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Efficacy of herbicides on weed management and productivity of castor (*Ricinus communis* L.)

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Abstract
Weed competition is a major limiting factor in castor (*Ricinus communis* L.) cultivation, which is significantly reducing growth, yield and economic returns of the crops. A two-year field experiment (2022-23 and 2023-24) was conducted at the College of Agriculture, Anand Agricultural University, Vaso, Gujarat to evaluate the efficacy of various herbicidal and integrated weed management strategies on weed suppression, growth and seed yield of castor. The field study comprised ten treatments involving pre-emergence (PE) and post-emergence (PoE) herbicides, sequential applications and manual weeding operations arranged in a randomized block design with three replications. Results revealed that IC *fb* HW at 20, 40 and 60 DAS (T_9) was the most effective treatment achieving the complete control of both monocot and dicot weeds at 25 DAS and maintaining the lowest weed density (2.45 and 2.47/m²) with corresponding weed dry weight of 2.45 and 2.47 g/m² at harvest with 100% weed control efficiency (WCE) at 25 DAS and 83.84% at harvest. This treatment also produced the tallest plants (163.07 and 160.67 cm), higher spikes per plant (8.38 and 7.97) and superior seed yields of 3154 and 2917 kg/ha across the two years, respectively. Among herbicide treatments, pendimethalin 30% EC 1000 g a.i./ha PE *fb* IC + HW at 40 DAS (T_2) and oxyfluorfen 23.5% EC PE *fb* IC + HW at 40 DAS (T_3) effectively suppressed weeds and produced seed yields at par with IC *fb* HW at 20, 40 and 60 DAS (T_9). The highest weed density and dry weight along with the lowest seed yields (1945 and 1659 kg/ha) both years were recorded under the weedy check (T_{10}).

Keywords: Castor, herbicides, weed control efficiency, integrated weed management and productivity

Introduction
Castor (*Ricinus communis* L.) is a commercially important industrial oilseed crop valued for its oil, which has diverse industrial applications. However, its slow initial growth, wide plant spacing and low canopy cover make it highly susceptible to weed competition particularly during early growth stages (Patel & Virdia, 2011) [7]. Weeds compete aggressively for space, sunlight, nutrients and moisture leading to reductions in plant height, number of spikes and seed yield (Dungarwal *et al*., 2002) [2].

Chemical weed control using pre-emergence (PE) and post-emergence (PoE) herbicides has been demonstrated as an effective approach for suppressing both monocot and dicot weeds in castor (Kalaichelvi & Kumar, 2016; Kowser *et al*., 2018) [3, 4]. Pendimethalin, a dinitroaniline herbicide inhibits cell division in germinating weed seedlings controlling primarily monocots, while oxyfluorfen, a diphenyl ether herbicide inhibits protoporphyrinogen oxidase targeting mainly dicots (Manickam *et al*., 2009; Vaghasia & Nadiyadhara, 2016) [5, 11]. Integration of chemical control with intercultural operations and hand weeding (IC *fb* HW) often enhances weed management efficiency and crop productivity (Patel *et al*., 2014; Patel *et al*., 2018) [8, 9]. The present study was conducted to evaluate the comparative efficacy of various herbicidal and integrated weed management strategies on weed suppression and castor productivity with particular emphasis on identifying treatments that are at par with the recommended intercultural operations followed by hand weeding.

Materials and Methods
The field experiment was conducted during the *Kharif* seasons of 2022-23 and 2023-24 at the College of Agriculture, Anand Agricultural University, Vaso, Gujarat. The site is characterized by a semi-arid subtropical climate with an average annual rainfall of 867 mm.

The experimental soil was loamy sand which is slightly alkaline (pH 8.17-8.22), low in organic carbon and nitrogen, medium in phosphorus and high in potassium.

The experiment was laid out in a randomized block design (RBD) with ten treatments replicated thrice. Treatments consisted of pre-plant incorporation, pre-emergence, post-emergence and late post-emergence herbicides as well as manual methods. The spraying was done by using Knapsack sprayer fitted with flat-fan nozzle using 500 L of water/ha. The castor variety GCH 7 was sown on 30th August 2022 and 24th August 2023 at a spacing of 120 × 60 cm using a seed rate of 6 kg/ha. Each plot had a gross area of 5.4 × 4.8 m with a net plot area of 4.8 × 4.8 m. The recommended dose of fertilizers (75-50-0 kg/ha of N, P and K) was applied uniformly to all treatments, using urea and diammonium phosphate as the sources of nitrogen and phosphorus, respectively. Standard crop management practices were followed.

The data on weed density and weed dry weight were not normally distributed; therefore, square root transformation ($\sqrt{X+1}$) was applied prior to statistical analysis. Weed observations were recorded randomly from 0.25 m² quadrats within the net plot of each treatment and extrapolated to 1 m². The mean values were used for further analysis. Duncan's New Multiple Range Test (DNMRT) was employed to compare treatment means at a 5% probability level.

Results and Discussion

Weed flora

Total fifteen weed flora were identified in experimental site. *Commelina benghalensis* L., *Eleusine indica* (L.) P. Beauv., *Digitaria sanguinalis* Scop and *Dactyloctenium aegyptium* (L.) P. Beauv. as monocot, *Digera arvensis* Forst, *Trianthema monogyna* L. Mant, *Boerhavia diffusa* L., *Phyllanthus niruri* L., *Chenopodium album* L. and *Euphorbia hirta* L. as dicot as well as *Cyperus rotundus* L. as sedge were found as dominant weed flora among the entire weed species observed during both the years of experimentation period.

Weed Density, Dry Weight and Weed Control Efficiency

Weed competition is a major constraint in castor cultivation, with both monocot and dicot species contributing significantly to crop weed competition. Over the two-year study (2022-23 and 2023-24), the weedy check (T_{10}) recorded the highest total weed density and dry weight. Monocot weed densities were 5.81 and 8.28/m² and dicot densities were 5.02 and 6.44/m² at 25 DAS and at harvest, respectively with corresponding weed dry weights of 5.56 and 15.38 g/m² for monocots and 6.79 and 13.76 g/m² for dicots. The high weed pressure in the untreated plots can be attributed to rapid weed growth, high fecundity and lack of initial crop competition, which leads to reduced light interception, nutrient uptake and moisture availability for castor (Patel & Virdia, 2011; Bai *et al.*, 2021) [7]. These results corroborate previous findings that unchecked weed growth significantly reduces castor productivity by outcompeting the crop during its early slow-growth phase (Dungarwal *et al*., 2002; Naik *et al*., 2016) [2, 6].

IC *fb* HW at 20, 40 and 60 DAS (T_9) was the most effective achieving complete control of both monocot and dicot weeds at 25 DAS. At harvest, weed densities were maintained at very low levels with monocots at 2.45/m² and dicots at 2.47/m². The corresponding weed dry weights were 4.65 g/m² for monocots and 5.61 g/m² for dicots. This treatment recorded 100% WCE at 25 DAS and 91.28% for monocots and 83.84% for dicots at harvest. The integrated mechanical approach allowed continuous removal of emerging weeds, limited regrowth, and ensured minimal competition throughout the crop cycle, thereby enhancing growth, nutrient uptake, and seed yield of castor (Kalaichelvi & Kumar, 2016) [3].

Among the chemical treatments evaluated, pendimethalin 30% EC 1000 g a.i./ha PE *fb* IC + HW at 40 DAS (T_2) and oxyfluorfen 23.5% EC 117.5 g a.i./ha PE *fb* IC + HW at 40 DAS (T_3) were highly effective in suppressing both monocot and dicot weeds throughout the crop growth period. At 25 DAS, these treatments maintained very low weed densities ranging from 1.40 to 1.53/m² for monocots and 1.30 to 1.63/m² for dicots with corresponding weed dry weights of 1.18 to 1.23 g/m² for monocots and 1.11 to 1.19 g/m² for dicots. At harvest, monocot densities remained low (2.88 to 3.00/m²) and dicot densities ranged from 2.96 to 3.09/m² with weed dry weights of 3.95 to 4.24 g/m² for monocots and 4.88 to 5.11 g/m² for dicots. The weed control efficiency (WCE) at harvest was 92.76-93.76% for monocots and 86.68-87.84% for dicots indicating sustained suppression of weed regrowth over the season. This indicates that early pre-emergence herbicide application combined with intercultural hand weeding effectively limits initial weed emergence and prevents subsequent infestation (Kowser *et al*., 2018) [4].

Growth and Yield Attributes

Weed management significantly influenced the growth and yield of castor. Intercultural operations followed by hand weeding at 20, 40 and 60 DAS (T_9) recorded taller plants (163.07 & 160.67cm), maximum spikes per plant (8.38 & 7.97), longest main spike (76.81 & 72.53 cm) and higher seed yield (3154 & 2917 kg/ha) during 2022-23 and 2023-24 demonstrating that continuous suppression of both monocot and dicot weeds throughout the crop growth period enhances nutrient and light utilization, thereby improving vegetative and reproductive performance (Kalaichelvi & Kumar, 2016) [3]. Pre-emergence herbicide treatments, pendimethalin 30% EC 1000 g a.i./ha PE *fb* IC + HW at 40 DAS (T_2) and oxyfluorfen 23.5% EC PE *fb* IC + HW at 40 DAS (T_3) remained at par with IC *fb* HW at 20, 40 and 60 DAS in plant height (155.46 & 158.51 cm), spikes per plant (7.23 & 8.21), and seed yield (3027 & 2767 kg/ha) indicating that early chemical intervention combined with intercultural hand weeding can achieve comparable growth and yield benefits while reducing labour requirements. In contrast, tank-mix and sequential post-emergence treatments (T_4 to T_8) showed intermediate performance due to partial weed control and regrowth, especially of dicots negatively affecting canopy development and spike formation (Singh *et al*., 2013; Vaghasia & Nadiyadhara, 2016) [10, 11]. The weedy check (T_{10}) recorded minimum plant height (125.11 and 127.68 cm), fewest spikes per plant (5.01 and 5.62), shorter main spike length (59.80 and 57.24 cm) and minimum seed yield (1945 and 1659 kg/ha) during 2022-23 and 2023-24, respectively showing the adverse effect of weed competition on castor growth and yield (Manickam *et al*., 2009;Patel *et al*., 2014) [5, 8].

Table 1: Effect of different herbicides on weed density, weed dry weight and weed control efficiency (WCE) (Mean data of two years)

Treatments	Weed density (No./m^2) at 25 DAS		Weed density (No./m^2) at harvest		Weed Dry weight (g/m^2) at 25 DAS		Weed Dry weight (g/m^2) at harvest		WCE (%) at 25 DAS		WCE (%) at harvest	
	Monocot	Dicot	Monocot	Dicot	Monocot	Dicot	Monocot	Dicot	Monocot	Dicot	Monocot	Dicot
T_1: Pendimethalin 38.7% CS 1000 g a.i./ha PPI *fb* IC + HW at 40 DAS	1.74^{cde} (2.10)	1.82^{de} (2.37)	4.30^{c} (17.57)	4.12^{de} (16.07)	1.73^{cd} (2.06)	1.64^{de} (1.70)	5.86^{de} (33.43)	7.36^{cde} (53.50)	93.14	96.24	85.86	71.68
T_2: Pendimethalin 30% EC 1000 g a.i./ha PE *fb* IC + HW at 40 DAS	1.53^{ef} (1.37)	1.63^{de} (1.70)	2.88^{g} (7.40)	2.96^{f} (7.83)	1.23^{e} (0.54)	1.19^{f} (0.42)	3.95^{g} (14.76)	4.88^{f} (22.98)	98.19	99.07	93.76	87.84
T_3: Oxyfluorfen 23.5% EC 117.5 g a.i./ha PE *fb* IC + HW at 40 DAS	1.40^{f} (1.00)	1.30^{f} (0.73)	3.00^{fg} (8.10)	3.09^{f} (8.60)	1.18^{e} (0.42)	1.11^{f} (0.25)	4.24^{fg} (17.12)	5.11^{f} (25.16)	98.61	99.44	92.76	86.68
T_4: Pendimethalin 30% EC 750 g a.i./ha + oxyfluorfen 23.5 % EC 117.5 g a.i./ha PE (Tank mix)	1.00^{g} (0.00)	1.16^{fg} (0.37)	5.68^{b} (31.27)	5.18^{b} (25.93)	1.00^{e} (0.00)	1.10^{f} (0.22)	10.46^{b} (108.86)	9.73^{b} (94.33)	100	99.52	53.96	50.06
T_5: Pendimethalin 30% EC 750 g a.i./ha PE *fb* quizalofop-ethyl 5% EC 50 g a.i./ha PoE	2.42^{b} (4.90)	3.04^{cd} (8.30)	3.26^{def} (9.67)	4.46^{cd} (18.97)	2.24^{b} (4.06)	3.59^{d} (11.94)	6.38^{de} (39.88)	7.51^{cde} (55.74)	86.47	73.61	83.13	70.50
T_6: Pendimethalin 30% EC 750 g a.i./ha PE *fb* propaquizafop 10% EC 75 g a.i./ha PoE	2.38^{bc} (4.80)	3.16^{bc} (9.07)	3.43^{de} (10.80)	4.62^{c} (20.47)	2.26^{b} (4.24)	4.08^{c} (15.78)	6.49^{cde} (41.27)	7.93^{cde} (62.25)	85.86	65.13	82.55	67.05
T_7: Pendimethalin 30% EC 750 g a.i./ha PE *fb* protected spray of glufosinate ammonium 13.5% SL 450 g a.i./ha LPoE	2.41^{b} (4.83)	3.38^{b} (10.53)	3.48^{de} (11.13)	4.12^{de} (16.10)	2.22^{bc} (3.94)	4.42^{b} (18.66)	6.90^{cd} (46.64)	8.10^{cd} (65.19)	86.87	58.75	80.27	65.49
T_8: Oxyfluorfen 23.5% EC 117.5 g a.i./ha PE *fb* quizalofop-ethyl 5% EC 50 g a.i./ha PoE	1.92^{cd} (2.70)	1.35^{f} (0.83)	3.64^{d} (12.37)	4.40^{cde} (18.47)	1.76^{cd} (2.12)	1.21^{f} (0.48)	7.17^{c} (50.77)	8.12^{c} (65.22)	92.94	98.95	78.53	65.47
T_9: IC *fb* HW at 20, 40 and 60 DAS	1.00^{g} (0.00)	1.00^{g} (0.00)	2.45^{h} (5.00)	2.47^{g} (5.23)	1.00^{e} (0.00)	1.00^{f} (0.00)	4.65^{f} (20.62)	5.61^{f} (30.53)	100	100	91.28	83.84
T_{10}: Weedy check	5.81^{a} (32.77)	5.02^{a} (24.30)	8.28^{a} (67.67)	6.44^{a} (40.57)	5.56^{a} (29.98)	6.79^{a} (45.24)	15.38^{a} (236.42)	13.76^{a} (188.91)	-	-	-	-
LSD (p=0.05)	0.19	0.24	0.36	0.41	0.20	0.23	0.67	0.80	-	-	-	-

Note: Values √(x+1) transformed; parentheses = original. Means with same letter not different at 5% (DNMRT).

Table 2: Effect of different herbicides on growth and yield attributes of castor

Treatments	Plant stand (net plot) at 15 DAS		Plant stand (net plot) at harvest		Plant height (cm) at harvest		Number of spikes/plant		Length of main spike (cm)		Seed yield (kg/ha)	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
T_1: Pendimethalin 38.7% CS 1000 g a.i./ha PPI *fb* IC + HW at 40 DAS	31.33	32.00	28.00	28.67	161.40	153.00	8.04	7.31	68.37	63.25	2847	2658
T_2: Pendimethalin 30% EC 1000 g a.i./ha PE *fb* IC + HW at 40 DAS	32.00	31.67	29.33	28.33	155.46	158.00	7.23	8.21	73.22	66.64	3027	2767
T_3: Oxyfluorfen 23.5% EC 117.5 g a.i./ha PE *fb* IC + HW at 40 DAS	31.00	31.67	27.33	28.67	158.51	157.33	7.86	8.01	72.13	67.76	2918	2722
T_4: Pendimethalin 30% EC 750 g a.i./ha + oxyfluorfen 23.5 % EC 117.5 g a.i./ha PE (Tank mix)	31.67	31.33	28.33	27.33	142.29	139.17	6.10	6.48	60.95	56.45	2361	2152
T_5: Pendimethalin 30% EC 750 g a.i./ha PE *fb* quizalofop-ethyl 5% EC 50 g a.i./ha PoE	31.33	31.67	29.67	29.33	151.40	148.89	6.50	6.82	66.58	59.25	2537	2388
T_6: Pendimethalin 30% EC 750 g a.i./ha PE *fb* propaquizafop 10% EC 75 g a.i./ha PoE	31.67	32.00	29.33	28.33	152.29	141.67	7.04	6.54	62.47	56.22	2413	2273
T_7: Pendimethalin 30% EC 750 g a.i./ha PE *fb* protected spray of glufosinate ammonium 13.5% SL 450 g a.i./ha LPoE	31.33	32.00	29.00	27.67	146.26	151.33	6.34	7.12	66.29	60.30	2707	2356
T_8: Oxyfluorfen 23.5% EC 117.5 g a.i./ha PE *fb* quizalofop-ethyl 5% EC 50 g a.i./ha PoE	32.00	31.33	26.67	27.33	148.96	147.83	6.84	6.92	65.25	63.41	2641	2388
T_9: IC *fb* HW at 20, 40 and 60 DAS	32.00	32.00	27.33	29.33	163.07	160.67	8.38	7.97	76.81	72.53	3154	2917
T_{10}: Weedy check	31.67	32.00	27.33	29.67	127.68	125.11	5.01	5.62	59.80	57.24	1945	1659
LSD (p=0.05)	NS	NS	NS	NS	14.14	15.67	0.93	0.95	8.82	7.79	374	391

Conclusion

Intercultural operations followed by hand weeding at 20, 40 and 60 DAS effectively suppressed both monocot and dicot weeds resulting in the higher seed yield in castor. Further, Either pre-emergence application of pendimethalin 30% EC 1000 g a.i./ha PE *fb* IC + HW at 40 DAS or oxyfluorfen 23.5% EC PE *fb* IC + HW at 40 DAS provided comparable weed control and seed yield of castor. Therefore, integrating herbicides with cultural practices represents a sustainable, economically viable and labour efficient weed management strategy for castor cultivation in semi-arid regions of Gujarat.

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