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Effect of weed management practices on growth, yield and quality of mustard (*Brassica juncea* L.)

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Abstract
A field experiment was conducted during the Rabi season to evaluate the effect of various weed management practices on weed dynamics, crop growth, yield, nutrient uptake, oil content, and profitability in Ind ian mustard (*Brassica juncea* L.). Eleven treatments comprising pre emergence (PE), post-emergence (PoE) herbicides, manual weeding, and integrated methods were arranged in a randomized block design with three replications. The untreated control [T_1: Weedy check] recorded the highest weed density (34.81 monocots and 45.67 dicots m^{-2} at 30 DAS; 46.91 total at harvest) and dry matter (38.62 g/m²), resulting in the lowest yield (935 kg/ha), oil content (38.35%), and negative net return (-₹4,626/ha; B:C = 0.91). The weed-free plot [T_2: Manual weeding throughout] had zero weed density, lowest weed biomass (2.70 g/m²), and highest yield (1716 kg/ha) and oil content (39.80%), but showed a moderate return (₹19,511/ha; B:C = 1.44) due to high labor cost. Integrated weed management (IWM) treatments outperformed others. [T_5: Pendimethalin 0.75 kg/ha PE + one hand weeding] showed excellent weed suppression (6.98 m^{-2}), high yield (1707 kg/ha), oil co ntent (39.71%), and nutrient uptake (N: 147.6, P: 28.9, K: 106.2 kg/ha). [T_7: Oxadiargyl 0.75 kg/ha PE + one hand weeding] yielded 1660 kg/ha with the highest net return (₹50,020/ha; B:C = 3.05). [T_6: Oxadiargyl PE] also performed well (1593 kg/ha; ₹49,520/ha). Thus, IWM strategies, especially [T_5] and [T_7], ensured optimal weed control, productivity, and profitability in mustard.

Keywords: Indian mustard, weed management, integrated weed control; yield, nutrient uptake, profitability

Introduction
Indian mustard (*Brassica juncea* L.), locally known as rai, raya, laha, and raiya, along with rapeseed, commonly referred to as sarson, toria, and yellow toria, are two of the most important oilseed crops extensively cultivated in India. These crops belong to t he family Brassicaceae (formerly Cruciferae), which comprises approximately 3,709 species and 338 genera (Warwick *et al*., 2006) [22]. Globally, this family ranks among the top ten most economically significant plant families (Rich, 1991) [15]. Indian mustard, a prominent rabi se ason oilseed crop, performs best under subtropical conditions, requiring cool temperatures and moderate weather throughout its growth period. In northern India, mustard is typically sown in October and November to coincide with the optimal climatic window for cultivation (Das *et al*., 2009) [4]. The mustard plant offers diverse uses. Its tender green leaves are popularly consumed as a traditional dish known as Sarson ka Saag, especially during winter. The oil extracted from mustard seeds is widely used across northern India for cooking, frying, and pickling, while also serving as a base for hair oil, medicinal formulations, soaps, lubricants, and tanning agents. Additionally, mustard seeds are commonly used as a spice and in the preparation of vegetable ghee. In contrast, rapeseed is n ot only valued for edible oil but also for its application in animal feed and biodiesel production, making it a key player in the renewable energy sector. With oil content ranging from 37% to 49% (Bhowmik *et al*., 2014) [1], mustard seeds are an economically viable source for oil extraction. Together, mustard and rapeseed serve critical roles in India's food industry, industrial sector, and sustainable agricultural practices. Beyond its economic value, Indian mustard holds significant nutritional importance. It contains approximately 4.51 grams of carbohydrates, 1.41 grams of sugars, 2.0 grams of dietary fiber, 0.47 grams of fat, and 2.56 grams of protein per 100 grams of se eds, making it a moderately nutritious food ingredient. More importantly, it is rich in

natural antioxidants, especially phenolic compounds like sinapic acid and sinapine, known for their anti-inflammatory, antimicrobial, and antioxidant properties (Thiyam *et al*., 2006) [20]. These bioactive compounds help reduce oxidative stress and may lower the risk of chronic conditions such as cardiovascular diseases and certain cancers. This nutritional and therapeutic potential makes Indian mustard a valuable addition to both traditional and modern diets, offering flavor, nourishment, and health benefits. Mustard is often cultivated as an intercrop or mixed crop, making it a flexible choice in various cropping systems. Its adaptability and low input requirements—particularly for water and fertilizers—make it an ideal crop for promoting diversification during the rabi season. Traditionally grown in states like Uttar Pradesh, Gujarat, Bihar, Madhya Pradesh, Rajasthan, and West Bengal, mustard has long been a staple in these regions. Due to its resilience in low -input conditions, especially in areas with minimal irrigation, mustard has also begun to expand into non-traditional states like Maharashtra, Andhra Pradesh, Tamil Nadu, and Karnataka. This expansion underscores a growing recognition of mustard's agronomic benefits and economic viability, especially for farmers seeking sustainable alternatives in diverse agro-ecological zones. As such, mustard plays an increasingly vital role in improving farm income, enhancing soil health through crop rotation, and supporting climate-resilient agriculture. Weeds not only reduce yield but also increase production costs due to the need for extra labor and chemical control measures. Furthermore, they degrade crop quality, serve as hosts for pests and pathogens, and reduce land value. According to Pandey (1980) [10], weeds can cause yield losses in mustard ranging from 30% to 70%—higher than the losses caused by pests and diseases, which account for about 45% of damage. Since mustard is largely grown under irrigated conditions, certain weed species like *Boerhavia diffusa*, *Trianthema monogyna*, *Asphod elus tenuifolius*, *Melilotus Alba*, and *Convolvulus arvensis* often dominate. However, weed composition varies with geography and field conditions, highlighting the need for site-specific weed management approaches. Weed growth is significantly influenced by factors such as soil type, climatic conditions, and agricultural practices. In mustard fields, weed competition severely reduces productivity by limiting access to vital resources. Raj *et al*., (2020) [13] documented heavy infestation of various weeds in mustard, including grasses like Phalaris minor and Cynodon dactylon; broad-leaved weeds such as *Chenopodium album, Anagallis arvensis, Melilotus spp., Vicia hirsuta, Lathyrus aphaca*, and *Rumex* spp.; and sedges like Cyperus rotundus. Shekhawat *et al*., (2012) [19] identified the critical weed -crop competition window as 15 to 40 days after sowing, after which mustard gains competitive strength. However, due to suboptimal soils and poor management, weed infestation remains a significant barrier to achieving high yields. Gill and Singh (2020) [5] reporte d that weed related yield losses in mustard average around 45%, depending on location, climate, and weed intensity. Globally, India ranks among the top three oilseed-producing nations, after Canada and China. Mustard is the second most important edible oilseed crop in India after groundnut. Indian mustard (*Brassica juncea*) accounts for nearly 75% of the total area under Brassica crops in the country. It contributes 24.7% of the total oilseed cultivation area and 29.4% of production during 2019-20 (Anonymous, 2019). Specifically, mustard was cultivated on 6.23 million hectares, producing 9.34 million tonnes with an average productivity of 1499 kg/ha in 2019 -20 (IndiaStat 2019-20). India's edible oil sector is the fourth largest globally after the U.S., China, and Brazil, holding 7% of production, 12% of consumption, and 20% of global imports during 2016 17 (USDA, 2018). In Rajasthan, mustard is the most significant rabi season oilseed crop, grown on 2.38 million hectares with an annual production of 3.95 million tonnes and an average productivity of 1656 kg/ha. In Maharashtra, however, the area under mustard cultivation is still limited. Given its suitability for both temperate and tropical climates, there is substantial potential to expand mustard cultivation in Maharashtra—especially in the Vidarbha region—to meet growing demand and improve farmer livelihoods.

Results and Discussion

Data pertaining to the number of total weeds m^{-2} revealed significant influence of different weed management practices at all the stages of mustard growth, supporting the findings of Kalita *et al*., (2017) [7] and Chatterjee and Singh (2018) [2], who also reported a significant decline in weed density under integrated weed control systems.

At 30 DAS, Weedy check recorded the highest weed count (80.48 m^{-2}), showing the consequence of no intervention, which corroborates earlier reports by Chatterjee and Singh (2018) [3]. In contrast, Weed -free check maintained absolute weed suppression (0.00 m^{-2}), reaffirming the results of Kalita *et al*., (2017) [7] regarding the effectiveness of frequent hand weedings in completely eliminating weed emergence.

Among the treatments, Pendimethalin 0.75 kg/ha PE + one hand weeding at 40 DAS showed the best control (28.72 m^{-2}), which is in line with Jangir *et al*., (2018) [6] and Sharma *et al*., (2021) [17] who demonstrated the superior efficacy of integrated herbicide and manual weeding methods. This was followed by Oxadiargyl 90 g/ha PE + one hand weeding at 40 DAS (32.35 m^{-2}) and Oxadiargyl 90g/ha PE alone (35.76 m^{-2}), findings consistent with the results of Yernaidu *et al.*, (2022) and S. Kumar (2012) [8] who observed effective early weed suppression with oxadiargyl in mustard.

By 60 DAS, the same treatments continued to outperform others. Weedy check still recorded high weed populat ion (60.04 m^{-2}), while Hand weeding twice (at 30 and 45 DAS) showed some control (39.39 m^{-2}). However, Pendimethalin + HW remained most effective (13.92 m^{-2}), followed by Oxadiargyl alone (10.22 m^{-2}) and Oxadiargyl + HW (10.95 m^{-2}), confirming findings by Pandey *et al*., (2022) [11] and Tyagi *et al*., (2022) [21] who noted better weed suppression with PE herbicides supplemented by mechanical measures.

At 90 DAS, weed suppression was sustained across integrated treatments. Weedy check still had a high weed count (48.01 m^{-2}), while Hand weeding twice also exhibited considerable weed population (27.20 m^{-2}). Weed -free check effectively maintained 0.00 m^{-2} weed density. Once again, Pendimethalin + HW performed best (7.44 m^{-2}), followed closely by Oxadiargyl + HW (6.62 m^{-2}), Oxadiargyl alone (8.37 m^{-2}), and Pendimethalin alone (17.67 m^{-2}), findings that align with Jangir *et al*., (2018) and Chatterjee and Singh (2018), demonstrating the long lasting efficacy of integrated weed management.

At Harvest stage, the weed count followed similar trends. Weedy check had the highest density (46.91 m^{-2}), and Hand weeding twice maintained moderate weed control (25.36 m^{-2}). Weed-free check again recorded complete control (0.00 m^{-2}), indicating consistent season-long management. Pendimethalin + HW (6.98 m^{-2}) and Oxadiargyl alone (7.75 m^{-2}) remained among the best - performing treatments, reaffirming their prolonged effectiveness as reported by Kalita *et al*., (2017) [7] and Sharma *et al*., (2021) [17].

Other treatments like Oxadiargyl + HW, Fluazifop-p-ethyl 0.125

kg/ha PoE + HW at 40 DAS, Fenoxaprop-p-ethyl 0.1 kg/ha PoE + HW at 40 DAS, and Pendimethalin alone also demonstrated moderate suppression, with final weed populations ranging from 6.38 to 16.89 m^{-2}.

In contrast, Fluazifop-p-ethyl alone (20.22 m^{-2}) and Fenoxaprop-p-ethyl alone (24.37 m^{-2}) showed higher weed presence, highlighting the limitations of post-emergence herbicides when applied without accompanying manual weed control—consistent with the conclusions of Kumar (2012) [8] and Prithvi Raj *et al*., (2020) [13].

Total weed dry matter production recorded at different crop stages (30, 60, 90 DAS and at harvest) exhibited significant differences among the weed management practices, reflecting their in suppressing weed growth throughout the cropping period. At 30 DAS, the highest weed dry matter accumulation was observed under the weedy check (T_1) with 4.49 g/m² (transformed value: 2.23), suggesting the unchecked proliferation of weed flora. Similarly high dry matter was also noted in Pendimethalin + one hand weeding (T_5) with 4.53 g/m² (2.24), possibly due to delayed suppression of early weed flushes. In contrast, the weed -free check (T_2) recorded the lowest dry matter (0.16 g/m², 0.81), reflecting complete suppression. Better performance was also shown by P endimethalin alone (T_4) and Fluazifopp-ethyl + one HW (T_9), recording 2.25 and 3.06 g/m², respectively, due to early residual effect and post -emergence control (Saini *et al*., 2022) [16]. By 60 DAS Dry matter accumulation increased significantly across all treatments. The highest values were recorded in weedy check (T_1) at 27.83 g/m² (5.32), and in Fenoxaprop-p-ethyl alone (T_{10}) at 20.46 g/m² (4.58), both of which showed poor weed suppression.

The lowest value was recorded in the weed-free check (T_2) with 3.22 g/m² (1.93), followed by Pendimethalin alone (T_4), Oxadiargyl + HW (T_7), and Pendimethalin + HW (T_5), which recorded 10.97, 10.69, and 10.15 g/m², respectively, demonstrating effective and sustained control due to pre-emergent and follow-up manual operations (Meena *et al*., 2020; Patel & Singh, 2023) [9, 12]. At 90 DAS, maximum weed dry matter was again observed in the weedy check (T_1) at 43.87 g/m² (6.66), emphasizing the cumulative impact of uncontrolled weed growth. The weed-free check (T_2) maintained the lowest value (4.21 g/m², 2.17). Noteworthy control was achieved in Pendimethalin + HW (T_5: 13.79 g/m²), Oxadiargyl alone (T_6: 16.31 g/m²), and Fluazifop-p-ethyl + HW (T_9: 16.31 g/m²), reflecting the effective residual and systemic action of herbicides along with manual interventions (Yadav *et al*., 2021; Choudhary *et al*., 2023). At harvest, the weedy check (T_1) recorded the highest total weed dry matter of 38.62 g/m² (6.25), followed by Fenoxaprop -p-ethyl (T_{10}: 24.88 g/m²), showing persistent weed presence. In contrast, the weed-free check (T_2) recorded only 2.70 g/m² (1.79), validating continuous weed suppression. Pendimethalin + HW (T_5: 11.38 g/m²), Pendimethalin alone (T_4: 14.70 g/m²), and other integrated approaches like Oxadiargyl + HW (T_7), Oxadiargyl alone (T_6), and Fluazifop-p-ethyl + HW (T_9) showed moderate dry matter production ranging from 12.77 to 15.13 g/m², indicating sustained weed control till maturity (Rani *et al*., 2024; Sharma & Kumar, 2022) [14, 18].

These findings are consistent with previous reports which highlight that integrated weed management approaches combining pre-emergence herbicides with hand weeding are more effective in reducing weed biomass compared to herbicide -alone treatments or untreated checks (Rani *et al*., 2024; Sharma & Kumar, 2022) [14, 18].

Cost of cultivation and return of mustard during crop duration

Treatments	**Common Cost (₹ ha⁻¹)**	**Treatment Cost (₹ ha⁻¹)**	**Total Cost (₹ ha⁻¹)**	**Seed yield (kg ha⁻¹)**	**Stover yield (kg ha⁻¹**	**Gross return (₹ ha⁻¹)**	**Net return (₹ ha⁻¹)**	**B:C Ratio**
T1 weedy check	54,553	0	54,553	935	3180	49,927	-4,626	0.91
T_2 Weed free check	54,553	4958	59,511	1716	4182	79,022	19,511	1.44
T_3 Hand weeding twice at 30&50 DAS	54,553	4472	59,025	1493	4711	76,570	17,545	1.41
T_4 Pendimethalin 0.75 kg/ha (PE)	54,553	727	55,280	1693	4788	60,000	4720	1.09
T_5 Pendimethalin 0.75 kg/ha (PE) + Hand weeding once at 40 DAS	54,553	2247	56,800	1707	4038	67,900	11,100	1.21
T_6 Oxadiargyl 0.75 kg/ha (PE)	54,553	927	55,480	1580	3821	1,05,000	49,520	3.05
T_7 Oxadiargyl 0.75 kg/ha (PE) + Hand weeding once at 40 DAS	54,553	1427	55,980	1660	3840	1,06,000	50,020	3.05
T_8 Fluazitop-p-ethyl 75 ml/ha (EPOE)	54,553	947	55,500	1473	4726	65,570	10,070	1.20
T_9 Fluazitop-p-ethyl 75 ml/ha (EPOE) + Hand weeding once at 40 DAS	54,553	1647	56,200	1602	3816	70,120	13,920	1.27
T_{10} Fenoxaprop-p-ethyl 75 ml/ha (EPOE)	54,553	1047	55,600	1435	3608	64,520	8920	1.18
T_{11} Fenoxaprop-p-ethyl 75 ml/ha (EPOE) + Hand weeding once at 40 DAS	54,553	1847	56,400	1578	3748	68,650	12,250	1.24

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