Table 6. Phytotoxicity symptoms of herbicides on succeeding soybean (pooled)

Treatment	Germination (%)	yellowing					stunting				
		1	3	5	7	10	1	3	5	7	10
Pendimethalin 1000 g/ha PE	87.59	0	0	0		0	0	0	0	0	0
Pendimethalin 1500 g/ha PE	86.75	0	0	0		0	0	0	0	0	0
Pyroxasulfone 127.5 g/ha PE	88.25	0	0	0		0	0	0	0	0	0
Pendimethalin + pyroxasulfone 1250 + 127.5 g/ha PE tank mix	87.36	0	0	0		0	0	0	0	0	0
Pyroxasulfone 127.5 g/ha + metsulfuron 4 g/ha PE	87.00	0	0	0		0	0	0	0	0	0
Pyroxasulfone 127.5 g/ha EPoE	87.36	0	0	0		0	0	0	0	0	0
Pyroxasulfone + metsulfuron 127.5 + 4 g/ha EPoE tank mix	87.71	0	0	0		0	0	0	0	0	0
Metribuzin 300 g/ha PE	89.64	0	0	0		0	0	0	0	0	0
Pendimethalin + metribuzin 1250 + 280 g/ha PE tank mix	88.66	0	0	0		0	0	0	0	0	0
Pendimethalin + metribuzin 127.5 + 280 g/ha PE tank mix	89.60	0	0	0		0	0	0	0	0	0
Weedy check	89.60	-	-	-	-	-	-	-	-	-	-
Weed free	89.97	-	-	-	-	-	-	-	-	-	-
LSD (p=0.05)	NS	-	-	-	-	-	-	-	-	-	-

Influenced on relative economics of wheat

Significantly higher cost of cultivation of wheat was recorded in weed free plot (₹ 53,770/ha). Where, as significantly higher gross returns, net returns and benefit cost ratio was recorded under pendimethalin + metribuzin 1250 + 280 g/ha PE tank mix. While, lower cost of cultivation of wheat was recorded in weedy check plot (₹ 48,445 /ha) but yield was to low shown in (**Table 5**). This might be due to higher labour was require for removing weeds from weed free plot as compared to weedy check plot. Similar results were also obtained by Singh *et al.* 2020.

Among various weed management practices through different herbicide application the weed free check recorded significantly higher gross return, net return and statistically higher benefit cost ratio (₹ 175482, ₹ 121712 and 3.26/ha, respectively), followed by pendimethalin 1250 g/ha + metribuzin 280 g/ha PE tank mix (₹ 171027, ₹ 121682 and 3.47/ ha, respectively) and pendimethalin 127.5 g/ha + metribuzin 280 g/ha PE tank mix (₹ 166785, ₹ 117981 and 3.42/ha, respectively). Weedy check treatment recorded significantly lower gross return, net return and benefit cost ratio (₹ 110857, ₹ 62412 and 2.29/ ha, respectively) as compared to other treatments (**Table 5**). The higher economics in the above-mentioned treatments can be attributed to higher yield of the respective treatments. The higher yield was achieved to better yield contributes and growth parameters. These parameters were results of efficient management of weeds in those treatment, which resulted in higher yield with better quality ultimately fetching more returns. Similar results were also obtained by Singh *et al.* 2020.

There is no phytotoxicity symptoms on succeeding crop of soybean

The current study definitively concluded that the pendimethalin + metribuzin at the rate of 1250 + 280 g/ha PE tank mix effectively managed a diverse weed flora in wheat, leading to enhanced grain yield and improved economic returns for wheat cultivation. Importantly pendimethalin + metribuzin PE tank mix was not shown any observable phototoxicity symptoms on the germination, root length, shoot length and seedling vigour index of the succeeding crop of soybean.

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