



RESEARCH ARTICLE

Effect of pre- and post-emergence herbicides on weed management, yield and profitability of Indian mustard in northern Haryana

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Abstract

Indian mustard (*Brassica juncea* (L.) Czern.) is a major oilseed crop in India with diverse industrial applications. However, weed infestation severely constrains crop growth, yield and quality. To evaluate the response of different pre- and post-emergence herbicides, a field experiment was conducted over two consecutive years at Research Farm of the Maharishi Markandeshwar (Deemed to be University) Mullana, Ambala, Haryana. Eleven weed management treatments were laid out in a randomized block design with three replications. The treatments included pendimethalin pre-emergence (PRE) at 750 g ha⁻¹, pendimethalin PRE at 1000 g ha⁻¹ + one hand weeding at 30 DAS, quizalafop-ethyl PRE at 60 g ha⁻¹, quizalafop-ethyl PRE at 60 g ha⁻¹ + one hand-weeding at 30 DAS, clodinafop post emergence (PoE) at 60 g ha⁻¹, oxyfluorfen PRE at 150 g ha⁻¹, oxyfluorfen PRE at 150 g ha⁻¹ + one hand-weeding at 30 DAS, oxadiargyl PRE at 90 g ha⁻¹, oxadiargyl PRE at 90 g ha⁻¹ + one hand-weeding at 30 DAS compared with weed free and weedy check treatments. Among all treatments, the weed-free plot showed the best overall performance. Among herbicidal options, PRE application of oxadiargyl at 90 g ha⁻¹ combined with one hand weeding provided excellent weed control, with the highest weed control efficiency recorded at 30 DAS (75.3 and 67.2 %) and 60 DAS (94.9 and 92.8 %). This treatment also resulted in significantly higher seed yield (1776 and 1393 kg ha⁻¹), stover yield (4977 and 4157 kg ha⁻¹) and harvest index (26.30 and 25.10). The highest gross and net returns, along with B:C ratio (1.92 and 1.62), were recorded with PRE application of oxadiargyl alone, closely followed by its integration with one hand weeding.

Keywords: B:C ratio; hand-weeding; Indian mustard; oxadiargyl; weed dynamics

Introduction

India ranked third in production of rapeseed-mustard after Canada and China and accounts for one-third of the total oil production (1). Rapeseed-mustard represents significant oilseed crop as its seeds contain 40–46 % oil (2). Moreover, its meal contains 38–40 % protein, which has a comprehensive quantity of amino acids together with lysine, methionine and cysteine (3). Among the oilseed crops grown in India, it occupies 24.70 % and 48.28 % of the total area and production, respectively (4). Rapeseed-mustard is primarily cultivated in Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh and Gujarat, covering an area of 9.18 million hectare (Mha) with a production of 13.26 million tons (Mt) and productivity of 1444 kg ha⁻¹ during the year 2023–24 (5).

Weeds being the major on the constraint inflict 35–60 % or even more yield losses depending upon the weed density, type of weed flora and duration of infestation (6, 7). The presence of weeds such as *Physalis minima* L., *Medicago sativa* L., *Sonchus arvensis* L. and *Chichorium intybus* L. in mustard field caused reduction in the productivity (8). However, *Chenopodium album* L., *Asphodelus tenuifolius* Cav., *Melilotus indicus* (L.) All., *Coronopus didymus* (L.) Sm., *Spergula arvensis* L., *Phalaris minor* Retz., etc. showed serious yield loss in mustard (9).

The most common herbicidal weed control measure recommended in Indian mustard is the pre-emergence application of pendimethalin, however, it mainly targets grassy and some of the broad-leaf weeds and its efficacy is limited to 30 days of sowing (DAS) (10, 11). Besides chemical weed control, manual weeding at 3–4 weeks after sowing is the most common practice to control weeds in Indian mustard but increasing wages and scarcity of labour compel the farmers to search for other alternatives (12). Thus, the present study was undertaken to identify the most economical weed control practices on weed dynamics and yield of Indian mustard.

Materials and Methods

The field experiment comprised of 11 weed management treatments, pendimethalin PRE at 750 g ha⁻¹ (T₁), pendimethalin PRE at 1000 g ha⁻¹ + one hand-weeding at 30 DAS (T₂), quizalafop-ethyl PRE at 60 g ha⁻¹ (T₃), quizalafop-ethyl PRE at 60 g ha⁻¹ + one hand-weeding at 30 DAS (T₄), clodinafop PoE at 60 g ha⁻¹ (T₅), oxyfluorfen PRE at 150 g ha⁻¹ (T₆), oxyfluorfen PRE at 150 g ha⁻¹ + one hand-weeding at 30 DAS (T₇), oxadiargyl PRE at 90 g ha⁻¹ (T₈), oxadiargyl PRE at 90 g ha⁻¹ + one hand-weeding at 30 DAS (T₉) compared with weed free (T₁₀) and weedy check (T₁₁).

The experiment was conducted at Research Farm of the Maharishi Markandeshwar (Deemed to be University) Mullana-Ambala, Haryana during the year 2023–24 and 2024–25. The treatments were laid in a randomised block design with three replications. The seeds of RH 1424 of mustard was used in sowing at a row spacing of 30 cm apart in plot of size 5 × 4.20 m² on November 15 and 8, during first and second year, respectively. The recommended cultural operations and plant protection measures were followed to raise a healthy crop.

Pre-emergence herbicides were applied just after sowing of crop, while post-emergence herbicide was applied at 25–30 DAS. Drift of herbicide from one plot to another was avoided by using spray guard and shield in between two plots. In weed free plots weeding was done manually with the help of hand hoe as and when weeds appear and none of the weed control measures was applied in weedy check plots.

Herbicides were applied with the help of power sprayer by using flat fan nozzle. A quadrat of size 0.25 m² (0.5 m × 0.5 m) was used to take observations on weed numbers and weed dry weight was recorded through random sampling from each plot. Weed density (number m⁻²) was recorded by categorizing the sampled weeds into narrow and broad-leaf weeds. The total number of weeds from one square meter area was counted species wise separately from each plot at 30 and 60 DAS.

Data on weed count and weed dry weight have shown high degree of variation. A relationship between the means and variance was observed. Therefore, the data on weed count and weed dry weight were subjected to $\sqrt{(x + 1)}$ transformation. Weed control efficiency was calculated on dry weight basis by using following formula (13):

Weed control efficiency (%) =

$$\frac{\text{Weed dry weight in weedy plot} - \text{weed dry weight in treated plot}}{\text{Weed dry weight in weedy plot}} \times 100$$

Phytotoxicity was recorded by using standard scale (14). For dry matter, the weeds collected from one square meter area were first dried in the sun and then dried in oven (65 °C) till the constant weight was achieved. Thereafter, their dry weight (g m⁻²) was recorded by using electronic balance. The crop was harvested from the net plot area (4 × 3 m²) of each plot to avoid border effect, then sun dried and threshed. The grain yield obtained from each plot was subsequently converted to yield per hectare.

Total value of the produce (both grain and stover) was computed as gross returns and expressed in ₹ ha⁻¹. Net returns for each treatment was calculated by subtracting the total cost of cultivation from the gross returns for the respective treatment. To calculate benefit to cost ratio in mustard, the gross returns was divided by the total cost of cultivation.

Results and Discussion

Weed flora

Among the broad-leaf weeds (57.9–65.4 and 56.9–67.7 %) the predominant weeds observed in the experimental area were *C. album*, *Rumex dentatus* L., *Fumaria parviflora* Lam., *Convolvulus*

arvensis L., *Anagallis arvensis* L., *Melilotus albus* Medik., *C. didymus* and in narrow-leaf weeds (34.5–42.1 and 32.3–41.0 %) *Cynodon dactylon* (L.) Pers. and *Cyperus rotundus* L. during both years. Similar weed flora in irrigated areas of northern India was reported in mustard field (15).

Crop phytotoxicity

Among the pre- and post-emergence herbicidal treatments, only pre-emergence application of oxyfluorfen caused transient phytotoxicity of scale-II (15 and 8 %) at 30 and 60 DAS, during first year and the plant recovered completely 21 days after herbicide application.

Weed density and dry weight

All the weed management treatments resulted into significant reduction in weeds dry weight (g m⁻²) at 30 and 60 DAS as compared to unweeded check during both years (Table 1–3). Weed density recorded at 30 and 60 DAS, showed significant influence due to different weed management practices (Table 4, 5). Among herbicidal applications, the minimum weed density was recorded in treatment pre-emergence application of oxadiargyl at 90 g a.i. ha⁻¹ alone and in the combination with one hand-weeding (statistically at par) as the herbicide was active on soil surface and controlled narrow- and broad-leaf annual weeds upon germination. However, among the weed control treatments, the minimum weed density was recorded in hand-weeding treatment at 30 and 60 DAS and at the same time, the maximum weed density was recorded in the weedy check treatment during both years.

Significant variation in total weed dry weight was recorded due to different weed-management practices (Table 4, 5). However, among herbicidal treatments, the treatment pre-emergence application of oxadiargyl at 90 g a.i. ha⁻¹ recorded the significantly minimum weed dry weight, which established its superiority over other treatments during both years. Similar findings were reported that the pre-emergence application of oxadiargyl at 75 g ha⁻¹ + one hand-weeding at 25 DAS was found equally effective with treatment pendimethalin at 0.5 kg ha⁻¹ + one hand-weeding at 25 DAS (16).

Weed control efficiency

Weed control efficiency (WCE) was defined as a density of weeds in terms of dry matter present in herbicidal treated plot as compared to weedy check plot (17). Integration of one hand-weeding with pre-emergence application of herbicides was more effective in reducing the weed density as compared to alone application of herbicide and resulted in higher weed control efficiency. However, the minimum weed control efficiency was recorded in weedy check during both years (Table 1, 2; Fig. 1). Further, among the other chemical treatments, pre-emergence application of oxadiargyl at 90 g a.i. ha⁻¹ proved superior as it recorded minimum weed dry weight and maximum weed control efficiency closely followed by integration of pre-emergence application of oxadiargyl with one hand-weeding. The effectiveness of reducing the population of *C. album* and *A. arvensis* has been reported by earlier workers (18).

Growth and yield

The plant height was found non-significant at 30 DAS during both years. Among all the treatments maximum plant height was noted under weed free and minimum under weedy check plot, however, among herbicidal treatments maximum plant height was found in pre-emergence application of oxadiargyl at 90 g ha⁻¹ + hand-weeding at 30 DAS during both years (Table 6).

Table 1. Effect of different pre- and post-emergence herbicides on weed dry weight (g m⁻²) at 30 DAS in Indian mustard

Treatments	Dose (g ha ⁻¹)	Time of application	Weed dry weight (g m ⁻²)						WCE (%)	
			2023-24			2024-25			2023-24	2024-25
			Broad leaf	Narrow leaf	Total weeds	Broad leaf	Narrow leaf	Total weeds		
T ₁	750	PRE	4.61 (20.3)	2.05 (3.2)	4.95 (23.6)	5.15 (25.6)	2.59 (5.8)	5.69 (31.4)	54.6	48.5
T ₂	1000	PRE and 30 DAS	5.00 (24.0)	2.39 (4.7)	5.45 (28.8)	5.53 (29.6)	2.93 (7.6)	6.17 (37.2)	44.6	39.0
T ₃	60	PRE	5.44 (28.6)	2.60 (5.8)	5.95 (34.4)	5.89 (33.7)	3.07 (8.4)	6.56 (42.1)	33.8	30.9
T ₄	60	PRE and 30 DAS	5.28 (26.9)	2.49 (5.2)	5.75 (32.1)	5.73 (31.9)	2.89 (7.4)	6.34 (39.3)	38.2	35.5
T ₅	60	PoE	6.64 (43.2)	3.30 (9.9)	7.35 (53.1)	6.99 (48.0)	3.69 (12.7)	7.85 (60.7)	0.0	0.6
T ₆	150	PRE and 30 DAS	4.31 (17.6)	1.81 (2.3)	4.57 (19.9)	4.83 (22.4)	2.38 (4.6)	5.29 (27.0)	61.7	55.7
T ₇	150	PRE	4.33 (17.8)	1.82 (2.4)	4.59 (20.1)	4.89 (23.1)	2.43 (4.9)	5.38 (28.0)	61.2	54.1
T ₈	90	PRE	3.59 (11.9)	1.48 (1.2)	3.76 (13.2)	4.22 (16.9)	2.08 (3.4)	4.61 (20.3)	74.7	66.8
T ₉	90	PRE and 30 DAS	3.50 (11.3)	1.58 (1.5)	3.71 (12.8)	4.13 (16.2)	2.20 (3.9)	4.57 (20.0)	75.3	67.2
T ₁₀	-	Hoeing at 30 and 60 DAS	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	100.0	100.0
T ₁₁	-	-	6.63 (43.0)	3.15 (8.9)	7.27 (51.9)	7.08 (49.2)	3.58 (11.8)	7.87 (61.0)	0.0	0.0
	SEm±		0.03	0.02	0.04	0.06	0.04	0.06		
	CD (p = 0.05)		0.11	0.05	0.12	0.17	0.13	0.17		

T₁: pendimethalin, T₂: pendimethalin + one hand weeding (HW), T₃: quizalofop-ethyl; T₄: quizalofop-ethyl + one HW, T₅: clodinafop, T₆: oxyflourfen, T₇: oxyflourfen + one HW, T₈: oxadiargyl, T₉: oxadiargyl + one HW, T₁₀: weed free and T₁₁: weedy check. Values in parenthesis are subjected to square root transformation ($\sqrt{x+1}$).

Table 2. Effect of different pre- and post-emergence herbicides on weed dry weight (g m⁻²) at 60 DAS in Indian mustard

Treatments	Dose (g ha ⁻¹)	Time of application	Weed dry weight (g m ⁻²)					
			2023-24			2024-25		
			Broad leaf	Narrow leaf	Total weeds	Broad leaf	Narrow leaf	Total weeds
T ₁	750	PRE	10.24 (103.8)	7.72 (58.5)	12.78 (162.3)	11.06 (121.4)	7.98 (62.8)	13.61 (184.2)
T ₂	1000	PRE and 30 DAS	3.58 (11.8)	2.22 (3.9)	4.09 (15.7)	4.53 (19.6)	2.93 (7.6)	5.30 (27.2)
T ₃	60	PRE	11.95 (141.9)	9.00 (80.0)	14.93 (221.9)	12.72 (160.8)	9.83 (95.6)	16.04 (256.4)
T ₄	60	PRE and 30 DAS	3.52 (11.4)	2.43 (5.0)	4.17 (16.4)	4.25 (17.1)	3.10 (8.7)	5.17 (25.8)
T ₅	60	PoE	11.11 (122.3)	2.45 (5.0)	11.33 (127.4)	11.50 (131.3)	2.82 (7.0)	11.80 (138.3)
T ₆	150	PRE and 30 DAS	8.83 (76.9)	6.80 (45.2)	11.09 (122.1)	9.45 (88.4)	7.64 (57.4)	12.113 (145.8)
T ₇	150	PRE	3.81 (13.5)	2.19 (3.8)	4.27 (17.3)	4.46 (19.0)	2.74 (6.5)	5.15 (25.6)
T ₈	90	PRE	8.27 (67.4)	6.40 (40.0)	10.41 (107.4)	9.16 (82.9)	7.01 (48.1)	11.48 (131.0)
T ₉	90	PRE and 30 DAS	3.21 (9.3)	2.11 (3.5)	3.71 (12.7)	3.90 (14.3)	2.79 (6.8)	4.69 (21.1)
T ₁₀	-	Hoeing at 30 and 60 DAS	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)
T ₁₁	-	-	12.35 (151.9)	9.84 (95.9)	15.77 (247.8)	13.48 (180.6)	10.65 (112.5)	17.15 (293.1)
	SEm±		0.07	0.03	0.08	0.09	0.04	0.10
	CD (p = 0.05)		0.19	0.09	0.23	0.27	0.12	0.30

T₁: pendimethalin, T₂: pendimethalin + one hand weeding (HW), T₃: quizalofop-ethyl; T₄: quizalofop-ethyl + one HW, T₅: clodinafop, T₆: oxyflourfen, T₇: oxyflourfen + one HW, T₈: oxadiargyl, T₉: oxadiargyl + one HW, T₁₀: weed free and T₁₁: weedy check. Values in parenthesis are subjected to square root transformation ($\sqrt{x+1}$).

Table 3. Effect of different pre- and post-emergence herbicides on yield and harvest index of Indian mustard

Treatments	Dose (g ha ⁻¹)	Time of application	Seed yield (kg ha ⁻¹)		Stover yield (kg ha ⁻¹)		Harvest index (%)	
			2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
			T ₁	750	PRE	1309	1045	3845
T ₂	1000	PRE and 30 DAS	1490	1158	4263	3511	25.90	24.80
T ₃	60	PRE	1048	832	3046	2598	25.60	24.26
T ₄	60	PRE and 30 DAS	1260	964	3618	2966	25.83	24.53
T ₅	60	PoE	1189	928	3445	2871	25.66	24.43
T ₆	150	PRE and 30 DAS	1352	1021	3888	3129	25.80	24.60
T ₇	150	PRE	1567	1252	4437	3776	26.10	24.90
T ₈	90	PRE	1632	1286	4645	3920	26.00	24.70
T ₉	90	PRE and 30 DAS	1776	1393	4977	4157	26.30	25.10
T ₁₀	-	Hoeing at 30 and 60 DAS	1857	1470	5135	4340	26.56	25.30
T ₁₁	-	-	1036	793	3391	2769	23.40	22.26
	SEm±		26	21	46	58	-	-
	CD (p = 0.05)		78	62	138	174	-	-

T₁: pendimethalin, T₂: pendimethalin + one hand weeding (HW), T₃: quizalofop-ethyl; T₄: quizalofop-ethyl + one HW, T₅: clodinafop, T₆: oxyflourfen, T₇: oxyflourfen + one HW, T₈: oxadiargyl, T₉: oxadiargyl + one HW, T₁₀: weed free and T₁₁: weedy check.

Table 4. Effect of different pre- and post-emergence herbicides on weed density (number m⁻²) at 30 DAS in Indian mustard

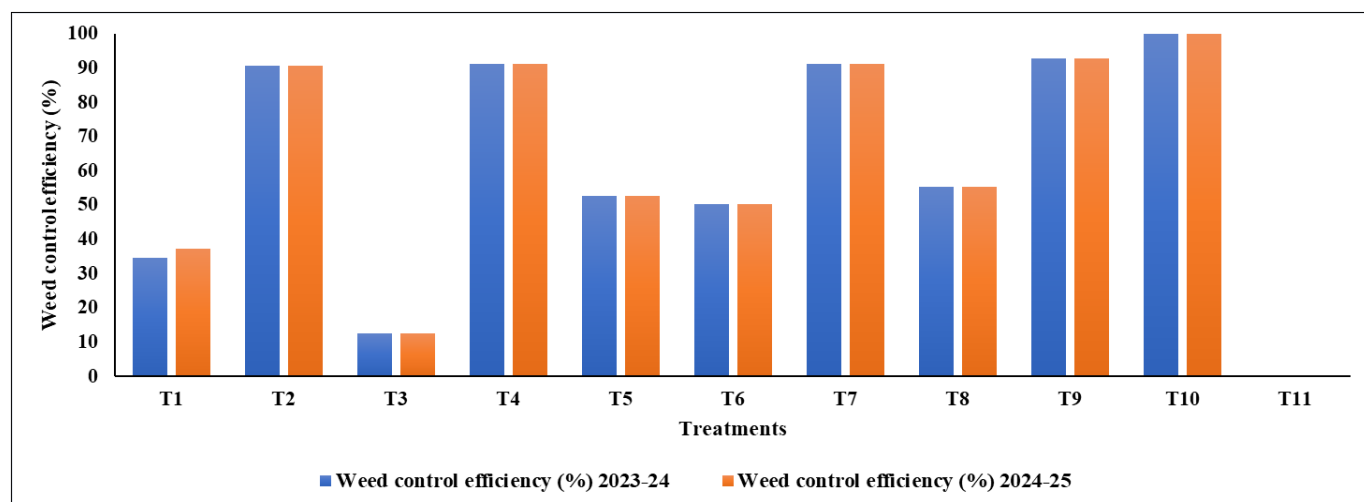
Treatments	Dose (g ha ⁻¹)	Time of application	Weed density (number m ⁻²)					
			2023-24			2024-25		
			Broad leaf	Narrow leaf	Total weeds	Broad leaf	Narrow leaf	Total weeds
T ₁	750	PRE	7.17 (50.7)	5.48 (29.1)	8.98 (79.8)	7.60 (56.8)	5.79 (32.6)	9.50 (89.4)
T ₂	1000	PRE and 30 DAS	7.34 (53.0)	5.62 (30.6)	9.19 (83.6)	7.77 (59.4)	5.93 (34.3)	9.72 (93.6)
T ₃	60	PRE	7.85 (60.8)	6.02 (35.3)	9.85 (96.1)	8.31 (68.1)	6.36 (39.5)	10.42 (107.6)
T ₄	60	PRE and 30 DAS	7.71 (58.6)	5.92 (34.2)	9.68 (92.8)	8.15 (65.6)	6.26 (38.3)	10.23 (103.9)
T ₅	60	PoE	8.90 (78.3)	6.83 (45.8)	11.18 (124.1)	9.41 (87.7)	7.23 (51.3)	11.83 (139.0)
T ₆	150	PRE and 30 DAS	6.83 (45.8)	4.96 (23.7)	8.38 (69.5)	7.22 (51.3)	5.24 (26.5)	8.86 (77.8)
T ₇	150	PRE	6.92 (47.2)	4.88 (22.9)	8.42 (70.1)	7.32 (52.9)	5.16 (25.6)	8.90 (78.5)
T ₈	90	PRE	6.25 (38.3)	4.58 (20.1)	7.69 (58.4)	6.49 (41.4)	4.76 (21.7)	7.99 (63.1)
T ₉	90	PRE and 30 DAS	6.20 (37.6)	4.64 (20.7)	7.68 (58.3)	6.44 (40.6)	4.83 (22.4)	7.98 (63.0)
T ₁₀	-	Hoeing (30 and 60 DAS)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)
T ₁₁	-	-	8.88 (78.0)	7.11 (49.6)	11.33 (127.6)	9.21 (84.2)	7.38 (53.6)	11.77 (137.8)
	SEM±		0.09	0.07	0.10	0.11	0.06	0.11
	CD (p = 0.05)		0.28	0.20	0.31	0.33	0.17	0.34

T₁: pendimethalin, T₂: pendimethalin + one hand weeding (HW), T₃: quizalofop-ethyl; T₄: quizalofop-ethyl + one HW, T₅: clodinafop, T₆: oxyflourfen, T₇: oxyflourfen + one HW, T₈: oxadiargyl, T₉: oxadiargyl + one HW, T₁₀: weed free and T₁₁: weedy check. Values in parenthesis are subjected to square root transformation ($\sqrt{x+1}$).

Table 5. Effect of different pre- and post-emergence herbicides on weed density at 60 DAS in Indian mustard

Treatments	Dose (g ha ⁻¹)	Time of application	Weed density (number m ⁻²)					
			2023-24			2024-25		
			Broad leaf	Narrow leaf	Total weeds	Broad leaf	Narrow leaf	Total weeds
T ₁	750	PRE	8.12 (64.9)	6.49 (41.2)	10.34 (106.1)	8.58 (72.7)	6.86 (46.1)	10.94 (118.8)
T ₂	1000	PRE and 30 DAS	4.18 (16.6)	2.94 (7.7)	5.02 (24.3)	4.41 (18.6)	3.10 (8.6)	5.30 (27.2)
T ₃	60	PRE	9.13 (82.5)	7.23 (51.3)	11.61 (133.8)	9.66 (92.4)	7.64 (57.5)	12.28 (149.9)
T ₄	60	PRE and 30 DAS	4.09 (15.8)	3.02 (8.2)	4.99 (24.0)	4.31 (17.7)	3.18 (9.2)	5.27 (26.9)
T ₅	60	PoE	9.11 (82.1)	3.72 (12.9)	9.79 (95.0)	9.59 (91.1)	3.92 (14.4)	10.32 (105.5)
T ₆	150	PRE and 30 DAS	7.37 (53.4)	5.87 (33.5)	9.37 (86.9)	7.79 (59.8)	6.20 (37.5)	9.91 (97.3)
T ₇	150	PRE	4.24 (17.1)	2.81 (6.9)	4.99 (24.0)	4.48 (19.2)	2.95 (7.7)	5.26 (26.9)
T ₈	90	PRE	6.98 (47.8)	5.53 (29.6)	8.85 (77.4)	7.25 (51.6)	5.66 (31.1)	9.14 (82.7)
T ₉	90	PRE and 30 DAS	3.71 (12.9)	2.86 (7.2)	4.58 (20.1)	3.85 (13.9)	2.95 (7.8)	4.74 (21.7)
T ₁₀	-	Hoeing at 30 and 60 DAS	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)
T ₁₁	-	-	9.40 (87.4)	8.03 (63.5)	12.32 (150.9)	9.76 (94.4)	8.34 (69.2)	12.80 (163.0)
	SEm±		0.06	0.03	0.08	0.08	0.05	0.09
	CD (p = 0.05)		0.19	0.10	0.24	0.23	0.14	0.28

T₁: pendimethalin, T₂: pendimethalin + one hand weeding (HW), T₃: quizalofop-ethyl; T₄: quizalofop-ethyl + one HW, T₅: clodinafop, T₆: oxyflourfen, T₇: oxyflourfen + one HW, T₈: oxadiargyl, T₉: oxadiargyl + one HW, T₁₀: weed free and T₁₁: weedy check. Values in parenthesis are subjected to square root transformation ($\sqrt{x+1}$).

**Fig. 1.** Effect of different weed management treatments on weed control efficiency at 60 DAS.

T₁: pendimethalin, T₂: pendimethalin + one hand weeding (HW), T₃: quizalofop-ethyl; T₄: quizalofop-ethyl + one HW, T₅: clodinafop, T₆: oxyflourfen, T₇: oxyflourfen + one HW, T₈: oxadiargyl, T₉: oxadiargyl + one HW, T₁₀: weed free and T₁₁: weedy check.

Table 6. Effect of different pre- and post-emergence herbicides on plant height of Indian mustard

Treatments	Dose (g ha ⁻¹)	Time of application	Plant height (cm)			
			2023-24		2024-25	
			30 DAS	60 DAS	30 DAS	60 DAS
T ₁	750	PRE	17.9	79.1	15.9	75.6
T ₂	1000	PRE and 30 DAS	17.6	80.2	15.7	76.8
T ₃	60	PRE	17.4	77.3	15.5	73.4
T ₄	60	PRE and 30 DAS	18.2	79.4	16.4	76.0
T ₅	60	PoE	17.2	75.8	15.3	72.2
T ₆	150	PRE and 30 DAS	17.5	73.5	15.6	69.9
T ₇	150	PRE	17.7	78.7	15.9	75.0
T ₈	90	PRE	17.7	79.6	15.7	76.0
T ₉	90	PRE and 30 DAS	17.4	81.2	15.5	77.7
T ₁₀	-	Hoeing at 30 and 60 DAS	18.1	83.6	16.2	80.1
T ₁₁	-	-	17.2	73.3	15.3	69.7
		SEm±	0.3	0.9	0.3	1.2
		CD ($\rho = 0.05$)	NS	2.6	NS	3.7

T₁: pendimethalin, T₂: pendimethalin + one hand weeding (HW), T₃: quizalofop-ethyl; T₄: quizalofop-ethyl + one HW, T₅: clodinafop, T₆: oxyflourfen, T₇: oxyflourfen + one HW, T₈: oxadiargyl, T₉: oxadiargyl + one HW, T₁₀: weed free and T₁₁: weedy check.

The significantly maximum seed yield (1776 and 1393 kg ha⁻¹) was found in treatment pre-emergence application of oxadiargyl at 90 g ha⁻¹ + hand-weeding at 30 DAS (Table 6). Similar trend was also found with respect to stover yield, while the maximum harvest index (%) was found under the application of oxadiargyl at 90 g ha⁻¹ + hand-weeding at 30 DAS followed by pendimethalin at 1000 g ha⁻¹ + hand-weeding at 30 DAS during both years (Table 3).

Economics

The highest gross returns of (₹100605 and 85560 ha⁻¹) obtained from weed free treatment, while among the herbicidal treatments, gross returns was highest (₹96039 and 80792 ha⁻¹) from pre-emergence application of oxadiargyl at 90 g ha⁻¹ + hand-weeding during the year 2023–24 and 2024–25, respectively (Table 7). Pre-emergence application of oxadiargyl at 90 g ha⁻¹ + hand-weeding resulted in the highest net returns (₹44372 and 29044 ha⁻¹ during 2023–24 and 2024–25, respectively). The highest benefit to cost ratio was registered with pre-emergence application of oxadiargyl at 90 g ha⁻¹ (1.92 and 1.62 during the year 2023–24 and 2024–25, respectively) as compared to other treatments (Table 2). Superiority of oxadiargyl at 90 g ha⁻¹ indicating the over other treatments. Similar findings reported that the highest net returns and B-C ratio (Rs. 67136 ha⁻¹ and 3.05) was recorded under pre-emergence application of

oxadiargyl 0.09 kg ha⁻¹ followed by one hand weeding 25 DAS (₹65757 ha⁻¹ and 2.76, respectively) (15).

Conclusion

Based on two years field study, it is concluded that among different pre- and post-emergence herbicides, application of oxadiargyl at 90 g ha⁻¹ + one hand-weeding at 30 DAS was found as the best treatment to control different weed flora and increasing yield of mustard crop, closely followed by oxadiargyl at 90 g ha⁻¹ at 30 DAS. Among the post-emergence herbicide treatments evaluated, the application of oxyfluorfen caused transient phytotoxicity (15 and 8 %) and substantial crop stand loss during both year of the study. The maximum benefit to cost ratio was registered with oxadiargyl at 90 g ha⁻¹ (1.92 and 1.62), closely followed by oxadiargyl at 90 g ha⁻¹ + one hand-weeding (1.86 and 1.56).

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Table 7. Effect of different pre- and post-emergence herbicides on economics of Indian mustard

Treatments	Cost of cultivation (₹ ha ⁻¹)		Gross returns (₹ ha ⁻¹)		Net returns (₹ ha ⁻¹)		B-C ratio	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
	T ₁	48021	48290	69460	52924	21439	4634	1.45
T ₂	53180	53382	79789	66199	26609	12817	1.50	1.24
T ₃	47355	47571	54475	45834	7120	-1737	1.15	0.96
T ₄	53355	53571	66614	54071	13259	500	1.25	1.01
T ₅	47643	47882	62514	51894	14871	4012	1.31	1.08
T ₆	46359	46495	71880	57685	25521	11190	1.55	1.24
T ₇	52359	52495	84105	72019	31746	19523	1.61	1.37
T ₈	45667	45748	87854	74201	42187	28453	1.92	1.62
T ₉	51667	51748	96039	80792	44372	29044	1.86	1.56
T ₁₀	56155	56155	100605	85560	44450	29405	1.79	1.52
T ₁₁	44166	44155	54067	43648	9912	-507	1.22	0.99

T₁: pendimethalin, T₂: pendimethalin + one hand weeding (HW), T₃: quizalofop-ethyl; T₄: quizalofop-ethyl + one HW, T₅: clodinafop, T₆: oxyflourfen, T₇: oxyflourfen + one HW, T₈: oxadiargyl, T₉: oxadiargyl + one HW, T₁₀: weed free and T₁₁: weedy check.

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Authors' contributions

AD was responsible for the planning, execution of the experiment and writing of the manuscript. PT, KS and D contributed to data recording and compilation. SS¹ and SS² performed the statistical analysis. SK and PK were involved in proofreading and finalizing the manuscript. All authors read and approved the final manuscript [SS¹ stands for Shivani Sharma and SS² for Shivani Sharma].

Compliance with ethical standards

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