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Weed management strategies for rapeseed-mustard in Jammu and Kashmir, Uttarakhand and Himachal Pradesh: A comprehensive review

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Abstract

Rapeseed-mustard is a major edible oilseed crops in India. Advancements in rapeseed-mustard production technology have led to significant productivity gains. However, various biotic stresses, particularly weed infestations, continue to pose substantial challenges, with potential yield losses reaching up to 45%. They lower the crop productivity and quality by competing with crop plants for available nutrients, water, and light while also affecting the agro-ecosystem. Numerous weed species impact these; however, the degree of yield and resource depletion is location-specific. Many weeds are specific to certain crops or locations. *Orobanche aegyptiaca* is increasingly prevalent in rainfed areas of Rajasthan, Haryana and Madhya Pradesh while *Chenopodium*, *Asphodelus*, *Melilotus* and *Trianthema* species are associated with yield reductions in other regions. The Himalayan region states such as Jammu and Kashmir, Himachal Pradesh and Uttarakhand account for a very small share of India's total rapeseed mustard output nonetheless the crop plays a major local role in crop diversification and is quite vital for edible oil self-reliance in these states. The crop in the hill states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand experiences significant weed infestations predominantly by broad leaved species such as *Chenopodium album*, *Melilotus indica*, *Anagallis arvensis*, *Vicia sativa*, grassy weeds *Phalaris minor*, *Avena fatua* and sedges *Cyperus rotundus*. Rapeseed-mustard is particularly vulnerable to weed competition during the first 20-40 DAS, comparatively more than other oilseed crops. The weed management in rapeseed-mustard is carried out both by cultural and herbicidal approaches. Henceforth, the application of herbicides at critical growth stages along with one or two hand weeding at appropriate intervals poses a significant suppressing effect on weeds and boosts the crop yield. The economic analysis of several studies has concluded that fluchloralin and pendimethalin alone or in combination with hand weeding at 30 DAS is most economical to suppress weeds.

Keywords: Rapeseed, mustard, jammu and kashmir, uttarakhand, himachal pradesh, weeds, weed management, herbicides, IWM

Introduction

Rapeseed-Mustard is world's third most important source of edible oil after soybean and palm oil. Canada is the leading producer of rapeseed-mustard in the world followed by China. India contributes around 14% to world's total production. Rapeseed-mustard are the important oilseed crops and with the production of 13.2 million tons during 2023-24 it recorded to be the largest oilseed crop in India. Rapeseed-mustard accounts for 30.3% of India's oilseed acreage and 33.2% of production in 2023-24. In 2023-24, productivity of rapeseed-mustard averaged 1443 kg/ha, higher than the combined oilseeds average of 1314 kg/ha in India (ICAR-DRMR). The cultivation of this oil seed crop is carried out across the diverse agro-climatic conditions ranging from north-eastern to northwestern hills and down south under irrigated/rainfed, timely/late sown, saline soils and mixed cropping. However, Rajasthan leads in the production of rapeseed-mustard (45.40%) followed by Madhya Pradesh (13.28%), Uttar Pradesh (14.24%), Haryana (10.78%), and West Bengal (6.0%) during 2023-24. Since rapeseed-mustard is cultivated across diverse agro-climatic conditions of India, its presence is noted in the temperate zones of the Himalayas such as Jammu and Kashmir, Himachal Pradesh and Uttarakhand during the winter season. The area, production and productivity of Himalayan region states such as Jammu and

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Kashmir, Himachal Pradesh and Uttarakhand at district level is given in Table 1. Jammu and Kashmir has emerged as a prominent mustard-growing area among the Himalayan regions. From 2020-21 to 2023-24, oilseed cultivation area of J&K has expanded significantly by 253%, growing from 40,000 ha to 140,000 ha. This rapid increase has resulted in a major boost of the production, with more than 133,000 metric tons of oilseeds production in 2023-24, which corresponds to about 44,000 metric tons of edible oil. Consequently, the state has nearly overcome its former 96% edible oil deficit and moved towards self-sufficiency. The Anantnag district of Jammu and Kashmir is the top mustard producer of the valley followed by Pulwama and Srinagar (Directorate of Agriculture, Kashmir-2024). In Himachal Pradesh, Chamba district alone contributes 50% to the total production of Mustard. The contribution of rapeseed mustard production to country's total production in 2023-24 in Jammu and Kashmir, Uttarakhand and Himachal Pradesh and is 0.27, 0.18 and 0.05 respectively (Ministry of Agriculture, Govt. of India).

Rapeseed-mustard is a group of oilseed crops encompassing toria (*Brassica campestris* L. var. toria), brown sarson (*Brassica campestris* L. var. brown sarson), yellow sarson (*Brassica campestris* L. var. yellow sarson), gobhi sarson (*Brassica napus* L.) and Ethiopian mustard or karan rai (*Brassica carinata* A. Braun), Indian mustard [*Brassica juncea* (L.) Czernj & Cosson], black mustard (*Brassica nigra*) and taramira (*Eruca sativa*) of which Indian mustard accounts for about 80% of total area under these crops across India. Rapeseed is locally termed as sarson and toria (lahi) while rai or raya or laha is referred as mustard. The oil content of rapeseed and mustard seeds typically ranges

from 30 to 48 percent, although this can vary based on the specific variety and growing conditions. In India, these crops are cultivated during the *rabi* season, which extends from September-October to February-March. Brown sarson is predominantly cultivated in Kashmir and Himachal valley. Toria (*Brassica campestris* L. var. toria) and yellow sarson (*Brassica campestris* L. var. yellow sarson) are grown in certain pockets particularly in the Tarai region and at certain elevations of Uttarakhand but Indian mustard is predominant in the state.

The crop has a per hectare productivity of 1443 kg/ha in the country, compared to the global average of approximately 1980 kg/ha. The stress imposed by weed infestation is one of the key causes of low productivity in this crop and is reported to cause a yield reduction of about 15-30 per cent (Mishra *et al.* 2016)^[10], depending on the type of weed flora and their intensity, stage, nature and duration of crop-weed competition. Weed competition in this crop poses severe threat in its early stages of growth due to the slow growing characteristics of crop during the initial 4-8 weeks after sowing. However, at later stages crop grows vigorously and exerts a strong suppressing effect on weeds. Hence, a period of 15-40 DAS is considered as critical for crop-weed competition during which weed management will yield optimal results to maximize the growth and production of rapeseed and mustard. Traditional practice of hand weeding at 25-30 DAS has been the most ubiquitous method of weed control in rapeseed-mustard however non-availability of labour and rising wages makes this method problematic and inconvenient, hence the application of herbicides is comparatively found effective and economic for controlling weeds in rapeseed-mustard crop.

Table 1: Area, Production and Productivity of the Himalayan Region States

State	District	Area (Hectare)	Production (Tonnes)	Yield (Tonne/Hectare)
Himachal Pradesh	1. Bilaspur	191	146	0.76
	2. Chamba	2,920.00	2,126.00	0.73
	3. Hamirpur	42	30	0.71
	4. Kangra	1,728.00	1,289.00	0.75
	5. Kinnaur	3	2	0.67
	6. Kullu	117	85	0.73
	7. Mandi	289	103	0.36
	8. Shimla	258	289	1.12
	9. Sirmaur	937	692	0.74
	10. Solan	659	593	0.9
	11. Una	1,420.00	1,892.00	1.33
Total		8564	7247	0.85
Jammu and Kashmir	1. Anantnag	14,413.00	11,458.66	0.8
	2. Badgam	5,187.00	5,488.42	1.06
	3. Bandipora	1,518.00	1,571.78	1.04
	4. Baramulla	128	113.26	0.88
	5. Doda	902	1,027.81	1.14
	6. Ganderbal	1,741.00	1,604.05	0.92
	7. Jammu	500	438.99	0.88
	8. Kathua	2,592.00	1,765.19	0.68
	9. Kishtwar	12	10.14	0.84
	10. Kulgam	2,843.00	2,767.49	0.97
	11. Poonch	30	25.34	0.84
	12. Pulwama	8,730.00	7,577.60	0.87
	13. Rajauri	367	271.74	0.74
	14. Ramban	119	100.53	0.84
	15. Reasi	66	37.03	0.56
	16. Samba	384	380.74	0.99
	17. Shopian	260	230.07	0.88
	18. Srinagar	124	109.72	0.88
	19. Udhampur	1,360.00	1,291.77	0.95
Total		41276	36270.32	0.88

Uttarakhand	1. Almora	1,964.00	1,358.00	0.69
	2. Bageshwar	292	236	0.81
	3. Chamoli	653	457	0.7
	4. Champawat	719	651	0.91
	5. Dehradun	749	751	1
	6. Haridwar	2,129.00	2,434.00	1.14
	7. Nainital	512	552	1.08
	8. Pauri Garhwal	1,324.00	618	0.47
	9. Pithoragarh	1,129.00	913	0.81
	10. Rudra Prayag	631	294	0.47
	11. Tehri Garhwal	972	454	0.47
	12. Udam Singh Nagar	8,076.00	9,513.00	1.18
	13. Uttar Kashi	1,149.00	858	0.75
Total		20299	19089	0.94

(Source: Ministry of Agriculture and Farmer Welfare, Govt of India)

Weed Flora in Rapeseed-Mustard

Many weed species infest rapeseed and mustard, with their composition and competitiveness varying according to soil, climate, cropping practices, and management. Generally, *Argemone mexicana*, *Chenopodium album*, *C. murale*, *Cyperus rotundus*, *Cynodon dactylon*, *Melilotus alba*, *Asphodelus tenuifolius*, *Orobancha* spp., and *Anagallis arvensis* are the most recurrent weeds found in rapeseed and mustard. Broomrape (*Orobancha*) is a parasitic weed of mustard. Among its various species, *O. aegyptiaca* which is quite prevalent in semiarid regions, is the most troublesome weed reducing the production and quality severely in rapeseed-mustard. The objectionable weed in rapeseed and mustard is *Argemone mexicana*, commonly known as Mexican poppy or "satyanashi" in hindi. Its seeds if mixed with mustard seeds either accidentally or purposefully, and ingestion of this contaminated oil potentially causes fatal "epidemic dropsy". The argemone seeds typically contain toxins such as alkaloids, sanguinarine and dihydrosanguinarine that target heart, liver, kidney and lungs.

Reported the infestation of *Chenopodium album*, *Convolvulus arvensis*, *Cynodon dactylon*, *Avena fatua*, *Asphodelus tenuifolius*, *Melilotus indica*, *Anagallis arvensis* and *Phalaris minor* in the mustard field. Occurrence of *Anagallis arvensis* L., *Chenopodium album* L., *Vicia sativa* L. *Cynodon dactylon* L. and *Asphodelus tenuifolius* were also reported in mustard crop. Mukherjee (2014)^[7] reported most dominant weed species of rapeseed at Darjeeling, West Bengal were *Anagallis arvensis*, *Chenopodium album*, *Convolvulus arvensis*, *Centella asiatica*, *Coronopus didymus*, *Melilotus indica*, *Medicago polymorpha*, *Oxalis latifolia* and *Vicia sativa*. In another study carried out by S. K Das (2016), broad leaf weed (BLW) like *Anagallis arvensis*, *Chenopodium album*, *Convolvulus arvensis*, *Fumaria parviflora*, *Melilotus alba*, *Lathyrus aphaca*, *Euphorbia hirta*, *Parthenium hysterophorus*, *Spergula arvensis*, *Gnaphalium leuteoalbum*, *Commelina benghalensis*, *Asphodelus tenuifolius*, *Cleome viscosa* and grasses like *Echinochloa colona*, *Cynodon dactylon*, *Paspalum scrobiculatum*, *Digitaria sanguinalis* and sedges like *Cyperus rotundus* were quite dominant in the field of yellow sarson.

Most invasive weed species found by Ashwani (2010) in Indian Mustard (*Brassica juncea*), dominant at Palampur, Himachal Pradesh were *Phalaris minor*, *Avena ludoviciana* and *Lolium temulentum*, and BLW such as *Vicia sativa*, *Coronopus didymus* and *Anagallis arvensis*. In a study conducted by Rani and Fayaz (2013-14) on weed flora of mustard crop at Poonch district of Jammu and Kashmir, *Cyperus rotundus*, *Cynodon dactylon*, *Vicia hirsuta*, *Anagallis arvensis*, *Ranunculus sceleratus*, *Phalaris minor*, *Melilotus alba*, *Chenopodium album*, *Amaranthus viridis* and *Chenopodium murale* severely infested

the crop among which *Cyperus rotundus* and *Cynodon dactylon* were more widespread. Jehangir *et al.* (2019)^[44] conducted an experiment on weed flora of brown Mustard (*Brassica rapa* var. brown sarson) at south (Anantnag, Kulgam, and Pulwama) and central districts (Budgam) of Kashmir valley during Rabi (2016-17 and 2017-18). The Poaceae family recorded highest number of species (4) and a proportional abundance of 0.2, followed by the Asteraceae, Brassicaceae, and Caryophyllaceae families, each with two species and a proportional abundance of 0.01. Regarding morphological classification, weed infestation was primarily composed of sixteen broad-leaved weed species accounting for 80% of the total, along with three grassy weeds from the Poaceae family (15%) and a single sedge species from the Cyperaceae family (5%). The utmost dominance of BLW species such as *Arenaria serpyllifolia*, *Fumaria parviflora*, *Poa annua*, *Capsella bursa-pastoris* and *Stellaria media* were common in all four districts. *Poa annua* was identified as the most dominant weed in brown sarson fields, exhibiting the highest IVI values of 84.9 in Pulwama, 50.6 in Anantnag and 44.1 in Kulgam. In contrast, *Veronica persica* recorded the highest IVI of 34.5 in Budgam district trailed by *Poa annua* at 31.3. The weed flora reported by Chishi *et al.* (2021)^[1] in mustard crop at Dehradun, Uttarakhand comprised of mixed population of broad-leaved weeds, viz. *Chenopodium album* and *Fumaria parviflora*; grassy weed, viz. *Cynodon dactylon* and sedge, viz. *Cyperus rotundus*. experimented on mustard (*Brassica juncea*) at Dehradun, Uttarakhand and found a mixed population of broad-leaved weeds namely *Chenopodium album* and *Fumaria parviflora* as well as a grassy weed *Cynodon dactylon* and sedge *Cyperus rotundus*.

The assessment of plant invasion in agroecosystem of Kashmir Himalayan by Pervaiz and Zafar (2022) revealed that Kashmir Himalayan agroecosystem is heavily invaded by alien species with invasion levels exceeding 70% (Table 2 and Figure 1). Mustard crop noted second highest proportion of alien species after orchards and also the variation in species diversity pattern after Oats (Table 3). The highest total and native species diversity as indicated by the highest values of Simpson, Shannon, Evenness, and Berger-Parker indices were recorded for orchards followed by Mustard cropland. These variations in diversity patterns are attributed to differences in the abundance and frequency of individual species, which were observed to vary across Kashmir Himalayan agroecosystems (Table 4).

Table 2: Native and Alien Species in Mustard crop of Kashmir Himalayan Agroecosystem

Crop	Native	Casual Alien	Naturalized Alien	Invasive Alien
Mustard	19	2	33	16

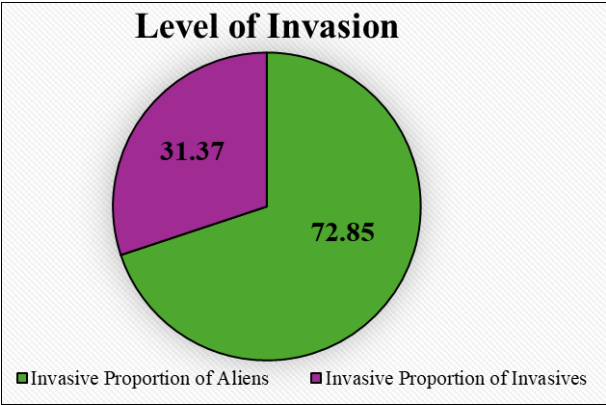


Fig 1: Level of species invasion in the Kashmir Himalayan Agroecosystems

Swati and Anil (2023) observed on *Brassica juncea* at Pantnagar, Uttarakhand that *Phalaris minor* was found to be the most prevalent grassy weed while as *Cynodon dactylon* being present in least number. Sedges were not prominent however only a few individuals of *Cyperus rotundus* were recorded with minimal presence. Among broadleaf weeds, *Medicago denticulate* and *Chenopodium album* recorded the highest populations while as *Anagallis arvensis* and *Cirsium arvensis* occurring less frequently. Narrow leaf weeds such as *Echinochloa crus-galli*, *Phalaris minor*, *Cynodon dactylon*, *Cyperus rotundus* and broad-leaf weeds such as *Parthenium hysterophorus*, *Anagallis arvensis*, *Rumex* spp., and *Raphanus raphanistrum* were observed on *Brassica juncea* by Sandeep et al. (2024)^[46] in the mid-hill region of Himachal Pradesh.

Table 3: Various diversity indexes in Mustard at Kashmir Himalayan Agroecosystem

Diversity Index	Mustard
Simpson-D _T	0.9365
Shannon H _T	3.42
Evenness (exp(H)/S) _T	0.4369
Berger-Parker _T	0.1616
Simoson-D _N	0.6469
Shannon H _N	1.643
Evenness (exp(H)/S) _N	0.2721
Berger-Parker _N	0.5486
Simoson-D _A	0.934
Shannon H _A	3.291
Evenness (exp(H)/S) _A	0.527
Berger-Parker _A	0.1623

* T- Total weed species diversity; N- Native weed species diversity; A- Alien weed species diversity

Table 4: Most Abundant and Frequent Weeds of Mustard in the Kashmir Himalayan Agroecosystems.

Mustard (in decreasing order of abundance and frequency)	
Species	Invasion Status
<i>Trifolium repens</i>	Invasive alien
<i>Medicago lipulina</i>	Naturalized alien
<i>Hordeum murinum</i>	Naturalized alien
<i>Bromus japonicus</i>	Naturalized alien
<i>Alopecurus aequalis</i>	Naturalized alien
<i>Poa annua</i>	Invasive alien

Weed Management in Rapeseed-Mustard

Mechanical method of weed control: Tillage is an age-old practice in agricultural systems which checks the weed population by uprooting, breaking apart and burying them

deep enough to avoid their emergence by altering the soil environment. Chahal *et al.* (2003)^[27] testified that no-till cropping system retains majority of the weed seeds within the top 1.0 cm of the soil profile. In contrast, deep tillage using mould board plough significantly reduces weed population by means of soil inversion, thereby relocating most weed seeds to deeper layers, which inhibits their emergence. Deep tillage prior to mustard sowing has earned increased significance for the effective management of prevalent annuals viz., *Anagallis arvensis* and *Medicago denticulata*, as well as perennials viz., *Convolvulus arvensis*. Ashwani (2010) found that two-handed weeding at 30 and 60 DAS were at par with pendimethalin @ 0.75 kg/ha in lowering the population and dry weight of weeds in Indian Mustard. Duary and Teja (2018)^[34] in their two-year experiment on weed suppression of yellow mustard noted that tillage significantly influenced the density and dry weight of monocot, dicot and total weeds at 45 DAS. Kumar (2020)^[31] reported that two hand weedings at 20 and 40 DAS resulted in decreased weed dry weight in toria (27.05 g m⁻² at 60 DAS) and recorded weed control efficiency of 80.87%. The practice of mulching is an effective method of weed control. observed that twice-hand weeding at 30 and 60 DAS noted the highest weed control efficiency and the lowest weed index in *Brassica juncea*. The mulch layer forms a barrier on the surface of soil which prevents the sunlight from reaching the weeds on ground thus inhibiting their photosynthesis. Bazaya *et al.* (2006)^[26] reported the application of polythene mulch in *B. juncea* acted as a physical barrier to weed emergence by raising the soil temperature and thus effectively controlling weeds. Choudhary and Kumar (2014)^[33] found that mulched plot recorded the lowest values for weed parameters. Duary *et al.* (2025)^[35] conducted a two-year experiment on weed suppression in yellow mustard by mulching with *Eichhornia crassipes* (water hyacinth) @ 15 t/ha and *Antigonon leptopus* (coral vine) @ 4 t/ha. The findings indicated that *Eichhornia crassipes* served as an effective mulch against dicots for both the years and proved to be at par with *Antigonon leptopus*. Application of weed mulch singlehanded cut down the total weed density by 51.89- 54.46% and decreased the biomass by 62.57-67.45% during the first and second year of experiment, respectively. Soil solarization for at least two weeks of May and June in India effectively suppresses weeds and can be extended for lasting results. This method controls weeds in both kharif and rabi. A reduction of about 90% in Orobanche infestation was reported by Singh (2011)^[29] in mustard due to soil solarization.

Cultural method of weed control: These practices held a major importance just before the popularization of herbicides. The main aim is to boost crop competitiveness against weeds which makes a provision for low-cost and safe weed control technique. The retention of preceding crop residues in the domain of conservation tillage can affect weed growth by altering light transmittance, soil temperature, moisture levels as well as by increasing weed seed predation. Selection of a highly competitive cultivar is considered a significant weed management method to boost overall competitiveness of the crop against weeds. Plant density also influences the weed population. Enhancing crop canopy coverage per unit area through the adjustment of plant density significantly contributes to the suppression of weed growth. demonstrated that increased seed rate had an inverse relationship with weed population and weed dry matter in mustard field. He noted significantly higher weed density and weed dry matter accumulation at the lowest seed rate of 4 kg/ha. In contrast, higher seed rates of 5 and 6

kg/ha resulted in the lowest values for both weed density and dry matter accumulation of weeds. This reduction in weed parameters due to increased seed rates may be attributed to denser plant population per unit area that caused suppression effect on weeds.

Chemical method of weed control: Owing to the rapid action of herbicides, this approach is generally regarded as the most preferred among various weed management practices. For effective weed control in mustard crop, pre-emergence application of pendimethalin was found effective as reported by Mukherjee (2014) [7] and Rao and Chauhan (2015) [17]. Consequently, pendimethalin is the most widely used herbicide in Indian mustard. In a study conducted ON Indian mustard use of pendimethalin @1.0 kg a.i. ha⁻¹ followed by clodinafop-propargyl @0.06 kg a.i. ha⁻¹ at 30 DAS was established as most effective in lowering the weed dry matter, followed by the application of fluazifop-p-butyl @0.08 kg a.i. ha⁻¹ at 30 DAS, clodinafop-propargyl @0.06 kg a.i. ha⁻¹ at 30 DAS, propaquizafop + oxyfluorfen @0.08 kg a.i. ha⁻¹ at 30 DAS and propaquizafop @0.10 kg a.i. ha⁻¹ at 30 DAS over weedy check. Oxadiargyl, pendimethalin, trifluralin and oxyfluorfen significantly reduces *Chenopodium album* and *Anagalis arvensis* population in Indian mustard, although oxadiargyl @90 g ha⁻¹ as pre-emergence herbicide recorded maximum value for weed control efficiency (81.82%) compared to control. Due to the effectiveness from initial growth stages of crop, application of pre-emergence herbicides holds great importance in rapeseed mustard crop. Additionally, late-emerging weeds can be controlled through the application of selective post-emergence herbicides. Patel *et al.* (2013) [18] observed in mustard the lowest weed density and weed dry matter accumulation in case of pendimethalin @0.5 kg ha⁻¹ (PE) + 1 HW at 25 DAS followed by oxadiargyl 75 g ha⁻¹ (PE) + 1 HW at 25 DAS. The least values for weed density and weed dry weight were recorded in case of pendimethalin @1 kg ha⁻¹ as pre-emergence application on *B. rapa* (Das, 2016) [6]. A key requirement for chemical weed management is to scout the field prior to selecting the herbicides based on the identified weeds. Similarly, following the 5Rs—using the right source, the right herbicide, the right dose, the right timing, and the right application method is critical to achieve optimal weed control. Table 5 provides a list of herbicides commonly applied for weed management in oilseed crops (Choudhary *et al.* 2022) [41].

Table 5: List of Herbicides for Application in Oilseed Crops

Herbicide	Dose (kg/ha)	Time of Application
Pendimethalin	0.678	Pre-emergence
Oxyfluorfen	0.15-0.25	Pre-emergence
Oxadiargyl	0.09	Pre-emergence
Napropamide	1.125-1.406	Pre-emergence
Isoproturon	1.00	Pre-emergence or post-emergence
Quizalofop	0.00.05	Post-emergence

The application of pendimethalin and isoproturon on gobhi mustard produced significantly low weed density as well as weed species biomass (Suryavanshi *et al.*, 2018) [19]. Pandey *et al.* (2022) [20] noted lowest weed density and dry weight m⁻² due to the application of metribuzin (PE) @175 g ha⁻¹ combined with hand weeding at 40 DAS in *B. juncea*. Pre-emergence application of oxyfluorfen @0.15 kg/ha in mustard recorded higher weed control efficiency after weed-free plots and was at par with pre-emergence application of pendimethalin @1.0 kg/ha. Tyagi *et al.* (2022) [12] noted that pendimethalin 30 EC

@1.0 kg a.i. ha⁻¹ PE fb quizalofop 5 EC @60 g a.i. ha⁻¹ PoE along with 125% RDF achieved highest weed control efficiency in mustard, statistically at par with pendimethalin @1.0 kg a.i. ha⁻¹ PE fb clodinafop @60 a.i. ha⁻¹ PoE. Application of pendimethalin @1 kg/ha or oxadiargyl @0.09 kg/ha as a pre-emergence followed by quizalofop @0.05 kg/ha at 15-20 DAS (post-emergence) or fluazifop-p-butyl @0.125 kg/ha at 25-30 DAS (post-emergence) resulted in effective control of broad-leaf weeds, improving seed yield in mustard and providing greater net profitability as established by Choudhary *et al.* (2022) [41]. Monocot weeds were significantly controlled by the application of Pendimethalin @0.75 kg a.i. ha⁻¹ during both the years of experiment on yellow mustard. Pendimethalin lowered the density of monocots weeds by 67.05% in the first year and 69.00% in the second year. However, it showed lower efficacy against dicot weeds. (Duary *et al.*, 2025) [25].

Integrated method of weed management: Integrated weed management (IWM) is the strategic combination of chemical, cultural and mechanical control tools and techniques for effective management of weeds. This approach can restrict the adaptation of weeds and thus provide efficacious long-term control. Bamboriya *et al.* (2016) [9] testified that combining the use of herbicides with one hoeing in mustard is highly efficacious in lowering the weed population at 60 DAS. One-hand weeding at 20 DAS followed by oxyfluorfen @100 ml ha⁻¹ PE at 2 DAS produced lowest weed density as noted by Shrivastava *et al.* (2013). The lowest weed index was enumerated in *Brassica juncea* attributed to paddy straw mulch @5t ha⁻¹ followed by pendimethalin @1.0 kg ha⁻¹ (PE) + clodinafop @60 g ha⁻¹ (PoE) (Singh and Kumar, 2020) [31]. Pendimethalin @0.75 kg/ha pre-emergence followed by one hand weeding was found effective against grassy, broad-leaf and sedge weeds in *Brassica juncea* as observed. The lowest density and dry weight of weeds enumerated in *Brassica juncea* were attributed to the pre-emergence application of Pendimethalin @1 kg/ha + hand weeding at 30 DAS (Swati and Anil, 2023). Sandeep *et al.* (2024) [46] concluded that pre-emergence application of Oxadiargyl @0.90 kg a.i. ha⁻¹ + two-hand weeding at 30 and 60 DAS minimized the weed density, weed control efficiency and weed index of both narrow and broad leaf weeds in *Brassica juncea*.

In conservation agriculture-based rice-yellow mustard-green gram cropping system, conservation tillage with recommended herbicide was as effective as conventional tillage with herbicide and hand weeding for efficacious weed control and productivity in yellow mustard (Duary and Teja, 2018) [34]. Mulching might be considered as one of the vital components of IWM in mustard. Utilising locally sourced weed species as bio-organic mulch represents an effective strategy for suppressing the proliferation of undesirable weeds. Inclusion of straw and weed mulch as IWM component were found efficacious in direct seeded rice, wheat and oilseed crops like sesame in eastern India (Malik *et al.* 2021) [23]. Moreover, integration of herbicides with cultural methods to improve the judicious and sustainable use of herbicides is also stressed upon. Rajesh Singh *et al.* (2013) [8] highlighted the paramount importance of integrated methods of weed management being eco-friendly. Amalgamation of herbicides with mechanical weed control is found to be the most effective and economically feasible approach for weed management in rapeseed-mustard.

Conclusion

Weed infestation in mustard significantly reduces the crop yield.

The duration of weed infestation in the field can influence crop yield, depending upon the specific weed species. To minimise economic losses, it is advisable to implement weed control measures during early crop growth stages, particularly the initial four to six weeks, which represents critical period of competition in rapeseed mustard cultivation. Weed management is a systematic approach that involves comprehensive land use planning carried out in advance to minimise aggressive weed invasions and provide crop plants with a competitive edge over weeds. The weeds occurring in rapeseed-mustard can be effectively managed with the application of pre-plant herbicides such as fluchloralin and trifluralin. Pre-emergence herbicides such as alachlor, butachlor, isoproturon, metolachlor, metribuzin, nitrofen, oxadiargyl, oxadiazon, oxyfluorfen, pendimethalin, terbutryn, and thiobencarb have demonstrated considerable potential. In recent years, integrated weed management approaches are gaining prominence for its environmental benefits. Employing integrated management strategies that incorporate preventive, cultural and herbicidal approaches can achieve effective and reliable weed control in rapeseed-mustard crop. Combining chemical weed control with mechanical weeding is a commonly used approach for managing weeds in rapeseed-mustard production due to its effectiveness and cost efficiency. However, it is also essential to conduct ongoing monitoring of weed flora in rapeseed-mustard across all agro-ecological regions of India. Region specific weed flora influenced by local microclimates necessitates tailored integrated weed management strategies for optimised crop productivity. This will facilitate the identification of emerging weed challenges and support the effective planning of both current and future weed management strategies for various agro-ecological zones.

Future Prospects

The future of weed management in rapeseed-mustard across the Himalayan states will be defined by integrated, technology-driven, and eco-friendly solutions. Precision agriculture-that deploys sensors, AI based detection and site-specific inputs- will enable smarter, resource-efficient weed control even in small-scale, hilly farms. Biological controls including bioherbicides and mulching with competitive cover crops, offer sustainable alternative suited to fragile mountain agro-ecosystems. The adaptation of harvest weed seed control devices, along with the breeding of weed-competitive and herbicide-tolerant mustard varieties, promises to revolutionise weed seedbank management. Paired with robust extension programs and policy backing, these strategies will empower farmers to sustainably manage weeds, improve yields and ensure long term profitability in the face of ongoing climatic and ecological change.

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