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Growth, Yield and Weed Dynamics in Indian Mustard (*Brassica juncea*) Influenced by Different Weed Management Practices

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Abstract

In order to determine the most efficient and cost-effective weed management strategy for mustard in Punjab's subtropical climate, a field experiment was carried out during the rabi season of 2024–2025 to examine the impact of weed management techniques on yield, weed dynamics, and mustard economics. The study's findings showed that the weed-free treatment had the lowest mean weed dry weight (00.0 g m^{-2}), the highest weed control efficiency (100%), the highest mean plant height (120.9 cm), dry matter accumulation (13.5 g $plant^{-1}$), siliqua $plant^{-1}$ (94.3), siliqua length (5.21 cm), mustard seed, straw, and biological yields (22.0, 39.20, and 61.20 q ha^{-1}), and it was statistically superior to the other treatments. Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE, on the other hand, proved to be the best chemical application because it recorded greater values of siliqua $plant^{-1}$ and yields. Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE treatment increased seed, straw, and biological yields by an average of 99.6%, 55.9%, and 70.1% over the control. The combination treatment of Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE produced the highest net returns (₹106022 ha^{-1}) and B:C ratio (4.20). Because weeds have a suppressive effect on mustard, the lowest values (₹62712 ha^{-1} and 3.13) were recorded under weedy check.

Keywords: Weed control effectiveness; Dry matter; Mustard; Net returns; Seed yield

Introduction

Indian mustard, or *Brassica juncea* L., is the most important edible oil crop in the Cruciferae family. The second-most significant edible oilseed crop is mustard, which accounts for one-fourth of India's oilseed production. India is a big producer of mustard and ranks third in the world (Source: name of web: https://eands.dacnet.nic.in). The country's total area and output were 7.92 M hectares and 11.44 M tonnes (GOI, 2024). Its cultivation is concentrated in the Indian states of Rajasthan, Uttar Pradesh, Madhya Pradesh, Haryana, and Punjab (Sharma et al., 2024). Because its seeds contain 40–46% oil, rapeseed-mustard is an important oilseed crop (Hussain et al., 2020). According to Dwivedi et al. (2020), it is useful in a variety of industries, including food, pharmaceuticals, and biofuels. Because of its greater adaptability and appropriateness to take use of leftover moisture, this crop has potential during the winter (Rabi) season (Bamboria et al., 2017). The current demand of India's expanding population is not met by the quantity of edible oil produced from mustard. Productivity must be increased to close the gap between supply and demand. However, the prevalence of weeds that compete with the crop for resources like nutrients, water, light, and space makes mustard production difficult. These weeds have an effect on the crop's microenvironment, which influences its growth and development, in addition to reducing agricultural yield (Bista et al., 2023).

Certain weed species, such as *Boerhavia diffusa*, *Trianthema monogyna*, *Asphod elus tenuifolius*, *Melilotus Alba*, and *Convolvulus arvensis*, frequently predominate because mustard is mostly farmed under irrigation. Indian mustard is especially vulnerable to weed competition in the first four to six weeks following seeding. According to Bamboria et al. (2017), the critical period of crop weed competition in rapeseed-mustard is 15–40 days. Depending on factors like weed species, density, mustard growth stage, and the type and duration of the crop weed competition, weeds can cause an alarming decline in crop production ranging from 35–60% to a total failure yield (Kumar et al., 2020). However, Kumar et al. (2015) found that unchecked weeds reduced mustard output by 41.7%. Gharde et al. (2018) found a 21.4% yield loss in India's mustard crop, following the same pattern.

Researchers and farmers are now aware of the potential effects of weed invasion on mustard. They have put weed management techniques into place to deal with this problem. These tactics include chemical, mechanical, and biological techniques (Bajwa et al., 2021). Currently, one hand weeding 25 to 30 DAS is sufficient to eliminate weeds in their early stages. However, due to labor shortages and rising wages, manual weed management has become expensive and time-consuming. Finding efficient post-emergence herbicides that can handle early weed flush has thus become crucial. According to Upadhyay et al. (2013), herbicide mixtures are more efficient than a single herbicide method at combating the threat of weeds and the nutrient depletion they cause. It is crucial to assess and contrast the impacts of various weed control techniques on the growth, yield characteristics of Indian mustard, and weed growth parameters in order to guarantee sustainable and lucrative mustard farming. Given the significance of the issue, the current study was conducted to determine how weed management techniques affect Indian mustard (*Brassica juncea*) yield and weed growth.

Material and methods

Experimental Sites

The experimental investigation was carried out at Rayat Bahra University School of Agriculture Sciences, Experimental Research Farm Sahauran (Mohali), which is situated in the subtropical region of Punjab, India. The location was roughly 350 meters above sea level, with latitudes ranging from 30°45′ to 30°46′ N and longitudes of 76°38′ to 76°39′ E. The distance from Chandigarh city is roughly 12 kilometers. In general, that region experiences hot summers, mild winters, and seasonal variations in rainfall. Furthermore, the growth and characteristics of crops like mustard and other rabi (winter) crops are significantly influenced by the weather. Massive mustard cultivation was made possible by the weather during the Rabi season in 2024–2025, when temperatures ranged from 14°C to 25°C, which was perfect for crop germination. After November, the days grew colder, with December having the lowest daytime temperature at 4°C. In February and March, the temperature started to increase once more. The temperature and phase changes necessary for the weather patterns in the research area had a major impact on the plant's growth. During the crop growing period, the temperature and humidity conditions were ideal for mustard development. The crop growing season of 2024–2025 saw a mean annual precipitation of 69.0 mm, primarily from November to March. Fig. 1 displays the meteorological information at the test site throughout the study period.

Experimental Details

To lessen the impact of heterogeneity within the experimental site, the study used a Randomized Block Design (R.B.D). Each of the eight weed control methods that were assessed was repeated three times. As a result, 24 experimental plots were produced. With a plant spacing of 10 cm and a row spacing of 30 cm, the net plot measured 2.4 * 2.2 m^2 (Table 2).

Land Preparation and Crop Management

The "Natraj" mustard variety served as the study's material plant. The ground was leveled and tilled twice a week prior to the mustard crop being sown. Prior to layout, a composite soil sample was taken from the experimental field at a depth of 0 to 15 cm. The sample was air dried, ground into a powder, and sieved through a 2 mm sieve before being subjected to physical and chemical soil analysis. Table 1 contains all of the information regarding the physical and chemical properties of the experimental soil. Due to favorable weather and sufficient rainfall during the growth season, the seeds germinated uniformly, and only two irrigations were supplied at the branching and pod formation stages of the crop (Fig. 1). In addition, mustard is a crop that requires little water. The elimination and control of host weeds that harbor insect diseases may be the reason why no notable insects or diseases were observed during the mustard trial's growth and development (Kaur and Singh, 2015).

Fertilizer application

Fertilizers were sprayed at the prescribed levels of 80 kg N, 60 kg P_2O_5, 40 kg K_2O, and 25 kg S per hectare. Half of the nitrogen was applied as a basal treatment, while the other half was applied as a top dressing following the initial irrigation.

Treatments Application

In accordance with the manufacturer's instructions and local laws, the herbicides Pendimethalin and Clodinoflop were administered at the prescribed rates as pre-emergence and post-emergence, respectively. The solutions used for the applications contained 600 liters of water per hectare. Additionally, two manual weeding at 30 and 60 DAS were carried out.

Data Collection

The mustard crop is harvested at 20% grain moisture content. In the second week of April, the net plots are collected one by one after the plants on the boundary are removed from the field. The agricultural goods are harvested, allowed to dry in the field for four to five days, and then packaged and converted to yield q ha^{-1}. Using a stick to strike the plant (siliqua) separates the grains. The grain is cleaned after threshing, and sun drying removes up to 8% of the moisture. The weight of the straw was determined by deducting the grain weight from the total biomass of the plant, and the result was expressed in q ha^{-1}. Standard techniques were used to measure outcome factors (yield attributes). Based on the market price of the produce, the yield of the mustard crop (grain + straw) was translated into gross return in rupees per hectare. The gross return, stated in rupees per hectare, was subtracted from the total cost of production to determine the net return. Ratio of benefits to costs (B: C) The net return was divided by the corresponding cultivation costs to determine the benefit:cost ratio. In the experimental plots, additional weed management techniques, such as hand weeding at 30 and 60 DAS, pre-emergence herbicide spraying, and/or post-emergence herbicide spraying, were used in accordance with treatment. Two quadrates (0.25 m x 0.25 m) were randomly placed in each plot to record the dry weight of weeds, which was then converted into m^2. Weeds were dried in a hot air oven at 70°C ± 10°C for 72 hours, or until a consistent weight was reached, in order to determine their dry weight. Weed control efficiency and weed index were calculated using formulas proposed by Gill and Kumar (1969) and Kondap and Upadhyay (1985), respectively.

$$\text{WCE } (\%) = \frac{\text{Weed dry weight in untreated plot} - \text{Weed dry weight in treated plot}}{\text{Weed dry weight in untreated plot}} \times 100$$

$$\text{WI } (\%) = \frac{\text{Maximum yield from the treatment plot} - \text{Yield from the treated plot for which WI to be worked out}}{\text{Weed dry weight in untreated plot Maximum yield from the treatment plot}} \times 100$$

Statistical analysis

SAS version 9.3 was used to analyze the data for analysis of variance (ANOVA). Calculate "F tests" to compare treatments. Total weed density data were converted to $\sqrt{X+0.5}$ and statistically examined. At the 5% probability level, major differences between treatments were compared (Gomez and Gomez, 1984). Using R software (version 3.5.1), Pearson correlation analysis was carried out to demonstrate the relationship between different variables and their interactions with various treatments. The association between various treatments was demonstrated using simple linear regression.

Results and Discussion

Growth attributes

Plant height

The direct impact of various weed control techniques significantly affected Indian mustard plant height at every stage of growth (Table 3). The weed-free treatment had the highest plant height (23.6 cm, 64.6 cm, 103.2 cm, and 120.9 cm) among the weed management techniques at 30, 60, 90 DAS, and harvest. This treatment was statistically superior to the other treatments at all growth stages, and it was followed by twice-hand weeding. With average plant heights of 22.2 cm, 61.2 cm, 99.7 cm, and 115.6 cm at each stage, the combination application of Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE demonstrated good early and post-season weed suppression among herbicidal treatments. However, the application of Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE at 30 DAS had a statistically comparable treatment effect to twice-hand weeding. It might be because these treatments kept weeds under control for the life of the crop, which decreased crop-weed competition and enhanced access to nutrients, light, and moisture, leading to greater growth (Singh et al., 2025). However, because of unregulated weed competition during the crop period, the weedy-check had the shortest plants, measuring 14.5 cm, 45.3 cm, 80.7 cm, and 96.9 cm at 30, 60, and 90 DAS as well as at harvest. These results are consistent with the findings of Singh et al. (2021a), who found that efficient weed control improves mustard vegetative development by enabling improved resource utilization.

Dry matter accumulation

Table 4 illustrates how the dry matter accumulation of Indian mustard was significantly impacted by the different weed control strategies. At 30 DAS, the weed-free treatment exhibited the highest average dry matter accumulation per plant (3.15 g $plant^{-1}$). This amount rose to 6.95 g $plant^{-1}$ and 10.1 g $plant^{-1}$ at 60 and 90 DAS, respectively, and reached 13.5 g $plant^{-1}$ by harvest time. This suggests that manual weed eradication throughout the cropping season had a beneficial effect on dry matter accumulation, resulting in increased dry matter accumulation. Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE yielded a decent dry matter accumulation per plant, yielding similar results. At 30, 60, 90 DAS, and harvest, the average dry matter accumulation per plant was 2.95 g, 6.50 g, 9.3 g, and 12.6 g, respectively. It might be because these treatments continued to effectively suppress weeds throughout the growth phase, improving assimilate partitioning and photosynthetic efficiency. On the other hand, the weedy-check, where weeds significantly impeded crop growth and resource intake, had the lowest dry matter accumulation (2.1 g plant^{-1} at 30 DAS, 4.65 g plant^{-1} at 60 DAS, 6.8 g plant^{-1} at 90 DAS, and 9.5 g plant^{-1} at harvest). Therefore, the weedy check treatment showed less dry matter development, suggesting that weed competition negatively impacted dry matter accumulation. Yadav et al. (2020) noted similar patterns and stressed that good weed control increases dry matter accumulation by enhancing plant health and resource acquisition.

Table 1. The initial physico-chemical properties of the soil

Physico-Chemical properties		
Item	**Value**	**Method employed**
(i) Coarse sand	50.00 %	Hydrometer method (Piper., 1950)
(ii) Fine sand	29.00 %	
(iii) Silt	9.70 %	
(iv) Clay	5.00 %	
(v) Textural class	Sandy loam	
(vi) Organic carbon (per cent)	0.15	Walkley and Black wet digestion method (Walkley and black, 1934)
(vii) Available nitrogen (kg ha^{-1})	160.16	Alkaline potassium per magnate method (Subbiah and Asija, 1956)
(viii) Available Phosphorus (kg ha^{-1})	15.38	0.5 N $NaHPCO_3$ Extractable Olsen method (Olsen, 1954)
(ix) Available Potassium (kg ha^{-1})	177.12	Ammonium Acetate method (Merwin and peach, 1951)
(x) Soil pH	6.4	Soil: water suspension 1:2, with the help of digital pH meter (Jackson, 1953)
(xi) Electrical conductivity (dS m^{-1} at 25° C)	0.21	Digital conductivity meter (Jackson, 1973)

Table 2. Treatments and layout details

Treatment symbol	**Name of the treatments**
T1	Weedy Check
T2	Pendimethalin 750g/ha PE
T3	Pendimethalin 750g/ha PE *fb* one HW at 30 DAS
T4	Clodinofop 60 g/ha POE
T5	Clodinofop 60g/ ha POE *fb* one HW at 60 DAS
T6	Hand weeding twice 30 and 60 DAS
T7	Weed free
T8	Pendimethalin 750 g/ha PE + clodinofop 60g/ha POE
Details of layout	
Experimental design	**RBD (Randomized Block Design)**
Total treatments	8
Replications	3
Total number of plots	24
Plot size	
a. Gross plot size	3.6 m*2.6m
b. Net plot size	2.4 m*2.2m
Spacing	30 cm*10 cm
Date of sowing	17th November 2024
Variety	Natraj
Seed rate	3kg/ha.

Yield attributes

Number of siliqua per plant

Table 5 displayed information regarding siliqua plant^{-1}. Due to the use of various weed control techniques, the siliqua plant^{-1} at harvest was determined to be substantial. Manual weeding had a positive impact on siliqua development, as evidenced by the maximum siliqua plant^{-1} (94.3) attained with weed-free treatment followed by hand weeding twice at 30 and 60 DAS. Additionally, the findings showed that the combined effect of Clodinafop 60g/ha POE and Pendimethalin 750g/ha PE had a substantial impact on the number of siliqua plant^{-1}, which led to (89.5). Because there is less crop-weed competition at this stage, which is crucial for successful reproduction, the rise in siliqua plant^{-1} may result in better photosynthate partitioning. The weedy-check plots, on the other hand, had the lowest number of siliqua plant^{-1} (68.3), as significant weed infestation impeded plant growth. These findings are consistent with those of Meena et al. (2019), who found that successful weed suppression techniques boosted mustard reproductive growth. The smallest siliqua in weedy check plots was 5.61 cm, according to Dixit and Gautam (2012), Gupta et al. (2019), Pandey et al. (2019), Singh et al. (2020), and Kumar (2020).

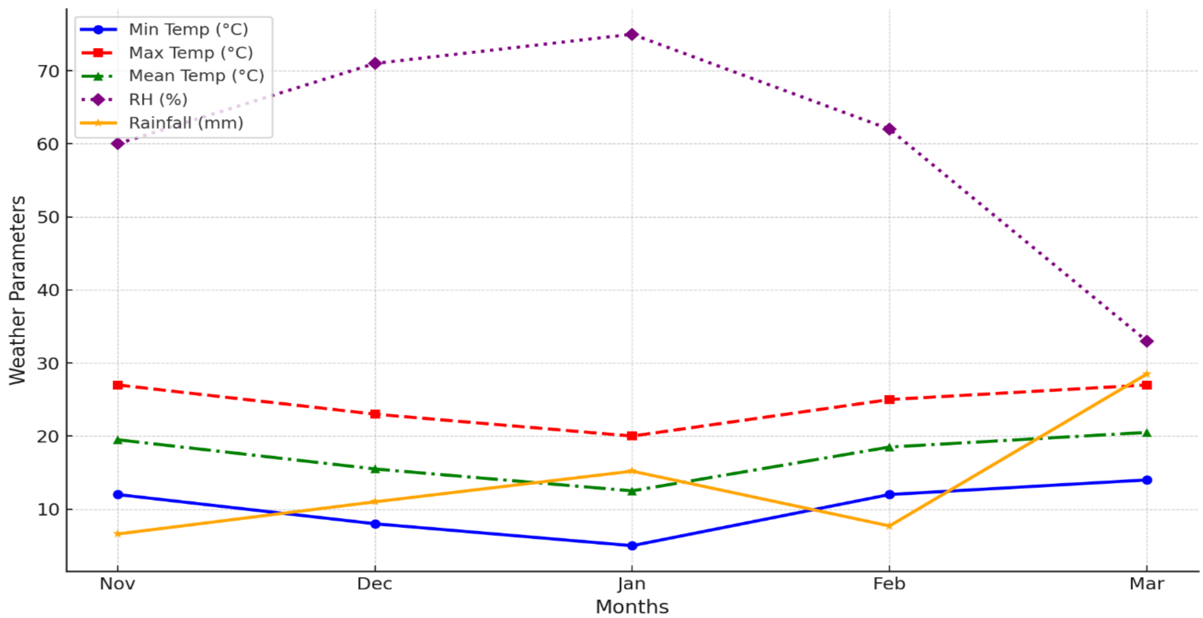

Fig. 1. Weather parameters during crop season 2024-25

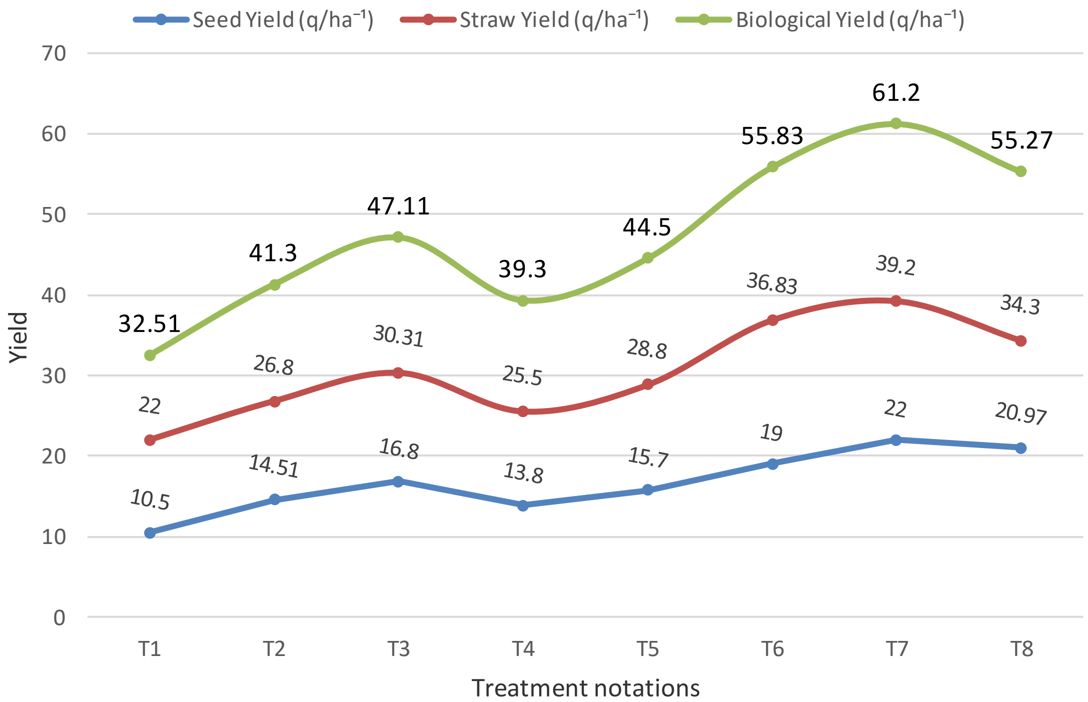

Fig. 2. Effect of weed management practices on crop yields (q ha^{-1}) of Indian mustard

Siliqua length (cm)

With an average siliqua length of 4.98 cm, which was comparable to twice manual weeding at 30 and 60 DAS, the weed-free treatment produced the longest siliqua (5.21 cm), followed by a combined application of Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE. This may be explained by reduced crop-weed competition for a longer growing period, which promoted better growth and development and improved expressions of yield-attributing characteristics, such as siliqua length and siliqua per plant, leading to a larger seed production. On the other hand, weedy-check had the shortest siliqua (3.83 cm). Singh et al. (2021b) revealed similar findings, emphasizing that weed competition negatively impacts seed set during the flowering and pod development periods.

Table 3. Effect of Weed Management Practices on Plant Height of Indian Mustard

Treatments	**Plant height (cm)**			
	30 DAS	**60 DAS**	**90 DAS**	**At harvest**
T1-weedy check	14.5	45.3	80.7	96.9
T2-Pendimethalin 750g/ha PE	18.5	55.4	92.4	106.5
T3- Pendimethalin 750g/ha PE fb HW at 30 DAS	21.4	60.2	97.7	113.6
T4- Clodinafop 60g/ha POE	17.2	52.2	89.5	104.5
T5- Clodinafop 60g/ha POE fb HW at 60 DAS	20.2	57.6	95.4	110.1
T6- HW twice @ 30 & 60 DAS	22.5	62.6	102.0	116.6
T7- Weed free	23.6	64.6	103.2	120.9
T8- Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE	22.2	61.2	99.7	115.6
SEm±	0.19	0.23	0.33	0.41
CD at 0.05	0.59	0.71	1.01	1.26

Table 4. Effect of Weed Management Practices on Dry matter accumulation of Indian Mustard

Treatment	**Dry matter accumulation (g plant^{-1})**			
	30 DAS	**60 DAS**	**90 DAS**	**At Harvest**
T1 - Weedy Check	2.10	4.65	6.81	9.50
T2 - Pendimethalin 750g/ha PE	2.75	5.91	8.25	10.20
T3 - Pendimethalin 750g/ha PE fb HW @ 30 DAS	2.90	6.25	9.11	11.32
T4 - Clodinafop 60g/ha POE	2.60	5.50	7.90	11.71
T5 – Clodinafop 60g/ha fb HW @ 60DAS	2.85	6.0	8.75	10.90
T6 - HW twice @30 & 60 DAS	3.20	7.11	10.42	12.80
T7 - Weed free	3.15	6.95	10.1	13.5
T8 - Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE	2.95	6.50	9.30	12.60
SEm±	0.01	0.02	0.11	0.12
CD at (0.05)	0.049	0.06	0.36	0.14

Yields

Seed yield (q/ha)

The most important indicator of the overall efficacy of weed control is seed output. The weed-free condition produced the maximum seed yield (22.0 q ha^{-1}), which was nearly equal to Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE (20.97 q ha^{-1}) (Fig. 2). In comparison to other treatments, weed-free demonstrated the highest level of weed control. According to Degra et al. (2011), the weed-free treatment considerably raised the mustard seed yield compared to the weedy check by 46.3%. Some weeds appeared in the later stages of crop growth during the Rabi season, while others appeared quite early. The successive application of herbicides is crucial for weed control under such circumstances. Therefore, applying herbicides in combination is crucial to controlling weeds that appear at different phases of crop growth. Weedy-check had the lowest seed yield (10.50 q ha^{-1}), demonstrating the detrimental effects of unchecked weeds on potential yield. This outcome supports the findings of Rathore et al. (2021), who found that integrated weed management techniques significantly increased mustard yield by reducing weed competition.

Straw yield (q ha^{-1})

The maximum straw production (39.20 q ha^{-1}) was produced by the weed-free treatment, demonstrating strong vegetative development and productivity (Fig. 2). On the other hand, the weedy-check treatment produced the lowest straw yield (22.0 q ha^{-1}). The next highest straw production (36.83 q/ha) came from the two manual weeding operations at 30 and 60 DAS. Pendimethalin 750 g/ha PE + Clodinafop 60 g/ha POE produced the highest straw yield (34.30 q ha^{-1}) among chemical treatments. According to Das (2016), Yadav et al. (2017), and Jangir et al. (2018), weed density and dry matter may have decreased as a result of weeds being successfully controlled first with pre-emergence herbicide treatment and later emergent weeds also being controlled with post-emergence herbicide. Furthermore, comparable results were reported by Kumar et al. (2020) and Chishi et al. (2021).

Table 5. Effect of Weed Management Practices on Yield Attributes and Economics of Indian Mustard

Treatment	**Siliqua per plant**	**Siliqua length (cm)**	**Gross Return (₹/ha)**	**Net Return (₹/ha)**	**B:C Ratio**
T1 – Weedy Check	68.3	3.83	82,720	62,712	3.13
T2 – Pendimethalin 750g/ha	78.2	4.24	1,20,600	96,880	4.08
T3 – Pendimethalin 750g/ha PE *fb* one HW at 30 DAS	86.0	4.46	1,27,740	1,02,696	4.10
T4 – Clodinafop 60g/ha	75.6	4.16	1,19,500	94,974	3.87
T5 – Clodinafop 60g/ha POE *fb* one HW at 60 DAS	81.8	4.35	1,25,880	1,01,031	4.07
T6 – HW twice 30 and 60 DAS	91.3	4.71	1,26,660	1,00,287	3.80
T7 – Weed free	94.3	5.21	1,33,600	1,06,832	3.99
T8 – Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE	89.5	4.98	1,31,280	1,06,022	4.20
SEm±	0.39	0.16	--	---	---
C.D. at (0.05)	1.20	0.49	---	---	---

Table 6. Effect of Weed Management Practices on different weed parameters in Indian Mustard

Treatments	**Dry weight (g/m²)**			**WCE (%)**			**Weed Index* (%)**
	60 DAS	**90 DAS**	**At harvest**	**60 DAS**	**90 DAS**	**At Harvest**	**At Harvest**
T1 – Weedy Check	328.5	405.71	418.86	00.00 (0.71)	00.00 (0.71)	00.00 (0.71)	52.27 (7.26)
T2 – Pendimethalin 750g/ha	152.06	194.66	206.23	53.71 (7.36)	52.02 (7.25)	50.76 (7.16)	34.09 (5.88)
T3 – Pendimethalin 750g/ha PE fb one HW at 30 DAS	113.16	151.93	165.9	65.55 (8.13)	62.55 (7.94)	60.39 (7.80)	23.64 (4.91)
T4 – Clodinafop 60g/ha	175.66	229.00	242.4	46.52 (6.86)	43.55 (6.64)	42.13 (6.53)	37.27 (6.15)
T5 – Clodinafop 60g/ha POE fb one HW at 60 DAS	162.7	207.4	217.83	50.47 (7.14)	48.88 (7.03)	47.99 (6.96)	28.64 (5.40)
T6 – HW twice 30 and 60 DAS	38.56	36.9	47.43	88.26 (9.42)	90.90 (9.56)	88.68 (9.44)	13.64 (3.76)
T7 – Weed free	00.00	00.00	00.00	100.00 (10.02)	100.00 (10.02)	100.00 (10.02)	0.00 (0.71)
T8 – Pendimethalin 750g/ha PE +Clodinafop 60g/ha POE	44.53	72.2	76.56	86.44 (9.32)	82.20 (9.09)	81.72 (9.07)	4.70 (2.28)
SEm±	5.42	4.19	6.84	--	--	--	--
CD (P=0.05)	10.28	12.7	20.75	--	--	--	--

*Figures in the parenthesis are original values. All Figures are subjected to transformed values to square root ($\sqrt{x + 0.5}$).

Biological yield (q ha⁻¹)

The maximum biological output (61.20 q ha^{-1}) was achieved by the weed-free treatment, demonstrating strong vegetative growth and productivity. On the other hand, the weedy-check treatment produced the lowest biological yield (32.51 q ha^{-1}). The next best biological yield (55.83 q ha^{-1}) came from the two manual weeding operations at 30 and 60 DAS. Pendimethalin 750 g/ha PE + Clodinafop 60 g/ha POE was the chemical treatment that produced the maximum biological yield (55.27 q ha^{-1}). According to Das (2016), Yadav et al. (2017), and Jangir et al. (2018), weed density and dry matter may have decreased as a result of weeds being successfully controlled first with pre-emergence herbicide treatment and later emergent weeds also being controlled with post-emergence herbicide. Furthermore, comparable results were reported by Singh et al. (2020), and Kumar (2020). Additionally, Kumar and Kaur (2015) found that weed management techniques increased yield compared to untreated plots.

Economics

The economic examination of different weed management strategies in Indian mustard revealed significant variations in gross returns, net returns, and benefit-to-cost ratios. The weed-free treatment outperformed the other treatments in terms of yield and market value, as evidenced by its greatest gross return of ₹ 133600 ha^{-1} (Table 5).

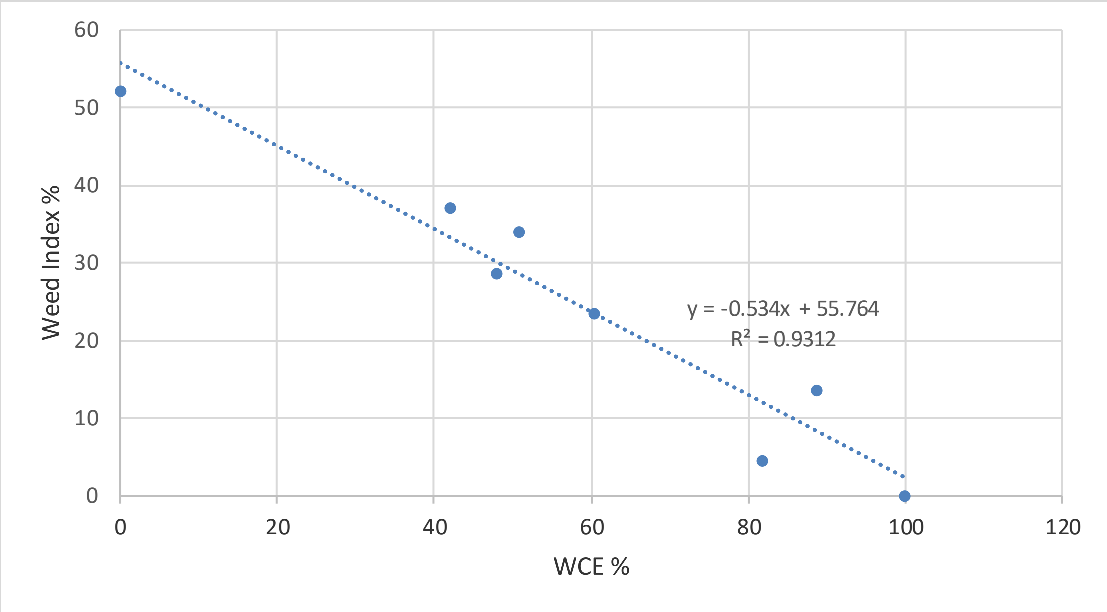

Fig. 3. Scatter plot between WCE (%) and Weed Index (%)

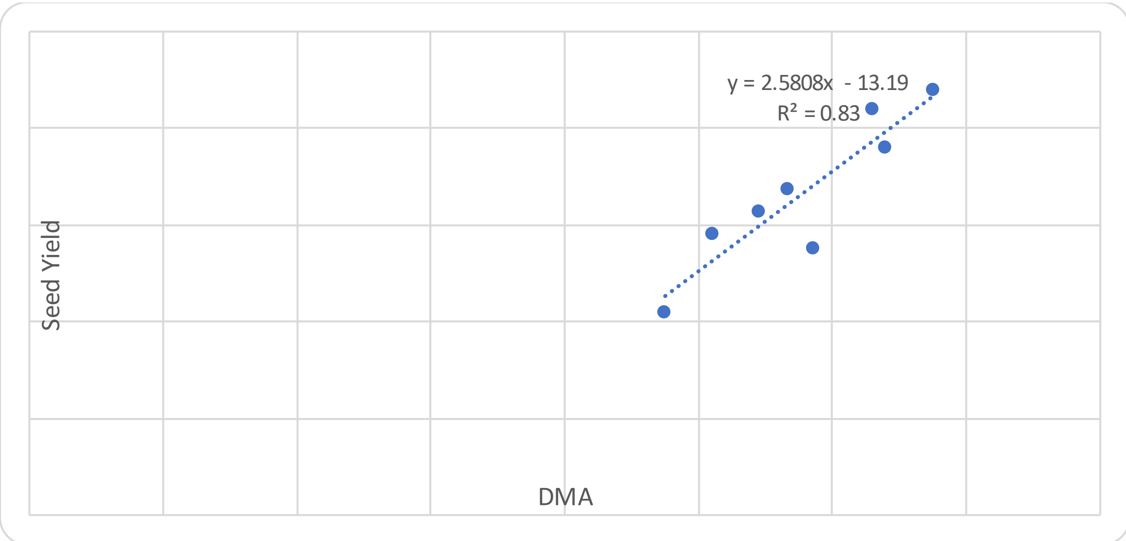

Fig. 4. Scatter plot between DMA and seed yield

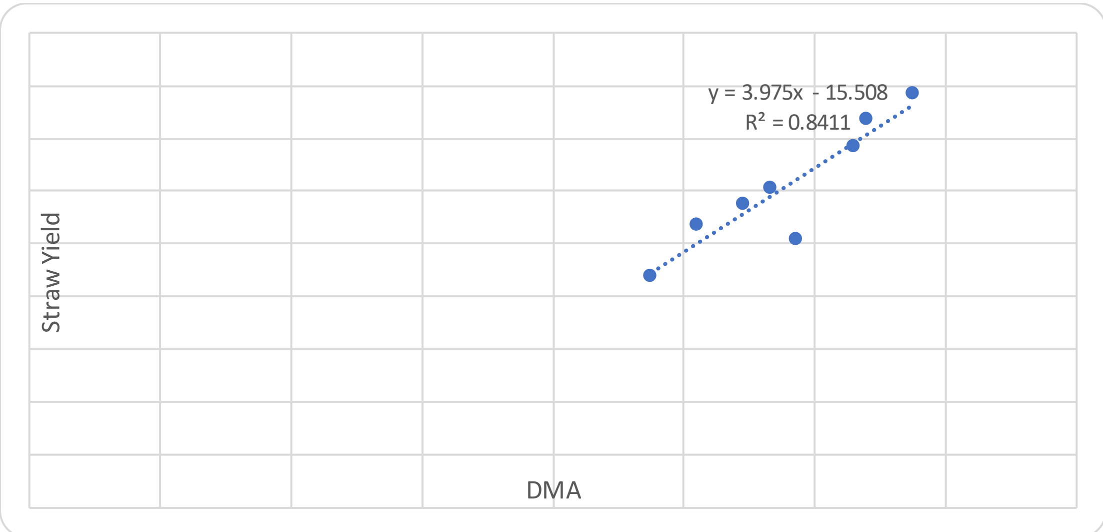

Fig. 5. Scatter plot between DMA and straw yield

The second-highest gross return of ₹131280 ha^{-1} was achieved by using Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE herbicides together. However, the weedy-check treatment yielded the lowest gross return (₹ 82720 ha^{-1}), suggesting that its effectiveness in increasing crop productivity and profitability is limited. The net return is a crucial indicator of total profitability after accounting for cultivation costs. The weed-free treatment yielded the highest net return of ₹ 106832 ha^{-1}, demonstrating the cost-effectiveness of manual weeding during the crop season. However, among the herbicidal treatments, the use of Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE herbicides had the second-highest net return of ₹ 106022 ha^{-1}, indicating its superiority in terms of cost of cultivation. On the other hand, the weedy-check treatment's net return of ₹ 62712 ha^{-1} was the lowest, demonstrating its poor profitability. Raj et al., 2020; Patel and Singh, 2021 highlight these results. The benefit-to-cost ratio is an essential indicator for evaluating the economic efficacy of weed management techniques. The application of Clodinafop 60g/ha POE and Pendimethalin 750g/ha PE together produced the best benefit-to-cost ratio of 4.20. Furthermore, Pendimethalin @ 750 g/ha + HW at 30 DAS demonstrated a competitive benefit-to-cost ratio of 4.10, emphasizing its financial advantages as an integrated weed management strategy. This could be attributed to higher mustard seed yield due to improved weed control and lower cultivation costs due to herbicide use when compared to hand weeding twice and weed-free.

Weed dynamics

One of the biggest obstacles to mustard production is weed infestation, and efficient weed control is essential to increasing output and resource efficiency. In terms of weed dry weight, weed control efficiency, and weed index, the current study found substantial variations between weed control regimens.

Weed Dry weight (g m^{-2})

A measure of overall weed pressure and competition is weed dry matter. Weed-free had the lowest dry matter buildup (0.00 g m^{-2} at 60, 90 DAS, and harvest), followed by hand weeding twice (38.56, 36.9, and 47.43 g m^{-2} at corresponding stages), indicating its physical suppressive impact (Table 6). On the other hand, at 60, 90 DAS, and harvest, the weedy-check plot had the highest weed biomass (328.5, 405.71, and 418.86 g m^{-2}), indicating fierce weed competition. Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE (44.53, 72.2, and 76.56 g/m^2 at respective stages) was the most effective combination of herbicidal treatments. This supports previous findings by Yadav et al. (2021) that crop resources can be preserved by using integrated weed control systems that combine pesticides and cultural techniques to reduce weed biomass.

Weed Control Efficiency (%)

Throughout the crop time, the weed-free treatment showed 100% weed control efficacy. Among chemical-based treatments, WCE of 86.44%, 82.20%, and 81.72% were obtained at 60, 90 DAS, and at harvest when Pendimethalin 750g/ha PE and Clodinafop 60g/ha POE were applied together. It could be because successful weed management reduced weed dry matter and increased weed control effectiveness (Singh and Kumar, 2020). Weedy-check, on the other hand, had the lowest efficacy with WCE 0.00%.

Weed Index

The weed-free plot had the lowest yield drop (0.00%) according to the weed index. Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE (4.70%) and hand weeding twice (13.64%) came next, suggesting that their yield potential was almost at its highest. The weedy-check had the highest weed index (52.27%), indicating significant yield suppression brought on by unmanaged weed competition. According to Patel et al. (2013), Kour et al. (2013), and Mukherjee (2014), a lower weed index may result from a decreased weed population and dry weight of weeds as well as a higher yield due to effective weed control.

Interpretation of Scatter plot between WCE (%) and Weed Index (%)

WCE (%) and Weed Index (%) have a strong negative linear association, according to the scatter plot (Fig. 3). The Weed Index significantly drops when WCE rises. According to the fitted line ($y = -0.534x + 55.764$), there is around a 0.53% decrease in Weed Index for every 1% rise in WCE. The substantial correlation and the fact that WCE accounts for the majority of the variation in Weed Index are indicated by the high R^2 value (0.9312).

Interpretation of Scatter plot between DMA and seed yield

The scatter plot (Fig. 4) shows that DMA and seed yield have a significant positive linear connection. Seed yield rises in direct proportion to DMA. According to the regression equation ($y = 2.5808x - 13.19$), there is roughly a 2.6-unit increase in seed yield for every unit rise in DMA. A good model fit is indicated by the comparatively high R^2 value (0.83), which demonstrates that DMA explains a significant amount of the variation in seed production.

Interpretation of Scatter plot between DMA and straw yield

The scatter Fig. 5 demonstrates a robust positive linear correlation between straw yield and DMA. Straw yield significantly increases as DMA rises. According to the regression equation ($y = 3.975x - 15.508$), straw yield increases by around 4 units for every unit rise in DMA. A strong and consistent link is indicated by the high R^2 value (0.8411), which implies that DMA explains the majority of the variability in straw yield.

Conclusion

The study's conclusion emphasizes how crucial efficient weed control techniques are to the production of Indian mustard. Weeds can cause farmers to lose money and are a serious threat to crop productivity. Any practice's economic viability determines its viability. Farmers may not accept a better weed control treatment if it does not yield a good return. The financial viability and sustainability of weed control are demonstrated by the greater benefit-cost ratio attained with Pendimethalin 750g/ha PE + Clodinafop 60g/ha POE treatment. The choice of herbicides should be carefully considered, though, as some may negatively impact crop development and output. The results highlight the necessity of ongoing study and modification of weed control techniques to deal with changing weed species and herbicide resistance. Farmers may maximize yields, lower production costs, and advance sustainable agriculture by implementing the best practices described in this study. In the end, efficient weed control benefits farming communities' livelihoods in addition to food security. Weed control must be given top priority as a basic component of contemporary farming methods since agriculture is still crucial to feeding the world's expanding population.

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