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Research notes

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RESEARCH ARTICLE

Weed control in direct-seeded rice with ready mix of penoxsulam + pendimethalin

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ABSTRACT

Diverse weed flora in direct-seeded rice (DSR) has underscored the need to identify broad-spectrum pre-emergence (PE) herbicide for managing weeds and to realize the yield potential of DSR. This study assessed weed dynamics and DSR productivity response to PE herbicide treatments, *viz*. penoxsulam 1% + pendimethalin 24% (penoxsulam + pendimethalin) at 500, 562.5 and 625 g/ha, pendimethalin at 750 g/ha and unsprayed control, during *Kharif* 2021 and 2022 in Department of Agronomy at Punjab Agricultural University, Ludhiana. Penoxsulam + pendimethalin 625 g/ha PE was most effective in controlling the weeds and reducing weeds biomass, mainly of grasses and sedges. During both years, no significant effect of PE herbicides on rice plant height was recorded except unsprayed control. Penoxsulam + pendimethalin 625 g/ha increased the effective tillers/m^2 of rice by 72% in 2021 and 87.8% in 2022 compared to unsprayed control. Moreover, penoxsulam + pendimethalin 625 g/ha significantly increased the mean grain yield of DSR by 187.0% (6.6 t/ha) compared with the unsprayed control (2.3 t/ha), but in 2022, it was at par to pendimethalin 750 g/ha (6.4 t/ha). Our study demonstrated that penoxsulam + pendimethalin 625 g/ha PE provided effective weed control by reducing weed biomass upto 30 DAS and enhanced productivity of DSR. However, need based post-emergence herbicide application needs to be done for better weed management in direct-seeded rice.

Keywords: Direct-seeded rice, Pendimethalin, Penoxsulam, Penoxsulam + pendimethalin, Weed management

INTRODUCTON

Globally, atleast 50% of the people rely on rice (*Oryza sativa* L.) as the primary food commodity (Dass *et al.* 2017). Over the past decade, India has produced 150 million tonnes of rice annualy from an area of 43 million hectares, with an average productivity of 3.2-3.7 tonnes/hectare (Singh and Ranguwal 2024). India should increase rice production by 3 million tonnes/year to ensure the continuing food security of its growing population (Dass *et al.* 2016). Puddled transplanted rice (PTR) is unsustainable in the long term due to demand of huge amount of labour, water, energy and deteriorates soil health due to repetitive tillage and puddling operations (Ojha and Kwatra 2014). Therefore, direct-seeded rice (DSR) is an emerging approach, to avoid the water-filled nurseries and transplanting by sowing rice seeds directly into the soil (Rao *et al.* 2017, Karthickraja *et al.* 2024). DSR technique saved 35-57% water over PTR (Bhushan *et al.* 2007). Yet, the area under DSR has not been expanded to the extent expected (Mohammad *et al.* 2018) mainly due to severe weed problem causing huge losses in rice productivity. Weeds could decrease DSR yield by 50 to 90% and the loss could be upto 100% (Bhullar *et al.* 2016). However, the intensity and duration of crop-weed competition governs the extent of crop yield loss (Sardana *et al.* 2017). The critical period of crop-weed competition in DSR is about 2-12 weeks which is far longer than PTR (Singh *et al.* 2014). For DSR success, weed management is considered as one of the key components.

In major rice growing Indian states, weeds are controlled by hand weeding and also by the application of herbicides. Under the conditions of growing labour shortage and high cost, hand weeding is labour intensive being much more costlier in DSR (Rao *et al.* 2007). The use of herbicides to control the weeds is easier and also less expensive (Chauhan 2012), therefore, the use of chemical weed control methods has become increasingly common practice in DSR cultivation. An ecological imbalance in weed shift, resistant biotypes and environmental deterioration results from the long-term use of herbicides of the same class in the same field (Hasan *et al.* 2022). It is crucial to identify broad-spectrum herbicides for sustainable weed management in DSR.

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Given the lacunae of the present weed management practices by the rice growers in relying solely on post-emergence herbicides, usage of pre-emergence application of herbicides as the weed management strategy should provide an initial advantage to reduce weed pressure, promote crop competitiveness, and enhance the economic benefits provided by DSR. Pre-emergence (PE) herbicides such as pendimethalin and penoxsulam have been well researched to control weeds (He *et al.* 2013) and were found to provide an efficient weed control with increased DSR yield. In this context, a herbicide which could provide broad spectrum control of weeds is desirable. The present field study was aimed to assess the efficacy of ready mix of penoxsulam 1% + pendimethalin 24% for weed management in DSR.

MATERIAL AND METHODS

A field experiment was conducted during *Kharif* 2021 and 2022 at Department of Agronomy, Punjab Agricultural University, Ludhiana to study the efficacy of ready-mix of penoxsulam 1% + pendimethalin 24% against weeds in direct-seeded rice. The climate in the Ludhiana (30°542 N and 75°482 E, 247 m above mean sea level) district of Punjab, India, is categorized by semi-arid with hot and dry early summer (March-June), hot and humid summer monsoon (July-September), mild winter (October-November) and very cold winter (December-February) seasons. The soil of the experimental site has a sandy loam texture. The evaluated treatments include: pre-emergence application (PE) of penoxsulam 1% + pendimethalin 24% (penoxsulam + pendimethalin) at 500, 562.5 and 625 g/ha, pendimethalin 750 g/ha PE and unsprayed control. The field experiment was conducted using randomized complete block design (RCBD) with four replications. Rice cv. PR 126 was sown on June 23rd, 2021 and June 9th, 2022 with seed rate of 20 kg/ha at 20 cm rows apart. All treatments were sprayed in moist soil using 500 litres of water/ha by using battery operated knapsack sprayer fitted with flood jet nozzle. The recommended package of practices, except weed control treatments, were followed to raise the crop. Bispyribac-sodium 25 g/ha was sprayed as post-emergence application (PoE) at 30 days after seeding (DAS) (after the weed data recording) in all PE herbicide treatments as blanket spray.

Data on weeds were recorded with quadrat (50cm × 50cm) from two locations in each plot. The plants were then placed them separately in brown paper bags to dry in the sun. After proper drying off the excess moisture, these paper bags were placed in an oven at 70±2°C for 72 hours until the weed samples attained a constant weight. The statistical analysis of the parameters measured was done by using CPCS-1 software, version 3.2.3 (Cochran and Cox 1957). The weed density and weed dry weight (weed biomass) data were subjected to square root transformation to normalize their distribution.

RESULTS AND DISCUSSION

Effect on weed density

All the herbicide treatments significantly influenced the density of weeds at 15 and 30 DAS over unsprayed control. Penoxsulam + pendimethalin 625 g/ha PE provided effective control of weeds including *Echinochloa colona, Digitaria sanguinalis* and *Cyperus iria* in 2021 and 2022. Weed density of grasses and sedge at both stages decreased with increase in dose of penoxsulam + pendimethalin during both the years. Density of *E. colona* at 15 DAS and *D. sanguinalis* at 15 and 30 DAS with pendimethalin 750 g/ha, penoxsulam + pendimethalin 562.5 and 625 g/ha were statistically at par with each other but significantly lower than penoxsulam + pendimethalin 500 g/ha and unsprayed control. Moreover, in 2021, penoxsulam + pendimethalin 625 g/ha significantly reduced the density of *E. colona* at 30 DAS than all other herbicide treatments and unsprayed control. In 2022, *E. colona* density with penoxsulam + pendimethalin 625 g/ha was statistically at par to pendimethalin 750 g/ha and significantly lower than all other herbicide treatments. During both years, at 15 DAS, penoxsulam + pendimethalin 625 g/ha resulted in reduced density of *C. iria* as compared to other herbicide treatments, but was statistically at par with lower dose of penoxsulam + pendimethalin 562.5 g/ha. In 2022, density of *C. iria* at 30 DAS with pendimethalin 750 g/ha was also statistically at par to penoxsulam + pendimethalin 625 g/ha but significantly lower than all other herbicide treatments. However, penoxsulam + pendimethalin 625 g/ha provided better control of *C. iria* population till 30 DAS as compared to other herbicide treatments (**Table 1**). Better performance of ready mix herbicide was known in controlling all types of weeds and this was due to synergistic effect of these herbicides. Pendimethalin inhibit microtubulin synthesis which are essential in the formation of cell wall microfibrils that stops cell enlargement and chromosome movement during mitosis in germinating seeds and young weed shoots (Appleby and Valverde 1989) and penoxsulam prevents producing acetolactate synthase, a necessary enzyme for plant growth, consequently results in less weed density. The results are in line with Yadav *et al.* (2008) and Mishra *et al.* (2007) who reported an excellent control of grasses and sedges with penoxsulam in PTR. Mahajan and Chauhan (2008) also reported the reduced density of *E. colona* and *Cyperus iria* with the application of penoxsulam as compared to control. Singh *et al.* (2019) also reported that pendimethalin 2 kg/ha provided control of weeds in DSR.

Effect on weed biomass

Biomass of grasses and sedge decreased with the increase in dose of penoxsulam + pendimethalin during both the years. Penoxsulam + pendimethalin 625 g/ha recorded less grass weeds biomass at 30 DAS than its lower dose of 500 and 562.5 g/ha, pendimethalin 750 g/ha and unsprayed control except in 2021 where biomass with penoxsulam + pendimethalin 562.5 and 625 g/ha were statistically at par to each other. During both years, penoxsulam + pendimethalin 500, 562.5 and 625 g/ha recorded significantly less biomass of sedges at 30 DAS over pendimethalin 750 g/ha and unsprayed control (**Table 2**). PE herbicides applied on the soil surface are absorbed by the soil colloids and provide a thin layer of herbicidal protection. The new emerging shoots of weeds contain meristematic tissues which absorb the chemical, causing them to exhibit some phytotoxic symptoms and decrease their biomass (Onwuchekwa-Henry *et al.* 2023). Khare *et al.* (2014) reported the lowest biomass of grass weeds in penoxsulam 25 g/ha in rice. Singh *et al.* (2019) recorded no biomass for all weed species with 2.0 kg/ha pendimethalin, whereas, *Leptochloa chinensis* and *D. aegyptium* failed to emerge in 1.0 kg/ha pendimethalin and produced no weed biomass at these application rates in DSR. Onwuchekwa-Henry *et al.* (2023) also reported that shoot dry weight of *E. crusgalli* was effectively controlled by pendimethalin 2 kg/ha.

Effect on rice growth and yield

During both years, all the herbicide treatments produced similar plant height but significantly higher than unsprayed control. Penoxsulam + pendimethalin 625 g/ha recorded significantly more number of effective tiller/m^2 as compared to lower doses of penoxsulam + pendimethalin 562.5 and 500 g/ha, except in 2022, where it was also statistically at par with pendimethalin 750 g/ha (Table 3). Weed free conditions at initial stages for proper growth and development of rice plants allowed the crop to absorb available nutrients, water and sunlight for its growth and tillering behavior and ultimately enhanced the

Table 1. Effect of different weed management treatments on weed density at 15 and 30 DAS in direct-seeded rice during 2021 and 2022

Treatment	Dose (g/ha)	Weed density* (no./m^2)											
		Grasses								Sedge			
		Echinochloa colona				*Digitaria sanguinalis*				*Cyperus iria*			
		15 DAS		30 DAS		15 DAS		30 DAS		15 DAS		30 DAS	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Penoxsulam + pendimethalin	500	2.5(5)	3.9(15)	3.5(12)	4.0(15)	2.7(6)	4.4(19)	3.3(11)	4.1(16)	2.7(7)	3.2(9)	4.6(21)	4.3(18)
Penoxsulam + pendimethalin	562.5	1.2(0.7)	1.3(0.7)	3.0(8)	3.5(11)	1.0(0)	1.1(0.3)	2.4(5)	3.0(8)	1.0(0)	1.4(1)	3.8(14)	4.5(19)
Penoxsulam + pendimethalin	625	1.0(0)	1.0(0)	2.2(4)	2.6(6)	1.0(0)	1.0(0)	2.4(5)	2.4(5)	1.0(0)	1.2(0.7)	2.9(7)	3.7(13)
Pendimethalin	750	1.0(0)	1.5(1)	3.5(12)	2.9(8)	1.0(0)	1.0(0)	2.4(5)	3.1(9)	4.1(16)	4.0(15)	4.5(20)	4.0(15)
Unsprayed Control	-	4.8(22)	4.8(22)	7.3(53)	4.8(23)	6.3(39)	4.7(21)	4.5(19)	4.6(20)	5.4(28)	6.4(41)	6.7(44)	7.0(48)
LSD (p=0.05)	-	0.29	0.68	0.61	0.77	0.45	0.54	0.48	0.77	0.96	0.71	0.89	0.59

*Figures in parentheses are original means. Data were subjected to square root transformation; DAS = days after seeding

Table 2. Effect of weed management treatments on weed biomass at 30 DAS (before POST application) in direct-seeded rice during 2021 and 2022

Treatment	Dose (g/ha)	Weed biomass* (g/m^2)			
		Grasses		Sedge	
		2021	2022	2021	2022
Penoxsulam + pendimethalin	500	3.92 (14)	4.51 (19)	3.46 (11)	4.35 (18)
Penoxsulam + pendimethalin	562.5	2.64 (6)	3.11 (9)	3.31 (10)	4.36 (18)
Penoxsulam + pendimethalin	625	2.29 (4)	2.31 (4)	3.04 (8)	4.00 (15)
Pendimethalin	750	3.74 (13)	3.41 (11)	5.66 (31)	5.23 (26)
Unsprayed control	-	12.13 (146)	11.76 (137)	10.83 (116)	11.30 (127)
LSD (p=0.05)	-	0.49	0.29	0.44	0.88

*Figures in parentheses are original means. Data were subjected to square root transformation; DAS = days after seeding

Table 3. Effect of weed management treatments on growth and grain yield of direct-seeded rice during 2021 and 2022

Treatment	Dose (g/ha)	Plant height (cm)		Effective tillers/m²		Grain yield (t/ha)		Mean grain yield (t/ha)
		2021	2022	2021	2022	2021	2022	
Penoxsulam + pendimethalin	500	99.80	98.37	322	325	5.3	5.6	5.4
Penoxsulam + pendimethalin	562.5	99.13	101.07	338	330	6.4	6.1	6.3
Penoxsulam + pendimethalin	625	98.43	98.43	344	338	6.7	6.5	6.6
Pendimethalin	750	99.87	98.97	334	335	6.3	6.4	6.4
Unsprayed control	-	93.47	92.37	200	180	2.6	2.0	2.3
LSD (p=0.05)	-	3.56	2.73	5	7	0.3	0.4	-

effective tillers/m² (Saha and Rao 2010). During both years and in pooled mean, penoxsulam + pendimethalin 625 g/ha recorded significantly higher rice grain yield than its lower doses 500 and 562.5 g/ha. Moreover, in 2022, rice grain yield (6.5 t/ha) recorded with penoxsulam + pendimethalin 625 g/ha was also statistically at par with pendimethalin 750 g/ha (6.4 t/ha) (**Table 3**). Pooled mean grain yield of penoxsulam + pendimethalin 625 g/ha was 187.0% higher over unsprayed control due to more numbers of effective tillers/m² which was consequently responsible for higher grain yield in rice. Reduced competition for space, light, moisture and nutrients between crop and weed flora along with effective suppression of weeds by these pre-emergence herbicides has helped in obtaining higher productivity (Singh *et al*. 2019). Efficiency of penoxsulam in controlling weeds and increasing grain yield of rice was also reported by Mishra *et al.* (2007) and Jason *et al.* (2007). Khare *et al.* (2014) also reported the highest grain yield of rice under penoxsulam at 25 g/ha. Onwuchekwa-Henry *et al.* (2023) also reported that tillers/m² and grain yield of rice were significantly increased by pendimethalin 1.5 kg/ha over control.

A negative linear correlation between weed biomass with rice grain yield showed that as weed biomass increased, grain yield of DSR decreased linearly (**Figure 1**). This correlation showed that presence of weeds at crop establishment stage adversely affected rice growth by competing for resources like nutrients, sunlight and water. Grain yield of DSR showed strong negative correlation with weed biomass at 30 DAS (R^2 = - 0.95), indicating that weed biomass accounted for 95% of the variation in DSR grain yield. The findings are supported by the research conducted by Roy *et al.* (2024).

Based on two year field study, it may be concluded that penoxsulam 1% + pendimethalin 24% at 625 g/ha PE provided effective control of annual weeds. However, post-emergence herbicide application as per the weed flora needs to be done for better weed control in DSR which proved to be a key in promoting sustainable agriculture and safeguarding food security.

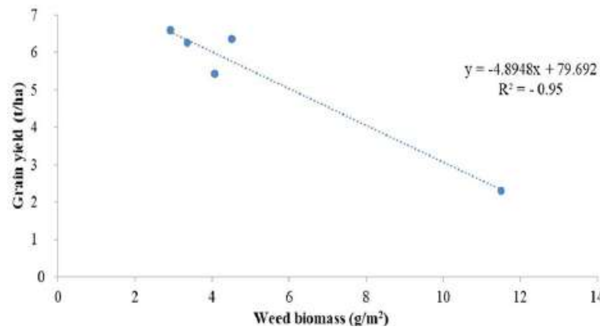

Figure 1. Relationship of grain yield with weed biomass at 30 DAS

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RESEARCH ARTICLE

Evaluation of weed competitiveness of rice varieties under two rice establishment methods

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ABSTRACT

An experiment was conducted during two consecutive *boro* seasons of 2015–16 and 2016–17 at the research farm of Regional Rainfed Lowland Rice Research Station, ICAR-National Rice Research Institute, Gerua, Hajo, Assam, India, to study the weed competitiveness of rice cultivars under two establishment methods. The split plot design with three replications was used with two rice establishment methods *i.e.*, wet-seeded rice (WSR) and transplanted (TPR) in main plots and 10 hybrids and high yielding varieties (HYVs) of rice in subplots. The weed density of grasses, sedges and broad-leaved weeds (BLWs) at all growth stages were significantly higher with WSR as compared to TPR. The maximum weed density was recorded at 30 days after seeding (DAS) in WSR and at 15 DAS in TPR and later there was a decline in weed density due to the shift in crop-weed competition balance in favour of rice. The maximum weed biomass was observed at 60 DAS. The rice established by transplanting recorded higher growth, yield attributes, grain and straw yield. Among, the rice cultivars, Naveen recorded the lowest weed density and biomass at 30 DAS while Tulasi and Mandya Vijaya recorded the lowest weed density and biomass at 45 and 60 DAS which indicated their competitiveness against weeds. Due to better competitiveness, Naveen produced more vigorous plants and yield attributes which resulted in significantly higher grain and straw yield followed by Tulasi and KRH 2. Thus, for higher rice productivity in the shallow lowlands of Assam, transplanting of rice may be suggested using rice cultivars Naveen, Tulasi and KRH2 that were more competitive in suppressing weeds.

Keywords: Cultivar competitiveness, Direct-seeded rice, Establishment methods, Transplanted rice, Weed management

INTRODUCTION

Weed management is the major challenge to the success of boro rice which is also known as summer rice in Southern Asia. Weeds are the most severe and widespread biological constraints to rice production in the World. Weeds cause heavy yield losses in rice, to the extent of complete crop failure under severe infestation conditions. Irrespective of the method of rice establishment, weeds are a major impediment to rice production due to their ability to compete for resources. In general, weeds problem in transplanted rice is lower than that of direct-seeded rice because of puddling and stagnation of water in transplanted rice during early growth stage of crop (Rao *et al.* 2015). But in some cases where continuous standing water cannot be maintained particularly for the first 45 days, weed infestation in transplanted rice also may be as high as direct-seeded rice. Uncontrolled weeds in transplanted rice causes 45-51% loss to productivity (Singh *et al.* 2017), whereas under direct-seeded rice weeds cause yield loss up to 80% (Jabran *et al.* 2012; Rao *et al.* 2017).

Competition for nutrients constitutes an important aspect of weed-crop competition. Nitrogen has been the most important element in crop-weed competition as it is extensively used in crop production. Weeds generally absorb mineral nutrients faster than the crop plants and accumulate them in huge amount in their tissues. To increase the efficiency of the applied inputs, weed management is one of the important operations in both transplanted rice and direct-seeded rice. Highly nutrient efficient rice hybrids and high yielding varieties (HYVs) having fast growth rate and ability to suppress the weeds are very useful to maintain weed population below economic threshold level (Mahajan and Chauhan 2013; Ramesh *et al.* 2017). Close spacing of rice cultivars also attribute to suppress weed density and weed biomass (Aggarwal and Singh 2015; Ramesh *et al*. 2017). Transplanting of younger seedlings produced more vigorous plant canopy which resulted in higher yield attributes and grain yield under rainfed shallow lowland (Singh *et al.* 2018). The use of weed-competitive rice cultivars in rice belts is a

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highly effective strategy to reduce cost of production and provide alternative solutions to the unavailability of herbicides (Dimaano *et al.* 2017). Thus, the present study was carried out to evaluate hybrids and HYVs of rice for their competitiveness against weeds under two rice establishment techniques.

MATERIALS AND METHODS

Field experiment was carried out during *boro* season of 2015–16 and 2016–17 at the research farm of Regional Rainfed Lowland Rice Research Station, ICAR-National Rice Research Institute, Gerua, Hajo, Assam which is located at 28^0 14^1 59^{11} N latitude, 91^0 33^1 44^{11} E longitudes and at an altitude of 49 m above mean sea level and characterized in the long-term by sub-tropical monsoon type climate with annual average rainfall 1500 mm. The soil was clay loam texture, having pH of 6.1, high in organic carbon (1.12%), medium in available nitrogen (286 kg/ha), high in available P (36.15 kg/ha) and medium in available potash (305 kg/ha). The experiment was carried out using split plot design with two crop establishment techniques i.e., wet-seeded rice (WSR) and transplanted rice (TPR) in main plots and 10 hybrids and HYVs of rice in subplots. These were replicated thrice. Rice seedlings of 45 days were transplanted and dry seeds were sown carefully on 15th February according to the treatments in the well-puddled experimental plots. The spacing of 20 cm × 15 cm was maintained. A fertilizer dose of 80-40-40 kg/ha of N-P-K was applied as urea, di-ammonium phosphate (DAP) and muriate of potash (MOP) in the field. One-third urea and full dose of DAP and three fourth of MOP were applied as basal dose at the time of final land preparation and incorporated well into the soil. Remaining two-third of urea was applied in two equal splits at 40 and 70 days after transplanting (DAT) while one fourth MOP was applied at panicle initiation. All other agronomic practices were kept normal and uniform for all the treatments of the experiment. Data on weeds, *viz*. weed density and weed dry matter accumulation (biomass) were recorded at 15 days interval after planting. Weed sampling was done by placing a quadrat of 1 m^2 randomly in each plot to determine the weed density and biomass. From each quadrat, weeds were separated species wise and the number counted and sorted into three categories *i.e.*, grasses, sedges and broad-leaved weeds. For recording dry matter accumulation, weed samples were sun-dried for 2-days then oven-dried at 70°C until constant weight recorded. Grain and straw yield were recorded at harvest. The data were subjected to analysis of variance (ANOVA) and results were presented at 5% level of significance (P = 0.05).

RESULTS AND DISCUSSION

Weed density and biomass

The weed flora observed across the treatments comprised of 15 species of weeds which were mainly dominated by sedges and grasses. The dominant weed flora includes *Scirpus juncoides* Roxb, *Cyperus difformis* L., *Cyperus iria* L., *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) P. Beauv., *Monochoria vaginalis* (Burm. f.) C. Presl ex Kunth, *Ludwigia octovalvis* (Jacq.) P.H. Raven., *Cyperus rotundus* L., *Leersia hexandra* Sw., *Paspalum distichum* L., *Pistia stratiotes* L., *Eclipta prostrate* (L.) L., *Leptochloa chinensis* (L.) Nees, *Fimbristylis miliacea* (L.) Vahl and *Marsilea minuta* L. Weed density of grasses, sedges and broad-leaved weeds (BLWs) at almost all stages found significantly higher under WSR as compared to TPR (Table 1). Grasses, sedges and BLWs density were not affected much at 15 DAS while the maximum weed density of grasses, sedges and BLWs were recorded with IIRR Dhan 44, PA 6444 and Dhanrasi at 15 DAS, respectively. All the rice cultivars recorded the highest grasses density at 30 DAS and later declining trend was observed until harvest which was mainly due to their competitive growth as compared to grasses. Sedges density was the maximum at 45 DAS for all rice cultivars. However, BLWs density initially high at 15 DAS and thereafter declining trend was recorded which was mainly due to competitive growth and water stagnation at later growth stages. All rice cultivars shown differential category-wise weed density which was mainly due to their weed competitiveness growth behaviour.

Total weed density and biomass were significantly higher with WSR as compared to TPR at all growth stages (**Table 2**). Total weed density in WSR increased at the highest level at 30 DAS and thereafter it gradually started decreasing while TPR recorded the maximum weed density at 15 DAS and thereafter it declined to at minimum level at 60 DAT. It might be due to more competition occurred between rice and weeds which eliminated weaker weed plants in later stages. The maximum weed biomass was recorded at 60 DAS with both the establishment of WSR and TPR which might be due to more mature weeds resulted higher dry weed biomass. Parida *et al.* (2020) found that the weed density and weed biomass were significantly higher under dry-DSR as compared to TPR. Farooq *et al.* (2017) also reported less accumulation of weed dry biomass with TPR establishment method.

The total weed density and biomass were highly influenced by the hybrids and HYVs of rice. Initially at 15 DAS, all cultivars have non-significant effect on total weed density and biomass which might be due to lack of crop-weed competition and slow growth of crop. Naveen recorded the lowest total weed density and biomass while the maximum values for same obtained with PA 6444 at 30 DAS and at harvest. Rice varieties Tulasi and Mandya Vijaya registered the lowest total weed density and biomass at 45 and 60 DAS, respectively. It was noticed that two rice hybrids PA 6444 and KRH 2 recorded higher total weed density and biomass at all vegetative stages which indicated that hybrids were lesser weed competitiveness as compared to HYVs.

Rice growth, yield attributes and productivity

Rice growth and yield attributes were significantly affected by the rice establishment techniques except 1000-grain weight (**Table 3**). Transplanted rice recorded significantly higher plant height, tillers/m^2, panicles/m^2, panicle length and weight, filled grains/panicle and chaffy grains/panicle which subsequently led to significantly higher grain and straw yield and harvest index over the WSR. Due to less weed pressure, TPR recorded significantly higher grain and straw yield than WSR under uncontrolled weeds situation. The higher productivity with TPR is mainly due to very less weed competition and favourable environment that led to higher values for yield attributes of rice. Higher grain yield of rice

Table 1. Effect of rice establishment methods and rice varieties on category-wise weed density (2-year mean data)

Treatment	Grassy weed density (no./m^2)					Sedges weed density (no./m^2)					Broad-leaved weed density (no./m^2)				
	15 DAS/ DAT	30 DAS/ DAT	45 DAS/ DAT	60 DAS/ DAT	Harvest	15 DAS/ DAT	30 DAS/ DAT	45 DAS/ DAT	60 DAS/ DAT	Harvest	15 DAS/ DAT	30 DAS/ DAT	45 DAS/ DAT	60 DAS/ DAT	Harvest
Rice establishment methods															
Wet-seeded rice	185.9	538.5	301.9	301.3	177.1	110.9	320.7	493.1	542.8	164.4	56.7	11.7	19.7	36.5	11.1
Transplanted rice	22.7	7.5	11.6	9.8	9.5	28.5	40.5	26.3	27.2	22.1	19.9	7.8	9.2	6.1	7.9
LSD (p=0.05)	55.5	134.7	39.4	67.06	24.09	25.04	67.29	163.94	139.41	20.95	18.96	NS	7.32	18.13	NS
Rice varieties															
Mandya Vijaya	109.3	301.3	170.7	136.2	53.3	65.3	187.3	294.0	282.7	158.0	42.0	9.8	15.3	20.7	11.3
Dhanrasi	106.7	276.0	155.3	118.3	98.7	74.7	167.3	243.3	234.7	124.7	46.0	14.0	12.0	12.0	8.7
PA6444	108.0	361.3	109.3	107.5	158.7	82.0	210.0	396.7	330.7	98.7	40.7	14.0	15.3	18.7	5.3
KRH2	86.7	264.0	126.7	157.8	123.3	74.0	184.0	322.0	311.3	121.3	38.7	15.3	7.3	19.3	9.3
IR 64	111.3	296.0	236.0	209.3	99.3	71.3	174.7	164.0	317.3	56.7	42.0	8.7	15.3	21.3	16.7
IIRR Dhan 44	133.3	225.3	196.0	225.8	41.3	76.7	180.7	234.7	270.0	139.3	40.7	6.7	12.0	36.0	12.0
Tulasi	94.0	308.7	119.3	197.8	148.7	72.0	158.0	213.3	235.3	26.0	37.3	9.3	20.0	12.7	8.7
CR 2829	100.0	304.7	158.0	177.8	84.0	58.7	220.7	232.0	298.0	95.3	32.7	7.2	6.7	20.7	8.0
Naveen	107.3	174.0	142.0	150.0	94.0	68.0	176.7	264.0	272.0	30.7	32.7	5.5	26.0	36.7	8.7
Sahabhagi Dhan	86.0	218.7	154.0	75.2	31.3	54.7	146.7	232.7	298.0	82.0	30.0	7.17	14.7	15.3	6.0
LSD (p=0.05)	NS	93.1	51.9	36.11	23.96	NS	41.80	47.75	36.47	31.60	NS	5.86	8.77	9.75	NS

DAS = days after seeding; DAT = days after transplanting

Table 2. Effect of rice establishment methods and rice varieties on total weed density and biomass (2-year mean data)

Treatment	Total weed density (no./m^2)					Total weed biomass (g/m^2)				
	15 DAS/ DAT	30 DAS/ DAT	45 DAS/ DAT	60 DAS/ DAT	Harvest	15 DAS/ DAT	30 DAS/ DAT	45 DAS/ DAT	60 DAS/ DAT	Harvest
Rice establishment methods										
Wet-seeded rice	353.5	870.9	811.5	788.6	352.5	7.1	167.4	150.0	190.3	82.1
Transplanted rice	71.1	55.8	47.1	43.2	39.5	2.1	9.2	8.5	9.4	8.9
LSD (p=0.05)	45.7	199.95	197.94	152.71	52.79	3.84	22.79	43.73	34.55	13.19
Rice varieties										
Mandya Vijaya	216.7	498.5	480.0	439.5	222.7	3.8	95.4	88.4	94.3	52.2
Dhanrasi	227.3	457.3	410.7	365.0	232.0	5.1	90.5	76.2	78.8	54.1
PA6444	230.7	585.3	521.3	456.8	262.7	5.1	128.5	95.2	98.4	61.6
KRH2	199.3	463.3	456.0	488.5	254.0	3.2	80.8	83.3	105.7	59.6
IR 64	224.7	479.3	415.3	548.0	172.7	5.0	80.1	76.1	118.1	39.7
IIRR Dhan 44	250.7	412.7	442.7	531.8	192.7	3.8	69.1	81.0	114.7	44.4
Tulasi	203.3	476.0	352.7	445.8	183.3	5.8	100.1	65.0	96.5	42.5
CR 2829	191.3	532.5	396.7	496.5	187.3	8.3	70.9	73.1	108.6	43.2
Naveen	208.0	356.2	432.0	458.7	133.3	2.8	70.2	79.6	99.3	27.1
Sahabhagi Dhan	170.7	372.5	401.3	388.5	119.3	3.0	97.3	74.4	84.1	30.3
LSD (p=0.05)	NS	92.95	62.65	36.77	38.61	NS	27.57	10.80	7.40	8.90

DAS = days after seeding; DAT = days after transplanting

Table 3. Effect of rice establishment methods and rice varieties on growth, yield attributes and yield of rice (2-year mean data)

Treatment	Plant height (cm)	Tillers (m^2)	No. of panicles (m^2)	Panicle length (cm)	Panicle weight (g)	Filled grains/ panicle	Chaffy grains/ panicle	1000-grain weight (g)	Straw yield (t/ha)	Grain yield (t/ha)			Harvest index
										2015 -16	2016 -17	Pooled	
Rice establishment methods													
Wet-seeded rice	88.1	92.4	88.3	21.3	2.09	81.8	14.7	22.4	1.95	1.19	1.22	1.21	0.32
Transplanted rice	95.3	212.9	209.1	24.3	2.26	110.9	19.8	22.6	4.93	3.74	3.90	3.82	0.41
LSD (p=0.05)	3.12	18.19	6.11	2.63	0.04	14.06	4.89	NS	0.59	0.66	0.91	0.64	0.06
Rice varieties													
Mandya Vijaya	96.3	158.5	169.7	24.5	2.16	102.6	18.3	18.6	3.40	2.18	2.22	2.20	0.33
Dhanrasi	104.3	147.3	141.5	23.5	2.23	101.0	18.4	21.7	4.37	2.72	2.31	2.52	0.27
PA6444	92.5	105.5	101.8	24.3	2.18	100.9	20.1	20.8	3.27	2.36	2.38	2.37	0.21
KRH2	89.9	163.8	154.7	24.2	2.28	120.5	24.2	23.2	3.25	2.63	2.90	2.76	0.43
IR 64	77.9	163.3	157.3	21.1	2.04	67.1	11.6	25.9	3.11	1.88	1.96	1.92	0.33
IIRR Dhan 44	89.0	127.3	122.7	22.1	1.86	123.1	14.1	24.0	2.88	2.34	2.49	2.41	0.44
Tulasi	76.3	168.7	163.5	18.8	1.70	64.4	9.8	22.5	3.34	2.59	3.05	2.84	0.44
CR 2829	100.8	182.5	177.0	23.2	2.49	81.6	18.3	23.3	3.40	2.50	2.29	2.40	0.35
Naveen	97.0	181.3	174.8	23.3	2.45	107.7	16.6	20.9	4.50	3.23	3.30	3.26	0.39
Sahabhagi Dhan	93.2	128.2	123.8	23.3	2.36	94.7	20.9	24.1	2.91	2.22	2.71	2.46	0.45
LSD (p=0.05)	5.82	23.21	19.26	2.02	0.11	18.72	5.13	1.32	NS	0.46	0.34	0.57	0.08

with machine and manual transplanting over direct-seeded rice was also reported (Ramulu *et al.* 2020).

Growth and yield parameters of any variety mainly depends on its genetic make-up and environmental situations. All the tested rice varieties showed the varied growth and yield attributes values (**Table 3**). Rice variety Dhanrasi recorded significantly taller plants (104.3 cm) followed by CR 2829, Naveen and Mandya Vijaya. However, rice varieties Tulasi and IR 64 recorded the lowest plant height among the tested rice varieties. Rice varieties CR 2829 and Naveen recorded significantly higher number of tillers/m^2 (182.5 and 181.3) and number of panicles/m^2 (177 and 174.8), respectively. The lowest values for tillers/m^2 (105.5) and panicles/m^2 (101.8) were recorded with rice hybrid PA 6444. The maximum panicle length was observed with rice variety Mandya Vijaya and was statistically at par with Dhanrasi, PA 6444, KRH 2, CR 2829, Naveen and Sahabhagi Dhan. However, the heavier panicles were recorded with CR 2829 and Naveen while Tulasi recorded the shortest and the lightest panicles among all the rice varieties. The maximum chaffy grains per panicle were recorded in rice hybrid KRH 2 which also remained at par with another hybrid PA 6444 and Sahabhagi Dhan. However, the minimum chaffy grains per panicle were observed in Mandya Vijaya. IR 64 recorded the highest 1000-grains weight followed by Sahabhagi Dhan and IIRR Dhan 44. The comparatively higher values of plant height and yield attributes like tillers/m^2, panicles/m^2, panicle length and weight with Naveen resulted the maximum grain and straw yield and remained significantly superior over all varieties except Tulasi and KRH 2. Thus, Naveen, Tulasi and KRH 2 rice cultivars had better weed competitiveness due to their vigorous growth and yield attributes under shallow lowland conditions. The least grain and straw yield were obtained from rice variety IR 64 followed by CR 2829 and rice hybrid PA 6444 due to their least competitiveness against weeds. The weed competitive rice cultivar should have weed suppressing traits like uniform crop establishment, high and early seedling vigour with rapid leaf area development during the early vegetative stage for weed suppression, allelopathic effect, and herbicide-resistance (Gibson and Fischer 2004; Zhao 2006, Mahajan and Chauhan 2013; Dass *et al.* 2013; Dimaano *et al.* 2017).

Conclusion

It can be concluded that transplanting of rice using rice cultivars Naveen, Tulasi and KRH 2, that have more vigorous growth, helps in suppressing weeds and obtaining higher rice productivity in the shallow lowlands.

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RESEARCH ARTICLE

Competition for nutrients between weeds and black rice as influenced by date of rice transplanting and weed management treatments in system of rice intensification (SRI)

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ABSTRACT

Heavy weed infestation is a major problem in System of Rice Intensification cultivation method of rice (SRI) due to wider spacing and lack of flooding in the field. Yield losses due to weed infestation amounts to 25-47%. Thus, a field experiment was conducted to study the competition for nutrients between weeds and black rice (*Oryza sativa* L.) as influenced by the date of transplanting and integrated weed management in SRI. The experiment was conducted in the experimental farm of SAS, Nagaland University during *Kharif* season 2019 and 2020. A split plot design was used with three dates of rice transplanting in main plots and five methods of weed management in sub plots. The transplanted black rice with pre-emergence application (PE) of pretilachlor 0.75 kg/ha at 3 days after transplanting (DAT) followed by (*fb*) handweeding at 40 DAT recorded maximum decrease in weeds biomass and nutrient depletion by weeds with significant increase in the weed control efficiency, nutrient uptake and yield of black rice.

Keywords: Black rice, Nutrient uptake, SRI, Pretilachlor, Transplanted rice, Weed management

INTRODUCTION

Black rice (*Oryza sativa* L. *indica*), a special variety of rice contains high amount of anthocyanin pigments in compared to red and white rice that is responsible for its violet or dark purple color in the aleurone layer (Hou *et al.* 2013). Black rice which is called as 'Chakhao', in Manipuri dialect meaning delicious rice is cultivated mostly by Meitei farmers of Manipur. Black rice has been consumed for centuries in Asian countries. Glycemic Index (GI) value of black rice is low which is good for a diabetic patient. Black rice is significantly rich in vitamins, anthocyanin levels, carbs, lipids, proteins, dietary fibers and minerals (Biswas 2018, Panda *et al*. 2022). There are many distinct kinds of black rice and the history of black rice is extensive. Most Asian nations, including India, China, Thailand and others, grow black rice. There are over 200 different types of black rice on the planet. China is the world's leading producer of black rice, accounting for 62% of global output (Panda *et al*. 2022). Now, black rice is consumed and grown in many countries. However, China alone constitute 62% of the total global production standing 1st in which is followed by India, Indonesia, Sri Lanka, Thailand (Amagliani *et al*. 2016). In India, it was cultivated in Odisha, but nowadays mainly developed in North-eastern states of India like Manipur and Assam. Currently, Manipur is the leading producer of black rice in India. Out of the various agronomic practices, timely transplanting is the most important factor as it indirectly decides the soil temperature, weather conditions and several biotic and abiotic stresses a young seedling of rice has to face during different phenological stages. Timely transplanting ensures higher yield attributing parameters and grain yield (Khalifa 2009). Optimizing the transplanting time is crucial for rice crop because of the differences in the growth duration, photo- and thermo-sensitiveness, and vegetative lag period of different varieties (Dixit *et al.* 2004). Heavy weed growth is a major problem in system of rice intensification due to wider spacing and non-flooded condition in the field. Weeds grow faster than the rice and thus absorb the available nutrients earlier, resulting in lack of nutrient for growth of the crop plants (Rao 2022). Prevention of weed competition and provision of weed free environment at critical period of rice growth is necessary for successful rice

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production (Murali and Gowthami 2017, Rao *et al.* 2017). Hence, a field experiment was carried out to study the effect of transplanting date and weed management methods on competition for nutrients between weeds and black rice.

MATERIALS AND METHODS

The field experiment was carried out during 2019 and 2020 at the experimental research farm of the SAS, Nagaland University, Medziphema, Nagaland, India. The farm is geographically situated at $20^0$45'43'' N latitude and $93^0$53'04'' E longitude at an altitude of 310 m above mean sea level. The climate of the region is sub-tropical having hot and humid summers and cold winters. The initial fertility status of soil was ascertained by collecting soil samples randomly from each experimental plot taken at a depth of 0-15 cm. The soil is clayey loam in texture, acidic in reaction (4.85pH), high in OC (1.21%), low in available N (253.12 kg/ha), low in available P (18.43 kg/ha) and medium in available K (142.62 kg/ha). A split plot design with three replications was used to carry out this experiment. The treatments of the main plots consist of dates of transplanting rice: D_1- on15th June, D_2- 30th June and D_3- 15th July and the sub-plots treatments comprised of W_1- weedy check, W_2- weeding with conoweeder (conoweeding) at 20 and 40 days after transplanting (DAT), W_3- pre-emergence application (PE) of pretilachlor at 0.75 kg/ha followed by (*fb*) hand weeding at 40 DAT, W_4- pretilachlor at 0.75 kg/ha PE *fb* conoweeder at 40 DAT and W_5-pretilachlor 0.75 kg/ha PE *fb* post-emergence application (PoE) of bispyribac-Na 25 g/ha. The experimental plot size was 4 m ×3 m. Cultivar used was Chakhao Poireiton.

Well decomposed FYM 7 t/ha was uniformly broadcasted over the field and incorporated thoroughly during the final land preparation. Transplanting of 12 days old rice seedlings was done as per the treatment on 15th June, 30th June and 15th July using one seedling/hill with 25 cm × 25 cm spacing. The recommended dose of fertilizer at 50 kg/ha N, 30 kg/ha P and 20 kg/ha K in the form of urea, single super phosphate (SSP) and muriate of potash (MOP) were applied in all the plots irrespective of the treatment for both the years. Based on the treatment, pre-emergence (PE) herbicide pretilachlor at 0.75 kg/ha and post-emergence (PoE) herbicide bispyribac-Na at 20 g/ha were applied at 3 DAT and 20 DAT, respectively, in respective plots.

The weed samples collected in each quadrat were washed, sundried and oven dried at 105^0 C for 48 hrs. The weight of the weed samples was recorded at 60 DAT after it attained a constant weight and weed dry weight (biomass) was noted. Weed control efficiency was calculated based on the data recorded at 60 DAT as per standard formula. Weed samples were drawn from each plot at 60 DAT of crop and randomly selected plant samples were collected treatment wise for determination of N, P and K content in weed and crop. Collected weeds, straw and grains were dried and grinded thoroughly and analyzed as per standard procedure of modified Kjeldahl method for N, Vanadomolybdo-phosphoric yellow colour method (Jackson 1973) for P and flame photometric method for K as suggested by Jackson (1973). The nutrient depletion and uptake were further calculated by using the formula and expressed in kg/ha,

$$\text{Weeds nutrient depletion (kg/ha)} = \frac{\text{Nutrient (\%) in weeds} \times \text{weed biomass (kg/ha)}}{100}$$

$$\text{Rice nutrient uptake (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{biological yield (kg/ha)}}{100}$$

Data obtained from various studies were statistically analyzed in split plot design using the technique of Analysis of Variance as described by Gomez and Gomez (1984). The significance differences were tested by 'F' test. Critical difference of different groups of treatments and their interactions at 5 per cent probability level were calculated whenever 'F' test was significance.

RESULTS AND DISCUSSION

Biomass of grasses, sedges and broad-leaved weeds

Significant difference in biomass of grasses, sedges and broad-leaved weeds were observed amongst the date of transplanting treatments at 60 DAT (**Table 1**). Early transplanting of black rice on 15th June recorded significantly lowest weed biomass while the highest was observed with 15th July transplanting date, during the both the years. Higher weed biomass with late transplanting could be due to higher density of weeds and its dominance in utilizing the limited resources as also observed by Bera *et al.* (2016) and Ghandor *et al.* (2017).

Among weed management treatments, pretilachlor 0.75 kg/ha PE at 3 DAT *fb* handweeding at 40 DAT recorded significantly lowest biomass of all the categories of weeds during both the years which may be attributed to the broad spectrum and season long weed control provided by application of herbicides and hand weeding. Similar results were also observed by Kashid (2019) and Akter *et al.* (2020). Weedy check recorded significantly highest weed biomass in both the years due to favourable conditions available for establishment of all the categories of weeds as also reported by Gangireddy *et al.* (2019) and Yogananda *et al.* (2019).

The interaction effect between transplanting date and integrated weed management were found to be significant in both the years of study except for biomass of grasses (**Table 2**). Transplanting of black rice on 15th June with combined application of pretilachlor 0.75 kg/ha PE at 3 DAT *fb* hand weeding at 40 DAT recorded significantly minimum weed biomass while significantly maximum was observed with the combination of 15th July transplanting date and weedy check.

Weed control efficiency

The differences in weed control efficiency due to date of transplanting and weed management treatments were found to be significant (**Table 1**). The highest weed control efficiency was recorded when rice was transplanted on 15th June and it was at par with the other two date of transplanting in the year 2019 while significantly lowest weed control efficiency was observed under 15th July transplanting date in the year 2020. Cono weeding at 20 and 40 DAT recorded lower weed control efficiency among weed management treatments and significantly highest weed control efficiency was recorded with pretilachlor 0.75 kg/ha PE at 3 DAT *fb* hand weeding at 40 DAT due to lower weed density and biomass production of weeds because of effective control of weed growth with this treatment. The results are in corroboration with those of Jadhav *et al.* (2016) and Ansari *et al.* (2017).

Nutrient depletion by weeds

Variation in NPK depletion by weeds due to date of transplanting and weed management treatments were found to be significant in both the years (**Table 1**). Maximum and minimum NPK depletion by weeds was recorded when the crop was transplanted on 15th July and 15th June respectively. Kumar *et al.* (2017) also reported minimum depletion with early transplanting due to the reduced weed density and biomass. Maximum depletion of NPK was observed in weedy check was due to higher weed density and biomass as reported by Kumar *et al.* (2020). Pretilachlor 0.75 kg/ha PE at 3 DAT *fb* hand weeding at 40 DAT recorded minimum nutrient depletion by weeds and was followed by pretilachlor 0.75 kg/ha PE at 3 DAT *fb* bispyribac-Na 25 g/ha PoE at 20 DAT which were found to be at par with the rest of the treatments. A similar decrease in depletion of NPK

Table 1. Biomass of grasses, sedges, broad-leaved weeds, weed control efficiency and NPK depletion by weeds at 60 DAT as influenced by date of rice transplanting and weed management treatments

Treatment	Grasses (g/m^2)		Sedges (g/m^2)		Broad-leaved weeds (g/m^2)		Weed control efficiency (%)		Nitrogen (kg/ha)		Phosphorus (kg/ha)		Potassium (kg/ha)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Date of rice transplanting														
15th June	2.25 (5.86)	2.45 (6.81)	6.12 (50.8)	6.02 (50.0)	5.48 (42.0)	5.34 (41.5)	71.81	72.4	13.18	13.19	2.99	3.03	11.87	11.89
30th June	3.04 (10.6)	3.26 (11.8)	6.76 (59.4)	6.71 (59.4)	6.41 (54.2)	6.25 (52.9)	70.19	70.6	16.76	16.81	3.82	3.86	15.04	15.09
15th July	3.43 (13.7)	3.60 (14.9)	7.75 (73.1)	7.68 (72.5)	7.43 (72.3)	7.34 (72.3)	68.68	69.1	21.65	21.91	4.98	5.06	19.32	19.48
LSD (p=0.05)	0.28	0.40	0.40	0.40	0.59	0.46	1.83	1.39	3.13	2.50	0.55	0.43	1.05	1.39
Weed management treatment														
Weedy check	5.39 (29.5)	5.60 (31.6)	14.21 (201.8)	14.26 (203.3)	13.87 (193.8)	13.99 (197.4)	0.00	0.00	58.14	59.51	13.50	13.89	51.93	53.03
Cono weeding at 20 and 40 DAT	2.73 (7.3)	2.98 (8.53)	5.61 (32.2)	5.65 (32.3)	5.51 (30.5)	5.38 (28.9)	83.9	84.1	9.34	9.29	2.10	2.12	8.41	8.42
Pretilachlor 0.75 kg/ha at 3 DAT *fb* HW at 40 DAT	1.55 (2.1)	1.83 (3.04)	4.15 (17.2)	3.88 (15.0)	3.39 (11.7)	3.10 (9.9)	92.9	93.7	3.98	3.56	0.84	0.77	3.62	3.27
Pretilachlor 0.75 kg/ha at 3 DAT *fb* cono weeder at 40 DAT	2.59 (6.5)	2.76 (7.40)	5.50 (30.3)	5.41 (29.9)	5.14 (26.5)	5.00 (25.1)	85.4	85.9	8.35	8.26	1.86	1.84	7.51	7.39
Pretilachlor 0.75 kg/ha at 3 DAT *fb* bispyribac-Na 25 g/ha at 20 DAT	2.26 (4.91)	2.35 (5.41)	4.92 (24.0)	4.79 (22.9)	4.29 (18.4)	4.08 (16.7)	89.0	89.8	6.16	5.92	1.34	1.30	5.59	5.33
LSD (P=0.05)	0.44	0.35	0.35	0.37	0.43	0.43	1.62	1.41	3.42	2.88	0.66	0.65	1.37	1.20

Original values were subjected to square root transformation. Figures in parenthesis are the original values; DAT = days after transplanting with application of herbicides at initial stage followed by mechanical/hand weeding/post emergence application of herbicides at later stage were also reported by Hassan and Upasani (2015) and Nazir *et al.* (2022).

Interaction of date of transplanting and integrated weed management on NPK depletion by weeds (**Table 2**) were found to be significant during both the years. Transplanting of black rice on 15th June along with application of pretilachlor 0.75 kg/ha PE at 3 DAT *fb* handweeding at 40 DAT recorded lower depletion of potassium by weeds while transplanting on 15th July in combination with weedy check recorded significantly highest potassium depletion by weeds.

NPK uptake by black rice: NPK uptake was significantly influenced by different dates of transplanting and weed management treatments (Table 3). Transplanting rice on 15th June recorded significantly highest uptake of NPK by rice and it was followed by 30th June while transplanting on 15th July recorded significantly lowest uptake of NPK by rice. Higher NPK uptake by rice in 15th transplanting date might be attributed to relatively early crop establishment, stronger root growth and longer growth period which in turn results in increased absorption of nutrients and moisture from the soil. The results are in agreement with the findings of Kabat and Satapathy (2011) and Kumari and Prasad (2021).

Among tested weed management treatments, significantly highest uptake of NPK by rice was recorded with pretilachlor 0.75 kg/ha at 3 DAT *fb* handweeding at 40 DAT, followed by pretilachlor 0.75 kg/ha at 3 DAT *fb* bispyribac-Na 25 g/ha at 20 DAT. The concentration of a certain nutrient in plant tissue and yield determine the nutrient uptake (Pandey 2009). The higher NPK uptake by black rice could be attributed to higher content in grain and straw and higher yield with the above treatments. Similar findings were reported by Goswami *et al.* (2017) and Sanodiya and Singh (2021). Pretilachlor 0.75 kg/ha PE *fb* conoweeder at 40 DAT and conoweeding at 20 and 40 DAT were at par with each other in both the years in case of potassium uptake. Weedy check recorded significantly minimum NPK uptake by black rice.

Grain and straw yield of black rice: Grain and straw yield of black rice were significantly influenced by different transplanting date and weed management treatments (**Table 3**). Transplanting black rice on 15th June significantly increased the rice grain and straw yield during both the years of 2019 and 2020. Significantly lowest rice grain and straw yield were recorded when black rice was transplanted on 15th July. Increase in grain yield by 39% and 24% and straw yield by 14.6% and 6.5% over 15th July and 30th June, respectively was recorded when black rice was transplanted on 15th June. This might be attributed to availability of optimal time for growth and development which allowed the crop to store greater amount of photosynthates in the grain as well as due to improved yield attributes exhibited by early transplanted crop compared to later planted crop (Singh *et al.* 2021 and Yumnam *et al.*2021).

Table 2. Interaction effect of date of transplanting and weed management treatments on biomass of sedges, broad-leaved weeds and NPK depletion by weeds at 60 DAT

Treatment	Sedges(g/m^2)		Broad-leaved weeds (g/ m^2)		Nitrogen (kg/ha)		Phosphorus (kg/ha)		Potassium (kg/ha)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
D_1W_1	13.4(181.0)	13.48(181.3)	12.32(151.3)	12.46(154.7)	47.18	48.25	10.89	11.27	42.39	43.35
D_1W_2	4.51(20.0)	4.70(21.7)	4.76(22.5)	4.66(21.4)	6.18	6.43	1.34	1.43	5.56	5.86
D_1W_3	3.39(11.1)	3.18(9.7)	2.49(5.9)	2.18(4.4)	2.22	1.98	0.47	0.42	2.07	1.81
D_1W_4	4.81(22.7)	4.59(20.7)	4.37(18.8)	4.21(17.4)	5.93	5.57	1.30	1.19	5.36	5.02
D_1W_5	4.44(19.2)	4.13(16.7)	3.47(11.7)	3.21(9.9)	4.36	3.75	0.95	0.83	3.97	3.43
D_2W_1	14.24(202.3)	14.35(205.8)	13.61(184.7)	13.65(185.7)	56.85	57.92	13.20	13.53	50.86	51.82
D_2W_2	5.26(27.3)	5.39(28.7)	5.52(30.3)	5.36(28.4)	8.82	8.86	1.96	1.99	7.98	8.01
D_2W_3	4.24(17.7)	4.01(15.7)	3.44(11.5)	3.12(9.5)	4.04	3.74	0.85	0.80	3.68	3.40
D_2W_4	5.18(26.4)	5.11(25.7)	5.05(25.2)	4.87(23.3)	7.85	7.67	1.72	1.69	7.03	6.87
D_2W_5	4.86(23.2)	4.67(21.4)	4.44(19.3)	4.22(17.6)	6.22	5.87	1.35	1.28	5.65	5.36
D_3W_1	14.93(222.3)	14.96(223.3)	15.68(245.3)	15.88(251.7)	70.38	72.38	16.41	16.86	62.53	63.91
D_3W_2	7.06(49.3)	6.86(46.7)	6.24(38.7)	6.11(36.9)	13.03	12.57	3.01	2.95	11.67	11.41
D_3W_3	4.81(22.8)	4.46(19.5)	4.24(17.7)	3.99(15.7)	5.68	4.96	1.21	1.09	5.13	4.60
D_3W_4	6.49(41.7)	6.54(42.4)	6.00(35.6)	5.92(34.7)	11.26	11.53	2.55	2.63	10.14	10.29
D_3W_5	5.47(29.5)	5.56(30.5)	4.98(24.3)	4.81(22.7	7.89	8.14	1.73	1.80	7.14	7.19
LSD (p=0.05) (D×W)	0.61	0.63	0.75	0.75	5.93	4.99	1.15	1.12	2.37	2.08
LSD (p=0.05) (W×D)	0.57	0.56	0.81	0.66	4.63	3.76	0.84	0.72	1.64	1.96

Original values were subjected to square root transformation. Figures in parentheses are the original values

Among the weed management treatments tested, rice grain and straw yield were significantly lowest under weedy check while significantly highest rice grain and straw yield were obtained with pretilachlor 0.75 kg/ha PE *fb* hand weeding at 40 DAT during both the years and it was followed by pretilachlor at 0.75 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE. Weed infestation reduced 44% grain yield in weedy check due to crop-weed competition compared to pretilachlor at 0.75 kg/ha PE *fb* handweeding at 40 DAT. Higher rice grain and straw yield with application of herbicides along with handweeding might be due to prevention of weed competition and providing a weed free environment at critical period resulting in more crop growth and yield attributes and ultimately yield. Similar observations were made by Kashyap *et al.* (2020) and Paul *et al.* (2019).

Rice grain yield was influenced significantly by the interaction of transplanting date and weed management treatments during both the years of study (**Table 4**). Significantly highest rice rain yield was obtained with black rice transplanted on 15th June along with application of pretilachlor at 0.75 kg/ha (PE) *fb* hand weeding at 40 DAT while treatment of 15th July transplanting in combination with weedy check recorded significantly lowest rice grain yield.

Table 4. Black rice grain yield as influenced by interaction of date of transplanting and weed management treatments

Treatment*	Black rice grain yield (kg/ha)		
	2019	2020	Pooled
D_1W_1	1340.20	1410.03	1375.12
D_1W_2	1917.11	2015.63	1966.37
D_1W_3	2527.54	2655.04	2591.29
D_1W_4	2068.23	2168.36	2118.30
D_1W_5	2297.54	2411.67	2354.61
D_2W_1	1181.91	1303.69	1242.80
D_2W_2	1487.86	1592.39	1540.13
D_2W_3	2106.44	2232.96	2169.70
D_2W_4	1528.16	1629.83	1579.00
D_2W_5	1803.99	1921.25	1862.62
D_3W_1	968.34	1078.59	1023.47
D_3W_2	1375.70	1487.83	1431.76
D_3W_3	1738.30	1847.13	1792.71
D_3W_4	1492.69	1595.03	1543.86
D_3W_5	1630.81	1746.34	1688.57
LSD (p=0.05) (D×W)	191.73	215.79	140.61
LSD (p=0.05) (W×D)	186.49	213.37	128.32

*Please refer material and methods for the full forms of treatments

Relation between nutrient depletion by weeds and black rice grain yield

Linear regression equations were developed among nutrient depletion and grain yield.The equations showed strong negative correlation between nutrient depletion by weeds and rice grain yield among different dates of rice transplanting and integrated weed management treatments. Higher nutrient depletion by weeds resulted to higher competition for nutrients uptake by rice and ultimately results in lower rice grain yield and thus the negative correlation. The linear regression equations are as follows.

Nitrogen depletion by weeds and rice grain yield among dates of rice transplanting

$y= -0.0134x +39.986$, $R^2=0.9076$ (2019)$y= -0.0141x+42.732$, $R^2=0.9102$ (2020)

Table 3. Effect of date of transplanting and weed management treatments on NPK uptake (kg/ha), grain and straw yield of black rice

Treatment	Nitrogen uptake (kg/ha)		Phosphorus uptake (kg/ha)		Potassium uptake (kg/ha)		Grain yield (kg/ha)		Straw yield (kg/ha)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Date of transplanting										
15th June	50.97	53.49	16.56	17.35	67.57	69.09	2030	2132	4063	4120
30th June	42.12	44.70	13.99	14.92	61.74	63.63	1622	1736	3800	3882
15th July	37.41	40.08	12.47	13.31	56.83	59.01	1441	1551	3532	3634
LSD (p=0.05)	2.71	3.08	0.87	1.22	3.46	3.01	133	152	242	226
Weed management treatments										
Weedy check	28.62	30.00	10.05	10.66	51.35	50.55	1163	1264	3287	3188
Cono weeding at 20 and 40 DAT	39.75	42.25	13.36	14.25	59.05	61.39	1593	1699	3636	3754
Pretilachlor 0.75 kg/ha at 3 DAT *fb* hand weeding at 40 DAT	55.92	59.12	17.81	18.88	71.97	74.49	2124	2245	4301	4419
Pretilachlor 0.75 at 3 DAT *fb* cono weeder at 40 DAT	43.73	46.62	14.44	15.19	61.83	64.20	1696	1798	3780	3897
Pretilachlor 0.75 kg/ha at 3 DAT *fb* bispyribac-Na 25 g/ha at 20 DAT	49.48	52.46	16.02	16.98	66.03	68.92	1911	2026	3988	4134
LSD (p=0.05)	2.84	2.60	0.90	0.84	3.69	3.77	111	125	237	219

DAT = days after transplanting

Nitrogen depletion by weeds and rice grain yield among integrated weed management

y= -0.0555x +111.34, R^2=0.762 (2019) y= -0.0558x+118.04, R^2=0.7568 (2020)

Phosphorus depletion by weeds and rice grain yield among date of transplanting

y= -0.0031x +9.2765, R^2=0.9038 (2019) y= -0.0033x+9.8939, R^2=0.906 (2020)

Phosphorus depletion by weeds and rice grain yield among integrated weed management

y= -0.0033x +9.8939, R^2=0.906 (2019) y= -0.0131x+27.623, R^2=0.7565 (2020)

Potassium depletion by weeds and rice grain yield among date of transplanting

y= -0.0118x +35.47, R^2=0.9094 (2019) y= -0.0123x+37.656, R^2=0.9144 (2020)

Potassium depletion by weeds and rice grain yield among integrated weed management

y= -0.0495x +99.378, R^2=0.7619 (2019) y= -0.0496x+105.12, R^2=0.7571 (2020)

Relation between nutrient uptake by black rice and its grain yield

In our study it was also noticed that more uptake of nutrients (NPK) by black rice resulted in higher black rice grain yield. Linear regression equations were developed among different nutrient uptake and rice grain yield. The linear regression equations are as follows.

Nitrogen uptake by black rice and its grain yield among date of transplanting

y= 0.0228x +4.8061, R^2=0.9979 (2019) y= 0.0229 x+4.6612, R^2=0.9992 (2020)

Nitrogen uptake by black rice and its grain yield among integrated weed management treatments

y= 0.0285x +4.8543, R^2=0.9979 (2019) y= 0.0297x+7.6193, R^2=0.9978 (2020)

Phosphorus uptake by black rice and its grain yield among date of transplanting

y= 0.0068x +2.7394, R^2=0.9947 (2019) y= 0.0068 x+2.8694, R^2=0.9919 (2020)

Phosphorus uptake by black rice and its grain yield among integrated weed management treatments

y= 0.0081x +0.6131, R^2=0.999 (2019) y= 0.0084x+0.0879, R^2=0.9997 (2020)

Potassium uptake by black rice and its grain yield among date of transplanting

y= 0.0176x +32.235, R^2=0.9712 (2019) y= 0.0168 x+33.596, R^2=0.975 (2020)

Potassium uptake by black rice and its grain yield among integrated weed management treatments

y= 0.0212x +26.025, R^2=0.9911 (2019) y= 0.0243x+20.097, R^2=0.9987 (2020)

It can be concluded that black rice could be transplanted on 15th June along with application of pretilachlor 0.75 kg/ha PE at 3 DAT *fb* hand weeding at 40 DAT to minimize NPK depletion by weeds with effective weed management and increase the productivity of black rice.

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RESEARCH ARTICLE

Seed-shattering phenology of *Phalaris minor* and *Avena ludoviciana* at wheat harvest in north-western India

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ABSTRACT

Weed infestations are primarily driven by the weed seedbank, making it essential to reduce seedbank replenishment for effective control. Seed shattering or retention is a weed plant-specific characteristics and can vary for different weed species, their cohorts or biotypes/populations and weather conditions. Seed shattering phenology of *Phalaris minor* and *Avena ludoviciana* and possible drivers (such as total number of seeds per panicle, plant height, number of tillers and plant biomass) for seed retention was studied at wheat harvest in a two-year study at Punjab Agricultural University, Ludhiana. The results suggested that 74% and 9% seed retention of *P. minor* and *A. ludoviciana*, respectively at wheat harvest. The plant biomass played a critical role in seed retention for *P. minor*, while none of the tested predictors significantly influenced retention in *A. ludoviciana*. This highlighted the weed species-specific differences in seed retention mechanisms, which could be essential for understanding their ecological and management implications. It is concluded that *P. minor* may be a suitable candidate (with 74% seed retention) for harvest weed seed control (HWSC) approaches while *A. ludoviciana* (with 9% seed retention) cannot be targeted with this approach.

Keywords: *Avena ludoviciana*, Harvest weed seed control, *Phalaris minor*, Plant height, Seed retention, Weed control

INTRODUCTION

Wheat [*Triticum aestivum* L. emend. Fiori et Paol.] is the most popular and staple food for human consumption in the world. It is the most significant crop in India in terms of area and production, after rice. Weeds are one of major biological constraints in wheat as crop is infested with complex weed flora. *Phalaris minor* Retz. and *Avena ludoviciana* L. are the dominant monocot weeds in the wheat crop. Both weeds are satellite weeds of wheat crop and mimics the crop. Their initial morphology and physiological similarities to wheat plant makes these grass weeds difficult to control with mechanical methods. Both weeds have similar ecological requirements to that of wheat. Recently, there are reports of evolution of herbicide resistance in *P. minor* and *A. ludoviciana* in northwest India (Kaur *et al.* 2022). *Phalaris minor* is a major weed of rice-wheat cropping system while *A. ludoviciana* is mainly observed in irrigated, well drained, lighter textured soils, and mainly in cotton/ maize-wheat cropping systems (Bhullar *et al.* 2017).

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Phalaris minor typically germinates between November-January and reaches maturity during March-April. The plant features an erect stem with well-defined nodes and internodes, and at maturity, it grows taller than wheat. It sheds its seeds from mid-March till wheat harvest in early-April. Early in the 1990s, *P. minor* has evolved resistance against isoproturon in the rice-wheat cropping system. The resistance evolution was mainly observed in the wheat fields where isoproturon herbicide has continuously been used for 10-15 years (Malik and Singh 1993). Thereafter, *P. minor* also evolved resistance against fenoxaprop, clodinafop and sulfosulfuron and pinoxaden (Kaur *et al.* 2015). *Avena ludoviciana* is particularly serious where wheat is grown in rotation with traditional crops such as cotton, maize, groundnut or with direct-seeded rice (Balyan *et al.* 1991). It is one of the worst annual (winter) weed of temperate agricultural region in the world (Holm *et al.* 2000). The earlier shedding of seed and ability to remain dormant for several years are some features which contributes to its success.

Weeds tend to have variable shattering that enable the weeds to persist in the cropping system. Shattered seeds will add to the weed seed bank and will infest the cropped fields for years (Shivrain *et al.* 2010). Therefore, seedbank replenishment must be reduced for efficient weed control (Schwartz-Lazaro and Copes 2019). To prevent faster evolution of herbicide resistance and reduce the weed pressure in future, it is crucial to ensure that no individual weed plant produces seeds for the next generation (Pulambi 2001). Harvest weed seed control (HWSC) is a technique for capturing unshattered weed seeds while harvesting operation and thus, lowering the number of viable seed delivered to the soil. By restricting seed production and inhibiting the gradual emergence of resistant sub-populations in the soil seed bank, HWSC can have a detrimental effect on the dynamics of weed populations. The effectiveness of HWSC depends upon seed retention at maturity, its collection and further milling/processing (Walsh *et al.* 2018). The seeds retained on the panicle/spike can be targeted by HWSC approaches especially weed seed destruction through impact mills such as Harrington seed Destructor or Redekop Combines (Schwartz-Lazaro *et al.* 2021a, 2021b, 2022). Seed shattering is genetically controlled, but is largely regulated by environmental conditions and agronomic practices (Shirtliffe *et al.* 2000, Walsh and Powles 2014). There is a need to test the potential of HWSC approaches for controlling *P. minor* and *A. ludoviciana* in wheat. Therefore, an experiment was conducted to study the seed retention or shattering behavior of *P. minor* and *A. ludoviciana* at wheat harvest. Also, weed growth parameters along with seed retention at harvest were studied to investigate the relationship between these factors, if any.

MATERIALS AND METHODS

The field experiment was conducted during the winter/*rabi* season of 2022-23 and 2023-24 at Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab, India. The experimental site is situated at an altitude of 247m above mean sea level in the Trans-Gangetic agro-climatic zone at 30°542 N latitude, 75°482 E longitude. The field with population of 100-150 plants/m^2 of *Phalaris minor* and *Avena ludoviciana* during past years was selected for conducting field trial. The field was prepared through conventional practice of ploughing with tractor driven rotavator in all plots and wheat crop (cv. PBW 826 with 100 kg/ha seed rate) was sown using seed-cum-fertilizer drill during first week of November during both years of study.

About 40 plants of both weed species were tagged during first year while 75-80 plants were tagged for recording the data during the second year. Cohorts emerged along with crop and after first irrigation were tagged soon after their emergence. Tagged weed plants were allowed to grow in the field with normal agronomic practices as for wheat crop. Inflorescence of both weeds was covered with bags made of butter paper after the complete emergence. Bag paper of size 15 cm × 10 cm and 30 cm ×10 cm was used to cover inflorescence of *P. minor and A. ludoviciana*, respectively. Seeds were collected at interval of 4 days after 15 days of spike/panicle emergence till the harvest of wheat crop at physiological maturity. Seed collected just before harvest was counted as total seed retained by weed at crop harvest. The observations on total seeds/panicle, plant height, number of tillers and plant biomass were recorded at wheat harvest.

The descriptive statistics was performed on individual years and after pooling the data over the years. The pooled analysis was performed as experimental error for both years was homogeneous according to Bartlett’s test of homogeneity of variance. The Pearson correlation coefficients were calculated for seed retention and individual plant growth parameters. Further, standard multiple regression analysis was performed on the pooled data with seed retention as outcome or dependent variable and plant growth parameters (total number of seeds per panicle, plant height, number of tillers and plant biomass) as independent variable or predictors. The assumptions for standard multiple regression analysis were tested before performing the analysis. Collinearity diagnostics was performed before fitting the regression model. The tolerance, variation inflation factor and cook’s distance were evaluated for the data and outliers were removed before fitting the regression model as below:

$$\hat{y} = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4$$

where, w is seed retention; $\hat{y}$ is intercept and $\beta_1, \beta_2, \beta_3$ and β_4 that are unstandardized regression coefficients for x_1, x_2, x_3 and x_4, that are total number of seeds per panicle, plant height, number of tillers and plant biomass, respectively. The analysis of variance (ANOVA) to test the significance of predictor effect in multiple correlation-regression was performed using IBM SPSS Statistics 19.

RESULTS AND DISCUSSION

The success of HWSC method such as impact mills is dependent upon weed seed retention on panicle per spike. Seed retention percentage in *P. minor* was found much higher as compared to *A. ludoviciana* (**Table 1**). Seed retention of *P. minor* varied from 70.2±1.4% (2022-23) to 74.1±1.24%

(2023-24), with a pooled average of 73.7±0.8%. Further, seed production per panicle in *P. minor* at wheat harvest was 256.0±9.6 and 330.8±9.4 during 2022-23 and 2023-24, respectively with a pooled average of 309.1±7.5. On the other hand, seed retention of *A. ludoviciana* at wheat harvest was 11.2% and 10% during 2022-23 and 2023-24, respectively, and total number of seeds per panicle ranged from 52.0±1.9 to 61.4±0.9 during two years of study. It indicated that most of seeds of *A. ludoviciana* would have shed at the time of wheat harvest.

The data in **Table 2** and **3** presented the Pearson correlation coefficients among various agronomic traits, including retention percentage, total seeds per panicle, plant height, tillers per plant, and biomass. In *P. minor*, seed retention percentage had a significant positive correlation with total seeds per panicle, plant height and biomass (**Table 2**). Total seeds/panicle demonstrated a strong positive correlation with plant height, a weak positive correlation with biomass, and a negligible correlation with tillers. These findings in *P. minor* indicated presence of significant associations among some traits in *P. minor* where the correlation coefficients exceed the critical value of 0.183, emphasizing the interdependence of these agronomic parameters. Seed shattering (or pod dehiscence, or fruit shedding) is an essential process for the propagation and the evolutionary success of wild plant species. In the cropped environment, weeds are under strong selective pressures and fruit morphology and associated dispersal strategies are of significant adaptive importance. There is molecular and hormonal regulation of tissues that are necessary for seed shattering and fruit shedding (Dong and Wang 2015).

Seed retention percentage in *A. ludoviciana* had a significant negative correlation with total seeds per panicle (**Table 3**). Total seeds per panicle exhibited a strong positive correlation with plant height and biomass but shows minimal correlation with tillers. Plant height was positively correlated with biomass and negatively correlated with tillers. These values highlighted the relationships among the traits, indicating significant associations where the absolute correlation coefficients exceed the critical value of

Table 1. Descriptive statistics of seed retention and growth characteristics of *Phalaris minor* and *Avena ludoviciana* during 2022-23 and 2023-24

Parameters	*Phalaris minor*			*Avena ludoviciana*		
	2022-23 (n=39)*	2023-24 (n=77)	Pooled (n=116)	2022-23 (n=35)	2023-24 (n=76)	Pooled (n=111)
Retention (%)	70.2±1.4 (46.7-84.8)	74.1±1.24 (14.0-91.4)	73.7±0.8 (54.4-91.4)	11.2±1.0 (0-30.4)	10.0±0.9 (0-50)	9.4±0.5 (0-25)
Total seeds/ panicle (no.)	256.0±9.6 (120-362)	(330.8±9.4) (106-536)	309.1±7.5 (145-536)	52.0±1.9 (23-75)	61.4±0.9 (0-30.4)	58.9±1.5 (23-119)
Plant height (cm)	103.0±3.5 (59-145)	113.9-1.8 (76-149)	110.1±1.8 (59-149)	119.6±2.7 (88-145)	130.5±1.6 (98-164)	127.6±1.4 (96-164)
Tillers/plant (no.)	3.0±0.2 (1-6)	3.2±0.1 (1-7)	3.2±0.1 (1-7)	3.9±0.3 (2-7)	3.184±0.14 (2-7)	3.4±0.1 (2-7)
Biomass/plant (g)	2.0±0.2 (0.6-5.1)	2.5±0.1 (0.9-5.8)	2.4±0.1 (0.6-5.8)	2.2±0.1 (0.9-4.4)	2.9±0.1 (1.4-6.8)	2.7±0.1 (0.9-6.8)

*Indicated the sample size (n) in a year. Results are presented as mean ± standard error. Figures in parentheses indicated the range from minimum to maximum

Table 2. Correlation matrix of seed retention and growth characteristics of *Phalaris minor*

Parameters	Seed retention (%)	Total Seeds/panicle (no.)	Plant height (cm)	Tillers (no.)
Total Seeds/panicle (no.)	0.303			
Plant height (cm)	0.183	0.512		
Tillers/plant (no.)	-0.002	0.018	-0.186	
Biomass/plant (g)	0.276	0.143	0.167	0.118
r (p=0.05)		0.183		

Table 3. Correlation matrix of seed retention and growth characteristics of *Avena ludoviciana* at wheat harvest

Parameters	Seed retention (%)	Total Seeds/panicle (no.)	Plant height (cm)	Tillers (no.)
Total Seeds/panicle (no.)	-0.192			
Plant height (cm)	-0.111	0.444		
Tillers/plant (no.)	0.142	0.034	-0.122	
Biomass/plant (g)	-0.011	0.348	0.463	-0.134
r (p=0.05)		0.187		

0.187.

The multiple regression analysis for estimating seed retention in *P. minor* and *A. ludoviciana* using four predictors (seeds per panicle, plant height, tillers per plant, and plant biomass) revealed notable differences in model performance and predictor influence (**Table 4**). The model for *P. minor* demonstrated a better fit, with multiple correlation coefficient, R = 0.362 and coefficient of determination, $R^2 = 0.131$ that 13.1% of the variance in seed retention is explained due to these four predictors. The adjusted R^2 (0.099) and a statistically significant ANOVA value ($p = 0.004$) indicated a modest but meaningful relationship between the predictors and the dependent variable. Among the predictors, plant biomass emerged as the most significant factor ($\beta = 2.174$, $p = 0.004$), positively influencing seed retention, while seeds per panicle, plant height, and tillers per plant had minimal or insignificant effects ($p > 0.05$).

In contrast, the model yielded a low multiple correlation coefficient (R = 0.160) and an R^2 value of 0.026 for *A. ludoviciana*, indicating minimal explanatory power of the predictors (**Table 4**). The adjusted R^2 was negative (-0.012), further suggesting a poor model fit. The ANOVA significance value (0.612) was not statistically significant, and none of the predictors showed significant effects, as reflected by their p-values (e.g., plant biomass: $p = 0.283$). Among the predictors, plant biomass had the largest regression coefficient ($\beta = -0.743$), indicating its relative influence, albeit non-significant.

In wheat cropped fields, these two grass weeds may emerge with or after the crop emergence with every irrigation or rainfall event. It was observed by Franke *et al.* (2007) that all *P. minor* plants were able to produce seeds. Smaller plants with lower aboveground biomass produced a smaller number of seeds with the similar individual seed weight as that of seeds produced by the larger plants. This was established that seed size or weight was unaffected by the above ground biomass of the mother plant. The cohorts that emerged late in the cropping season produced only 1.1 g shoot biomass but resulted in the production of 205 seeds/plant. There are multiple cohorts of these weeds present in a field at one time which result in variable maturity and thus, longer period of seed shattering. This adaptive behaviour of weeds allowed them to manage seed bank. Therefore, early crop harvest may maximize the weed seed export from the field (into the combine) and could prevent significant long-distance dispersal if clubbed with sanitation, cleaning of farm machinery and narrow windrow burning. However, under late crop harvest scenario, both *P. minor* and *Avena* spp. will have less seed retention on spike/panicle *i.e.* more of seed shed.

Residue burning may have detrimental effect on mortality of weed seeds lying on soil surface depending upon the residue load (Kaur *et al.* 2021). Moreover, most weeds are prolific seed producers and can distribute seeds in the vicinity areas through shattering over a long duration following physiological maturity. Seed shattering has also been recognized as an essential adaptive trait that favours seed dispersal, seedbank establishment and weediness in many species (Delouche *et al.* 2007, Burton *et al.* 2017). The retained seeds on the spike per panicles can be harvested and spread across the field by the combine harvester for long-distance dispersal through contamination of harvested crop

Table 4. Multiple regression model estimates for estimating retention (dependent variable) of seeds of *Phalaris minor* and *Avena ludoviciana* from four predictors (seeds/panicle, plant height, tillers, biomass)

Model estimates		*Phalaris minor*	*Avena ludoviciana*
Multiple correlation, R		0.362	0.160
R square		0.131	0.026
Adjusted R square		0.099	-0.012
df		112	106
ANOVA significance		0.004	0.612
α		59.140	8.941
β	Seeds/panicle	0.004	-0.035
	Plant height	0.077	0.033
	Tillers/plant	-0.098	0.095
	Plant biomass	2.174	-0.743
Sig.	Seeds/panicle	0.697	0.357
	Plant height	0.117	0.445
	Tillers/plant	0.876	0.801
	Plant biomass	0.004	0.283

seed. Weeds are very adaptive to crop production practices. HWSC is widely adopted in Australia and USA, and there is a need to study if weeds retain only some seeds and shatter most of their seed before the harvest of crop as an evolutionary adaptation to avoid HWSC methods (Walsh *et al.* 2013, Walsh and Powles 2014, Walsh *et al.* 2018).

Based on two-year study, plant biomass has a significant positive effect on seed retention in *P. minor*. Further, it is concluded that *P. minor* may be a suitable target candidate (with 74% seed retention) for HWSC approaches while *A. ludoviciana* (with 9% seed retention) cannot be targeted for this approach.

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RESEARCH ARTICLE

Compatibility and efficacy of post-emergence herbicides tank mixed with zinc sulphate and urea for weed management in wheat

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ABSTRACT

A study was conducted to evaluate the compatibility and efficacy of post-emergence herbicides with zinc sulphate and urea (tank-mixed) in wheat during the year 2018–19, 2019–20 and 2020–21 at the research farm of CCSHAU Regional Research Station, Bawal, Haryana, India. The experiment was designed in a factorial randomized block design with three replications. The first factor included two treatments: with foliar spray of zinc sulphate plus urea and without the foliar spray of zinc sulphate plus urea, while the second factor comprised of seven weed control treatments: metsulfuron 4 g/ha, carfentrazone 20 g/ha, 2,4-D sodium salt 500 g/ha, 2,4-D ester salt 500 g/ha, metsulfuron + carfentrazone (RM) 24 g/ha, unweeded check, and weed-free. The herbicides tested were found compatible with zinc sulphate (0.5%) + urea (2.5%) when tank-mixed, as no phytotoxicity was observed on the crop at any stage. The application of zinc sulphate (0.5%) + urea (2.5%) was found to be compatible with different herbicides recommended for the post-emergence management of broad-leaved weeds and increased wheat grain yield by 4%. Among different herbicides, metsulfuron + carfentrazone (RM) 24 g/ha recorded the highest grain yield (6.06 t/ha) and achieved the maximum net returns (₹ 85,907/ha) with a benefit-cost (B:C) ratio of 2.78 over three seasons. The highest weed control efficiency was also observed with metsulfuron + carfentrazone (RM) 24 g/ha tank-mixed with zinc sulphate and urea. The various herbicides when tank mixed with zinc sulphate plus urea provided higher weed control efficiency than the herbicides used alone.

Keywords: Compatibility, Herbicides, Metsulfuron + carfentrazone, Weed control efficiency, Wheat, Zinc sulphate with urea

INTRODUCTION

Wheat is one of the major cereal crops globally, cultivated in an area of 219.5 million hectares, with a production of 808.4 million tonnes (Anonymous 2022a). India is the second largest wheat producer after China, contributing 13.3% of global production with 107.7 million tonnes in 2022, grown on 30.46 million hectares (13.9% of global wheat acreage) (Anonymous 2022b). By 2050, it is estimated that a sustainable increase in global food supply of 70–100% will be required to meet the demands of a population projected to reach 9 billion (Godfray *et al.* 2010). Given the limited scope for expanding cultivated areas, increasing crop productivity remains the only viable strategy to address the food security challenge. In arid and semi-arid regions, wheat yields are significantly limited by inadequate nutrient supply (Nagora *et al.* 2023). Weeds also pose a major constraint to wheat production, with the potential for the greatest losses among biotic factors, including pathogens, insects, and animals. In India, weeds result in an annual economic loss of over USD 11 billion (Gharde *et al.* 2018). They compete with crops for essential resources such as nutrients, moisture, light, and space, leading to yield losses ranging from 15 to 53% and in severe cases, complete crop failure (Jitender *et al.* 2021; Nibhoria *et al.* 2021, 2022; Malik and Singh 1995; Soni *et al.* 2023, 2024).

Among weed management methods, chemical control is considered the most efficient, cost-effective, and time-saving. Moreover, various herbicides have been recommended for different types of weed flora. Wheat in south western parts of Haryana state is mainly dominated by broad-leaved weeds. Nutrient management is another critical factor affecting yield and quality. Combined application of agrochemicals, such as herbicides and micronutrients, can address both weed management and nutrient deficiencies while reducing operational costs. However, herbicide performance can be

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influenced by co-applied agrochemicals, resulting in synergistic, antagonistic, or additive effects depending on their chemistry, application rates, formulations, spray volume, target weeds, and environmental conditions (Daramola *et al.* 2023). In Brazilian farms, approximately 97% of agrochemical users tank mix up to six or more products, applying them concomitantly, such as herbicides with insecticides and fungicides (Gazziero 2015). Such combinations can also create synergistic effects, enhancing weed control efficiency (Li *et al.* 2019). In maize, the addition of urea to herbicides increased both phytotoxicity and herbicide efficacy (Tahir *et al.* 2011). Similarly, in wheat, herbicide efficacy improved when combined with zinc (Jitender *et al.* 2022). Zinc (Zn) is a vital micronutrient for plants, contributing to enzymatic activities, crop yield, and quality (Sheoran *et al.* 2021). In India, nearly 49% of soils are deficient in micronutrients like Zn and Fe (Shukla *et al.* 2012). Deficiencies in plant-available zinc lead to lower zinc content in grains, which in turn exacerbates malnutrition in humans. Factors such as high soil pH, high calcium carbonate content, sandy soil texture, and low organic matter contribute to zinc deficiency in soils, despite its natural abundance. Mixing urea with zinc also enhances nutrient assimilation in crops and boosts herbicide performance. Foliar application of water-soluble fertilizers has emerged as an effective and economical method to enhance crop production under such conditions. Given the rising production costs and the overlapping timings for the application of post-emergence herbicides and micronutrient sprays, farmers could benefit from their concurrent use. This approach saves time, labour, and energy, while also reducing costs. However, limited research is available on the compatibility of herbicides with zinc sulphate and urea. Thus, this study was designed to determine the compatibility of herbicides with zinc sulphate and urea to provide valuable insights and practical solutions for wheat growers.

MATERIALS AND METHODS

The experiment was carried out in three consecutive seasons, *i.e.* 2018-19 to 2020-21 at CCS Haryana Agricultural University, Regional Research Station, Bawal (Rewari) Haryana, India (coordinates of 28º4' N latitude and 76º35' E longitude, an altitude of 266 m from mean sea level). Climate of Bawal (Rewari), India classified as tropical and semiarid with hot and dry winds in summer, severe cold in winter; and humid, warm weather during the rainy season. The average rainfall of the region is 350-550 mm. A total 34.3, 110.3 and 68.6 mm of rainfall was received during cropping seasons 2018-19, 2019-20 and 2020-21, respectively (**Figure 1, 2, 3**). The soil of the experimental field was loamy sand (typic ustochrept) in texture and slightly alkaline in reaction with pH 7.8, low in soil organic carbon (0.21%) and nitrogen (89 kg/ha); and medium in available phosphorus (10.8 kg/ha soil) and potash (166 kg/ha soil). Seeds of wheat crop variety WH 1105 were drilled manually with the help of hand plough into rows at 20 cm spacing on well-prepared seed bed. The crop was fertilized as per the recommended dose, i.e., 150 kg N, 60 kg P, and 30 kg K per hectare. Five irrigations were applied at 22, 45, 65, 85, and 105 days after sowing (DAS) in all seasons. Other agronomic operations were conducted according to the recommended packages of practices developed by the university.

Treatment details

The experiment was designed in a factorial randomized block design (RCBD) with three replications with gross plot size of 5m × 2.6m. The first factor included two treatments: with and without the spray of zinc sulphate (0.5%) + urea (2.5%), while the second factor comprised seven weed control treatments: post-emergence application (PoE) of metsulfuron 4 g/ha, carfentrazone 20 g/ha, 2,4-D sodium salt 500 g/ha, 2,4-D ester salt 500 g/ha, metsulfuron + carfentrazone - ready mix (RM) 24 g/ha, unweeded check (UWC), and weed-free check (WFC). Post-emergence application of herbicides was done at 35 days after sowing (DAS) of wheat using a knapsack sprayer with a flat fan nozzle calibrated to deliver 375 L water per ha. In weeds-free plots, weeds were removed manually as and when appeared; and no weeding was done in unweeded check treatment.

Observations on weeds

The data on weed density and total dry weight (weed biomasss) were recorded at 75 DAS using a quadrat of 0.5 x 0.5 m^2, placed randomly at 4 spots in each of the plot. The total weed counts were summed up to express weed density per meter square. All weeds were uprooted, and sundried followed by oven drying at 65±5 ^{0}C till a constant weight was achieved. The dried samples of weeds were weighed and the total weeds biomass was expressed as g/m^2. Weed control efficiency (WCE%) was calculated using following formula:

$$WCE = \frac{Wc - Wt}{Wc} \times 100$$

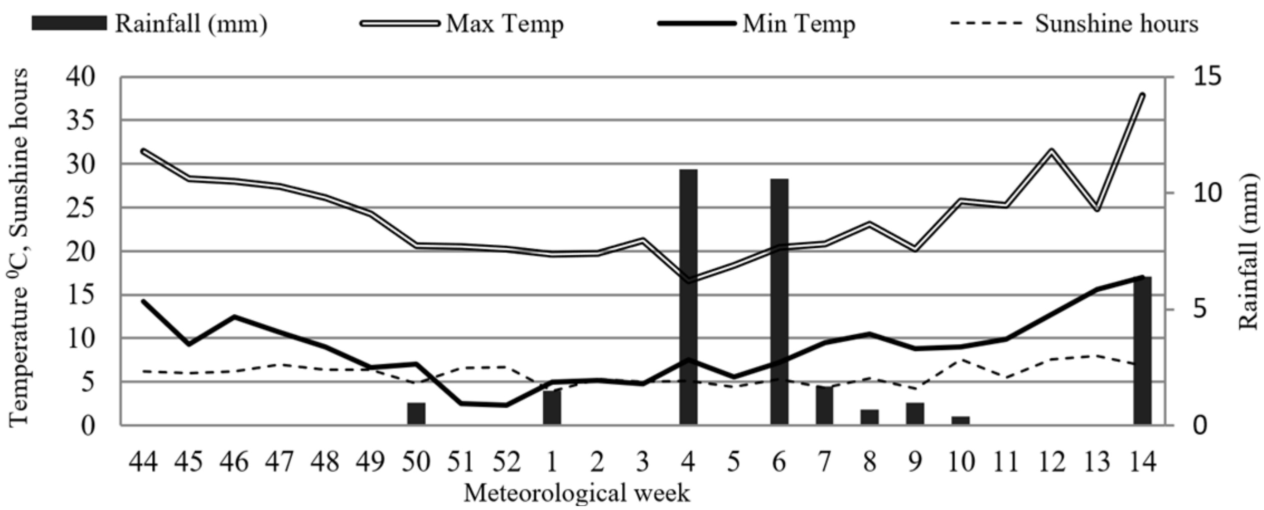

Figure 1. Weather data of crop season 2018-19

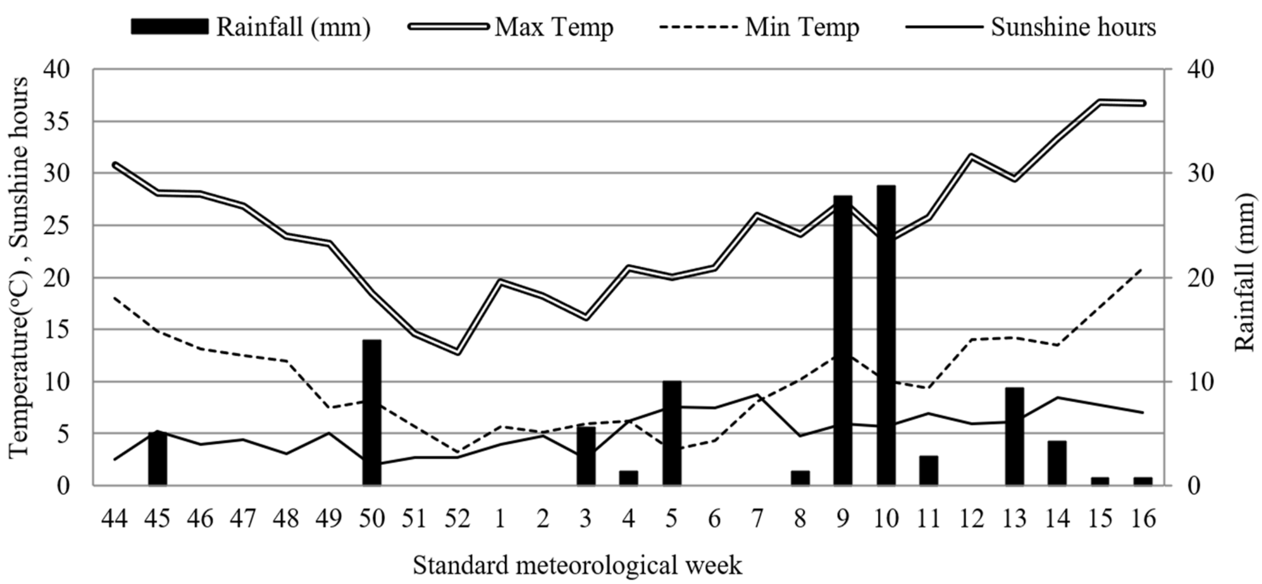

Figure 2. Weather data of crop season 2019-20

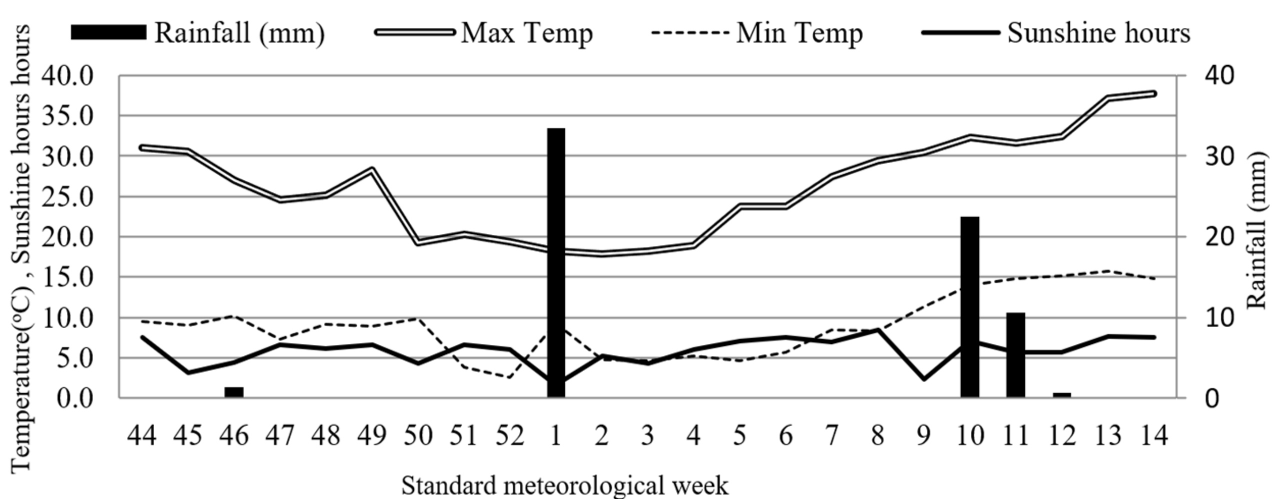

Figure 3. Weather data of crop season 2020-21

Where,

Wc = weeds biomass in weedy plot (g)

Wt = weeds biomass in treated plot (g)

Wheat yield attributes, including effective tillers (no./m²), grains per spike, and 1000-grain weight were recorded at harvest. Effective tillers were calculated by averaging counts from three random one-meter row lengths per plot and converting them to m² based on row spacing. Grains per spike were determined by threshing and counting grains from twenty randomly collected spikes per plot. The 1000-grain weight was measured by weighing thousand healthy grains from each plot using a digital balance. Wheat grain and straw yields (t/ha) were measured by threshing the sun-dried wheat harvested from the net plot area using a mini-plot thresher and weighing the produce with a digital balance.

Economics

The cost of cultivation was calculated based on the prevailing market rates for all operations and inputs. Gross returns were determined by multiplying wheat grain and straw yield with minimum support price of wheat and prevailing market rates of straw, respectively, in corresponding seasons. Net returns were the difference between gross returns and cost of cultivation per ha. Benefit- cost (B: C) ratio was calculated using the following formula:

B: C = Gross returns (Rs/ha) ÷ Gross cost (Rs/ha)

Statistical analysis

Statistical analysis was performed using STAR (Statistical Tools for Agricultural Researcher) software package (STAR version 2014). The significance of the treatment was determined by the F-test, and the difference between the means of treatments with factors having more than two levels, multiple comparisons were performed using Tukey HSD at 5% probability level. To homogenize the variance of weed density and biomass, square root ($\sqrt{x+1}$) transformation was performed. Additionally, correlation analysis was conducted to assess the relationships between key variables such as weed density, weed biomass, yield attributes, and yield. Regression analysis was performed to model the influence of independent variables (weed biomass (dry weight), weed density and WCE) on dependent variables (grain yield).

RESULTS AND DISCUSSION

The crop was mainly infested with broad-leaved weeds, *viz. Chenopodium album, Chenopodium murale, Anagallis arvensis, Corronopus didymus, Convolvulus arvensis* etc. The application of $ZnSO_4$ (0.5%) and urea (2.5%) with tested post-emergence herbicides significantly reduced weed density and biomass in comparison to weedy check (**Table 1**). The density of weeds significantly reduced with all weed control treatments in comparison to unweeded check that may be ascribed to the application of zinc sulphate + urea led to better crop growth and lesser competition between crop and weeds. Among various herbicidal treatments for weed management, metsulfuron + carfentrazone (RM) 24 g/ha recorded the least weed density as well as weeds biomass over a period of three seasons **(Table 1)**. The interaction was insignificant. These results are in agreement with Gandini *et al.* (2020).

Weed control efficiency (WCE)

Significantly highest WCE was achieved with metsulfuron + carfentrazone (RM) 24 g/ha in with and without combinations of zinc sulphate with urea **(Figure 4)**. However, the inclusion of zinc sulphate with urea consistently improved the WCE across all herbicide treatments. The combination of metsulfuron and carfentrazone offers superior weed control due to their complementary modes of action. Metsulfuron, a systemic ALS inhibitor, provides long-lasting control by targeting amino acid synthesis, while carfentrazone, a contact PPO inhibitor, delivers rapid knockdown by disrupting chlorophyll production. This synergy enhances overall efficacy compared to other herbicides like 2,4-D, offering both immediate and sustained weed suppression. Further, improvement with the addition of zinc sulphate with urea attributed to several synergistic effects. Zinc sulphate, as a micronutrient, enhances enzymatic activity and chlorophyll synthesis in crops, improving their vigour and enabling them to compete more effectively with weeds. Urea, on the other hand, can alter the pH of the spray solution, enhancing the absorption and translocation of systemic herbicides like metsulfuron and 2,4-D, while also improving the efficacy of contact herbicides such as carfentrazone. Additionally, the nutrient combination of zinc and urea may impose metabolic stress on weeds, making them more susceptible to herbicidal action. These combined effects likely contributed to the increased efficacy of herbicides in the presence of zinc sulphate and urea, leading to superior weed control and crop performance. The findings underscore the importance of integrating nutrient management with herbicide application to achieve enhanced weed suppression and sustainable crop production. Similar increase in WCE has been reported by Sabeti (2015) wherein about 10 per cent increase in herbicide efficacy was reported due to tank mixture of micronutrients and herbicides.

Crop yield attributes and yield

Mixture of $ZnSO_4$ and urea was compatible with various herbicides in tank mixing, leading to enhanced crop yield attributes. Foliar application of zinc sulfate combined with urea resulted in an improvement across all yield parameters, with a significant increase noted specifically in grains per spike. Various herbicidal treatments significantly increased tillers per meter square by 6-8 and grains per spike by 11-13 per cent over unweeded check (**Table 2**). Importantly, no phytotoxicity was observed from any herbicide application, whether zinc plus urea was included or not. Furthermore, the interaction between $ZnSO_4$ + urea and the applied herbicides was statistically insignificant. These results are consistent with findings reported by Jitender *et al.* (2023).

Grain yield

Spray of $ZnSO_4$ (0.5%) + urea (2.5 %) tank mixed with herbicides exerted significant effect (4% increase) on grain yield of wheat over three cropping seasons (**Table 3**). Similarly, Maurya *et al.* (2015) reported 26 % hike in grain yield of wheat with two foliar spray of $ZnSO_4$ (0.5%) + urea (2.0%) at 25 and

Table 1. Effect of zinc sulphate with urea and different weed control treatments on weed density and biomass in wheat at 75 DAS (Mean of 2018-19 to 2020-21)

Treatment	Weed density (no./m^2)	Weeds biomass (g/m^2)
Zinc sulphate with urea		
No spray of $ZnSO_4$ (0.5%) + urea (2.5%)	5.7^b (25.0)	4.4^b (15.4)
Spray of $ZnSO_4$ (0.5%) + urea (2.5%)	5.1^a (20.2)	3.8^a (13.4)
Herbicides		
Metsulfuron 4 g/ha PoE	4.7^b (20.1)	3.4^b (13.4)
Carfentrazone 20 g/ha PoE	4.4^a (20.1)	3.2^b (12.0)
2, 4-D Na salt 500 g/ha PoE	4.7^b (23.0)	3.4^b (12.0)
2, 4-D ester salt 500 g/ha PoE	4.9^b (18.4)	3.6^b (9.2)
Metsulfuron + carfentrazone (RM) 24 g/ha PoE	3.0^c (8.1)	1.8^a (3.8)
Unweeded check	15.1^d (134.9)	12.7^c (98.2)
Weed free check	1.0 (0)	1.0^d (0)
P-value at 5% level of significance		
Year	0.0000*	0.0003*
Zinc	0.0000*	0.0000*
Herbicide	0.0000*	0.0000*
Zinc × Herbicide	0.0665	0.1568
Year × Zinc	0.5500	0.6012
Year × Herbicide	0.0000*	0.0000*
Year × Zinc × Herbicide	0.1089	0.9244

Figures in parentheses are original values which were subjected square root transformation. RM: ready mix

The values in the table represent p-values, a p-value < 0.05 suggests a significant effect, while a p-value ≥ 0.05 indicates a non-significant effect.

Means marked with at least one common letter are not significantly different from each other under a particular factor (p<0.05). DAS = days after seeding; PoE = Post emergence application; RM = ready mix

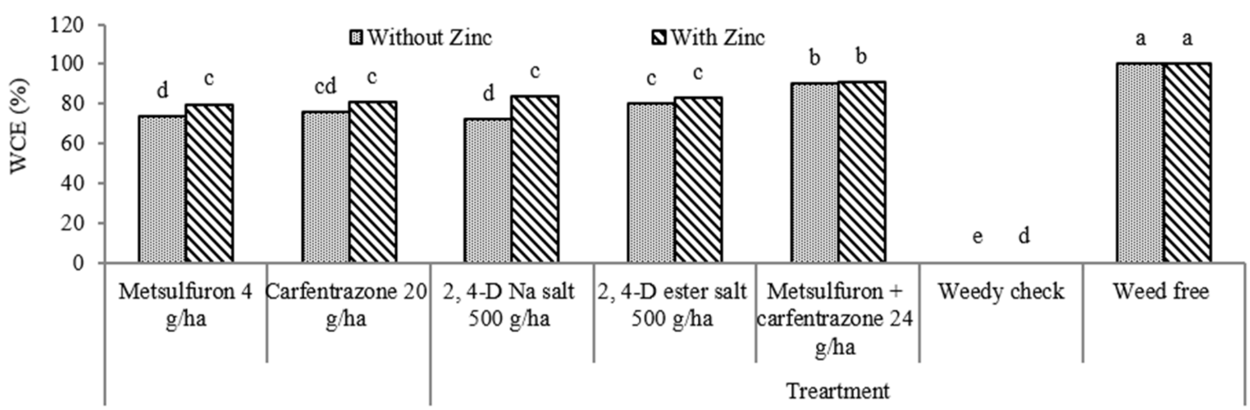

Figure 4. Weed control efficiency of different weed management treatments with and without tank mixing of zinc sulphate + urea at 75 DAS in wheat (mean of 2018-19 to 2020-21)

50 DAS. These results are further supported by Gao *et al.* (2024) who reported that increasing Zn supply via foliar spraying could effectively correct or prevent the symptomatic occurrence of Zn deficiency, ensure sufficient Zn uptake by wheat and improve grain yields. Among various weed control treatments, maximum increase in grain yield (33%) over unweeded check was recorded under metsulfuron + carfentrazone (RM) 24 g/ha and weed free check followed by 30% with carfentrazone 20g/ha. The mean grain yield of three years of study under all herbicidal treatments was significantly higher than

Table 2. Effect of application of zinc sulphate with urea and different weed control treatments on yield attributes of wheat (mean of 2018-19 to 2020-21)

Treatment	Tillers/m^2	Grains/spike	1000-grain wt. (g)
Zinc sulphate with urea			
No spray of $ZnSO_4$ (0.5%) + urea (2.5%)	348.3^{ns}	43.9^{b}	42.1^{ns}
Spray of $ZnSO_4$ (0.5%) + urea (2.5%)	350.8^{ns}	45.4^{a}	42.6^{ns}
Herbicides			
Metsulfuron 4 g/ha PoE	352.0^{a}	45.1^{a}	42.8^{a}
Carfentrazone 20 g/ha PoE	352.7^{a}	45.1^{a}	42.8^{a}
2, 4-D Na salt 500 g/ha PoE	350.2^{a}	44.9^{a}	42.9^{a}
2, 4-D ester salt 500 g/ha PoE	352.7^{a}	45.2^{a}	42.7^{a}
Metsulfuron + carfentrazone (RM) 24 g/ha PoE	356.2^{a}	45.7^{a}	43.5^{a}
Unweeded check	328.8^{b}	40.6^{b}	38.8^{b}
Weed free check	354.3^{a}	45.9^{a}	43.2^{a}
P-value at 5% level of significance			
Year	0.0000*	0.0000*	0.0003*
Zinc	0.0641	0.001*	0.1828
Herbicide	0.0000*	0.0000*	0.0000*
Zinc × Herbicide	0.9973	0.9256	0.9995
Year × Zinc	0.8605	0.3300	0.4698
Year × Herbicide	0.1680	0.9701	0.9996
Year × Zinc × Herbicide	0.9979	1.0000	0.9999

The values in the table represent p-values, a p-value < 0.05 suggests a significant effect, while a p-value ≥ 0.05 indicates a non-significant effect.

Means marked with at least one common letter are not significantly different from each other under a particular factor (p<0.05). PoE = Post emergence application; RM = ready mix

Table 3. Effect of application of sulphate with urea and different weed control treatments on grain and straw yield of wheat

Treatment	Grain yield (t/ha)				Straw yield (t/ha)			
	2018-19	2019-20	2020-21	Mean	2018-19	2019-20	2020-21	Mean
Zinc sulphate with urea								
No Spray of $ZnSO_4$ + urea	6.26^{ns}	5.33^{b}	5.37^{b}	5.65^{b}	9.46^{ns}	9.36^{ns}	9.98^{b}	9.54^{b}
Spray of $ZnSO_4$ + urea	6.30^{ns}	5.66^{a}	5.63^{a}	5.87^{a}	9.50^{ns}	9.82^{ns}	10.40^{a}	9.91^{a}
Herbicides								
Metsulfuron 4 g/ha PoE	6.42^{a}	5.59^{a}	5.62^{a}	5.90^{a}	9.69^{a}	9.75^{a}	10.24^{a}	9.89^{a}
Carfentrazone 20 g/ha PoE	6.53^{a}	5.72^{a}	5.71^{a}	5.95^{a}	9.64^{a}	9.95^{a}	10.48^{a}	10.03^{a}
2, 4-D Na salt 500 g/ha PoE	6.59^{a}	5.58^{a}	5.62^{a}	5.90^{a}	9.70^{a}	9.75^{a}	10.23^{a}	9.89^{a}
2, 4-D ester salt 500 g/ha PoE	6.46^{a}	5.61^{a}	5.64^{a}	5.90^{a}	9.67^{a}	9.82^{a}	10.32^{a}	9.94^{a}
Metsulfuron + carfentrazone (RM) 24 g/ha PoE	6.49^{a}	5.84^{a}	5.78^{a}	6.06^{a}	9.76^{a}	10.03^{a}	10.70^{a}	10.17^{a}
Unweeded check	4.98^{b}	4.37^{b}	4.35^{b}	4.56^{b}	8.11^{b}	7.84^{b}	8.25^{b}	8.07^{b}
Weed free check	6.51^{a}	5.77^{a}	5.78^{a}	6.05^{a}	9.81^{a}	9.99^{a}	10.50^{a}	10.10^{a}
P-value at 5% level of significance								
Year	--	--	--	0.000*	--	--	--	0.0003*
Zinc	0.7966	0.0079*	0.0021*	0.004*	0.7515	0.1915	0.0442*	0.0288*
Herbicide	0.000*	0.000*	0.000*	0.000*	0.000*	0.0244*	0.0126*	0.000*
Zinc × Herbicide	0.9804	0.9999	0.8929	0.9824	0.9999	1.0000	0.9999	0.9998
Year × Zinc	--	--	--	0.2329	--	--	--	0.3507
Year × Herbicide	--	--	--	0.9985	--	--	--	0.9998
Year × Zinc × Herbicide	--	--	--	0.9995	--	--	--	1.000

The values in the table represent p-values, a p-value < 0.05 suggests a significant effect, while a p-value ≥ 0.05 indicates a non-significant effect.

Means marked with at least one common letter are not significantly different from each other under a particular factor (p<0.05). PoE = Post emergence application; RM= ready mix unweeded check and statistically similar to that of weed free check treatment. The straw yield of wheat also followed almost similar trend over study period. The synergistic effect of tank mixed zinc and herbicide resulted in better translocation of photosynthates form source to sink and ultimately higher economic yield and thereby giving better returns. Furthermore, fertilizers enhance the plant´s adaptive potential by minimizing injury from herbicides (Machado *et al.* 2017). Foliar fertilizers and growth regulators can induce adaptive plant responses to harmful substances by acting to detoxify superoxide anions in them (Upreti and Sharma 2016). Ram *et al.* (2022) also reported 5.74% increased grain yield with foliar Zn + herbicide mixture than control.

Economics

Over three years, the application of $ZnSO_4$ + urea in wheat resulted in higher net returns and benefit-cost ratio (B:C). The tank mixing of $ZnSO_4$ (0.5%) + urea (2.5%) increased the net returns by Rs. 5116/ha and B: C from 2.53 to 2.60 over 3 seasons (**Table 4**). Similar outcomes of improvement in B: C with foliar spray of zinc sulphate mixed with urea was reported by Maurya *et al.* (2015). All weed management treatments fetched statistically similar gross returns, net returns and B: C except unweeded check which recorded significantly lower economic parameters in comparison to all other treatments. Among various weed management treatments, metsulfuron + carfentrazone (RM) 24 g/ha resulted in the highest net returns (Rs.85,907/ha) and B: C (2.78). Other herbicidal treatments also resulted in increase in net returns as well as B: C in comparison to unweeded check. Interestingly, weed-free plots recorded significantly lower net returns (Rs. 56,934/ ha) and B:C (1.68) than herbicidal treatments. This could be attributed to the higher cost of labor involved in manual weed management. The improvement in economic parameters, such as net returns and B:C, was primarily due to enhanced grain and straw yield in wheat under treatments involving the foliar application of zinc and herbicides (Jitender *et al.* 2023). Daramola *et al.* (2023) also highlighted the benefits of co-application of agrochemicals, emphasizing advantages such as time efficiency, reduced field application trips, improved pest control, lower fuel consumption, and minimized environmental pollution.

Box plot analysis

The analysis of the box plot data reveals that the combined application of $ZnSO_4$ with urea significantly enhances wheat performance in terms of weed control efficiency (WCE), grain yield, and straw yield compared to herbicide alone under combined herbicide treatments in three seasons **(Figure 5)**. The mean WCE increased from 70.22% without $ZnSO_4$ + urea to 73.98% with $ZnSO_4$ + urea,

Table 4. Effect of application of zinc sulphate with urea and different weed control treatments on economics of wheat (mean of 2018-19 to 2020-21)

Treatment	Gross returns (Rs./ha)	Net returns (Rs./ha)	B: C
Zinc sulphate with urea			
No Spray of $ZnSO_4$ + urea	133715[b]	75038[b]	2.53[b]
Spray of $ZnSO_4$ + urea	138512[a]	80154[a]	2.60[a]
Herbicides			
Metsulfuron 4 g/ha PoE	138686[a]	82622[a]	2.74[a]
Carfentrazone 20 g/ha PoE	141185[a]	84720[a]	2.73[a]
2, 4-D Na salt 500 g/ha PoE	139674[a]	83455[a]	2.73[a]
2, 4-D ester salt 500 g/ha PoE	139355[a]	83058[a]	2.73[a]
Metsulfuron + carfentrazone (RM) 24 g/ha PoE	142514[a]	85907[a]	2.78[a]
Unweeded check	109388[b]	55964[c]	2.16[b]
Weed free check	141990[a]	74445[b]	2.19[b]
P-value at 5% level of significance			
Year	0.0031*	0.0000*	0.0000*
Zinc	0.0005*	0.0002*	0.0113*
Herbicide	0.0000*	0.0000*	0.0000*
Zinc × Herbicide	0.9751	0.9875	0.9772
Year × Zinc	0.0162	0.0705	0.5299
Year × Herbicide	0.9990	0.9993	0.0000*
Year × Zinc × Herbicide	0.9999	0.9997	0.9993

The values in the table represent p-values, a p-value < 0.05 suggests a significant effect, while a p-value ≥ 0.05 indicates a non-significant effect.

Means marked with at least one common letter are not significantly different from each other under a particular factor (p<0.05). PoE = Post emergence application; RM = ready mix with a more stable range (65.47 to 100% vs. 42.54 to 100%). This highlights the role of $ZnSO_4$ with urea in improving crop vigour, which indirectly suppresses weed growth through better competition via synergy with herbicides used in experiments. In terms of grain yield, the mean yield under the combined treatment of $ZnSO_4$ with urea was higher (5.9 t/ha) compared to herbicide alone (5.7 t/ha). Moreover, the range of grain yield shifted towards higher values (4.1 to 7.5 t/ha with $ZnSO_4$ with urea, compared to 3.9 to 7.4 t/ha without $ZnSO_4$ and urea), indicating consistent yield improvements driven by better nutrient uptake and utilization facilitated by zinc. The addition of $ZnSO_4$ with urea likely supported enzymatic activities and nutrient assimilation, directly enhancing grain development. Straw yield, an indicator of biomass production, also benefitted from the combined application of $ZnSO_4$ with urea. The mean straw yield increased from 9.5 t/ha with herbicide alone to 9.9 t/ha with $ZnSO_4$ and urea with herbicides, with an extended upper range (7.0 to 12.3 t/ha vs. 7.3 to 11.3 t/ha). This suggests that $ZnSO_4$ with urea enhances root and shoot development, leading to improved overall plant growth and higher biomass accumulation.

Regression studies

Wheat grain yield showed a strong negative linear relationship with weed density and biomass, and a positive linear relationship with WCE (**Figure 6**). The regression analysis highlights the impacts of weed biomass, density, and weed control efficiency (WCE) on wheat grain yield. For weed biomass , the equation $y= -0.006x + 5.916$ (R^2=0.279) indicates that a unit increase in weed biomass leads to a proportional reduction of 0.006 times in grain yield, explaining 27.9% of the yield variation. Similarly, for weed density, the equation $y= -0.0047x+5.954$ (R^2=0.364) shows a proportional reduction of 0.0047 times in grain yield per unit increase in weed density, accounting for 36.4% of the variation. In contrast, for WCE, the equation $y=0.0148x+4.694$ (R^2=0.420) suggests that a unit increase in WCE results in a proportional increase of 0.0148 times in grain yield, explaining 42.0% of the variation. These findings emphasize the critical role of managing weeds and improving WCE to enhance wheat grain yield.

Correlation studies

The correlation analysis among various yield parameters and weed-related traits with grain yield in

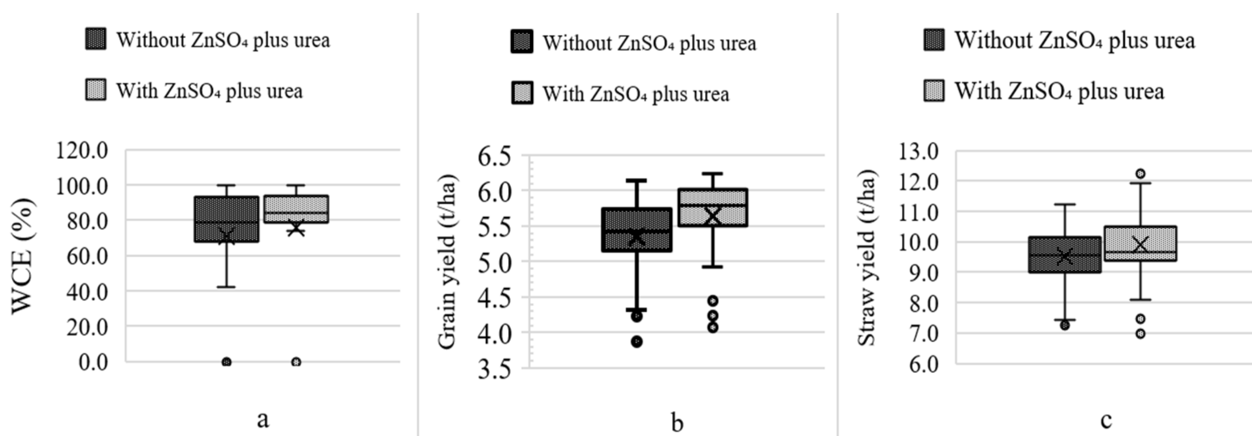

Figure 5. Effect of $ZnSO_4$ with urea on (a) Weed Control Efficiency, (b) Grain Yield, and (c) Straw Yield in Wheat (combined means of herbicides and seasons)

Table 5. Correlation of grain yield with yield parameters and weed parameters of wheat

Parameters*	Tillers/m^2	Grains per spike	1000 grain wt.	Grain yield	Harvest index	Weed density at 75 DAS	Weeds biomass at 75 DAS	WCE
Tillers/m^2	—							
Grains per spike	0.949**							
1000 grain wt.	0.987**	0.957**						
Grain yield	0.983**	0.963**	0.987**					
Harvest index	0.901**	0.873**	0.907**	0.948**				
Weed density 75 DAS	-0.972**	-0.924**	-0.964**	-0.955**	-0.883**			
Weed biomass at 75 DAS	-0.983**	-0.936**	-0.978**	-0.973**	-0.913**	0.994**		
WCE	0.977**	0.930**	0.972**	0.969**	0.913**	-0.993**	-0.999**	--

*DAS = days after seeding

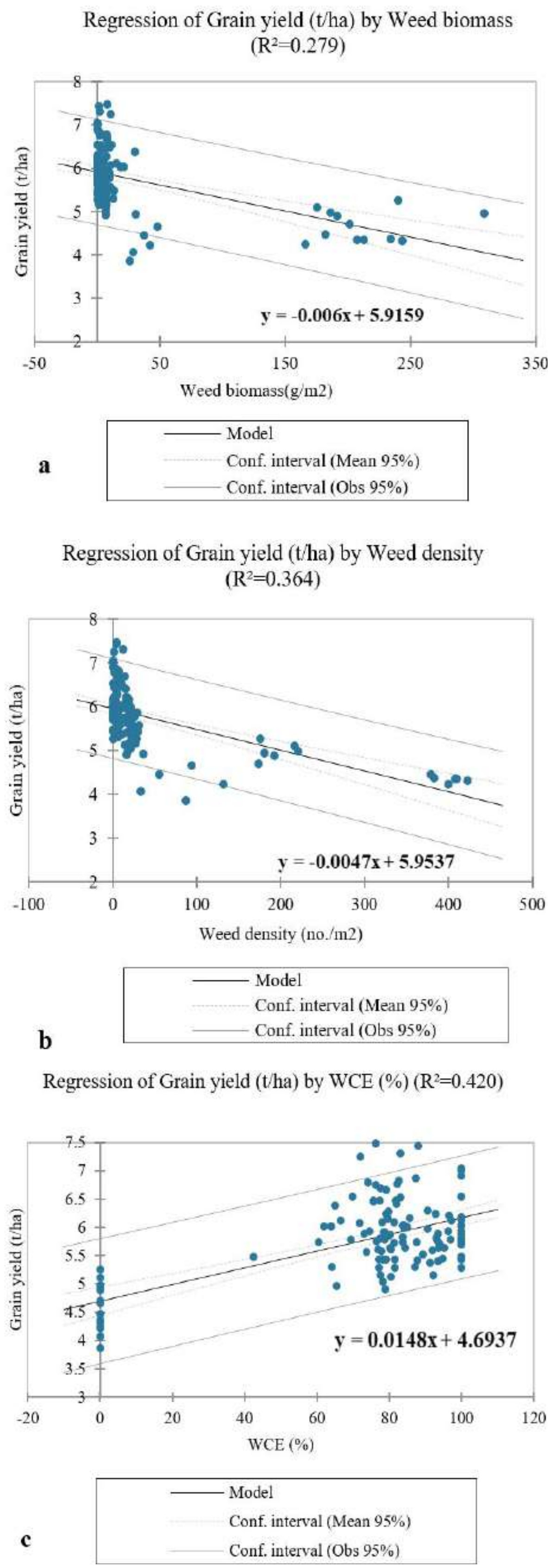

Figure 6. Relationship between wheat grain yield and weed parameters (pooled data of three seasons), (a) weed biomass, (b) weed density, (c) WCE

wheat was performed using Spearman's correlation coefficient (**Table 5**). The findings reveal critical insights into the relationships between yield determinants and weed attributes. Grain yield exhibited a highly significant and positive correlation with tillers/m² (0.983), grains per spike (0.963), and 1000-grain weight (0.987), indicating that these yield components are vital contributors to wheat productivity. These parameters enhance the plant's capacity to generate more grains and allocate resources efficiently, leading to higher yields. Similarly, harvest index showed a strong positive correlation with grain yield (0.948), reflecting its importance in determining the proportion of biological yield that is converted into economic yield.

Weed control efficiency (WCE) displayed a highly significant positive correlation with grain yield (0.969). This emphasizes that effective weed management is crucial for reducing competition between weeds and wheat, thus enhancing crop growth and productivity. On the contrary, weed density and the weeds biomass at 75 DAS showed highly significant and negative correlations with grain yield (-0.955 and -0.973, respectively). The negative correlations suggest that higher weed presence and biomass adversely impact yield attributes by competing for vital resources like nutrients, water, and light.

Conclusion

Application of $ZnSO_4$ (0.5%) with urea (2.5%) was found compatible when tank mixed with different post-emergence herbicides recommended for management for broad-leaved weeds. This combination resulted in a 4.7 % increase in wheat grain yield. Among different herbicides, metsulfuron + carfentrazone (RM) 24 g/ha recorded highest yield (6.06 t/ha) and achieved the maximum net returns (Rs. 85,907/ha) with a B: C ratio of 2.78 over three seasons. To enhance weed control efficiency, maximize yield, and improve economic returns, the co-application of zinc sulphate and urea with post-emergence herbicides is recommended. This integrated approach offers a practical and cost-effective strategy for efficient weed management in wheat cultivation.

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RESEARCH ARTICLE

Productivity of sesame as affected by herbicides and nitrogen levels and their residual effects on subsequent chickpea

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ABSTRACT

A field experiment was conducted with an objective to identify effective herbicides and optimum nitrogen level for managing weeds and enhance productivity of sesame (*Sesamum indicum* L.) and to study their residual effects on succeeding chickpea (*Cicer arietinum* L.). The study was carried at the Instructional Farm of the College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, situated in Bikaner, during the *Kharif* seasons of 2022 and 2023 and the *Rabi* seasons of 2022-23 and 2023-24. There were 20 treatments combinations, with four nitrogen levels (control, 20, 40, and 60 kg/ha) assigned to the main plots and five weed control treatments: weed-free, pre-emergence application (PE) of pendimethalin 750 g/ha, flumioxazin 75 g/ha PE, post-emergence application (PoE) of imazethapyr 50 g/ha PoE and weedy check, designated to the subplots. The highest weed biomass was observed with 60 kg N/ha. Among the herbicidal treatments, pendimethalin 750 g/ha PE, flumioxazin 75 g/ha PE, and imazethapyr 50 g/ha PoE resulted in the lowest density and biomass of grassy weeds, broad-leaved weeds, and sedges. The highest uptake of nitrogen, phosphorus, and potassium by weeds was recorded in the weedy check. The maximum sesame seed yield (770 kg/ha), net return (67,609 ₹/ha), and benefit-cost ratio of 3.28 were recorded with pendimethalin 750 g/ha PE compared to flumioxazin at 75 g/ha and imazethapyr at 50 g/ ha. No statistically significant interaction effects were observed between nitrogen levels and weed control measures during both years and in the pooled analysis. Additionally, there was no residual effect of the applied nitrogen and herbicides on the subsequent chickpea crop.

Keywords: Chickpea, Flumioxazin, Imazethapyr, Nitrogen levels, Pendimethalin, Residual effect, Sesame, Weed management

INTRODUCTION

Sesame (*Sesamum indicum* L.) is a vital oilseed crop in India, frequently referred to as the "Queen of oilseeds" because of its remarkable quality of polyunsaturated stable fatty acids. These seeds serve as a valuable source of consumable oil, comprising 48-55% of their content, but also pack a significant protein punch, with 20-28% protein enriched with vitamins like niacin and minerals such as calcium and phosphorus (Kamani *et al*. 2022). The principal protein in sesame seeds, globulin, is abundant in sulfur-containing amino acids, particularly methionine and tryptophan, which are crucial for protein biosynthesis. Often dubbed as the poor man's substitute for ghee, sesame seeds offer a substantial amount of oil, making them an affordable and nutritious option. A100 grams of sesame seeds provide approximately 592 calories of energy. One of the remarkable qualities of sesame oil is its resistance to oxidative rancidity, allowing it to be stored for extended periods due to its stability. The primary fatty acids in sesame include palmitic, stearic, oleic, and linoleic acids. Moreover, sesame oil has 17 aroma components, with acetyl pyrazine being particularly notable for imparting a strong, popcorn-like aroma. Sesame oil is predominantly used for edible purposes, accounting for approximately 73% of its total usage. It is also utilized for hydrogenation (around 8.3%) and various industrial applications (about 4.2%), including the manufacturing of insecticides, perfumed oils, paints, and pharmaceuticals. Additionally, sesame cake, a byproduct of oil extraction, serves as an excellent manure, containing significant amounts of nitrogen (6-6.2%), phosphorus (2-2.2%), and potassium (1-1.2%) (Dhaka *et al.* 2013).

Sesame is cultivated during the rainy season and its slow initial growth creates favorable conditions for weed proliferation. The sesame is highly sensitive to weed competition, especially when compared to C_4

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plants. Without effective weed management, sesame yields can be reduced by 50 to 75% (Lins *et al*. 2019). Major weeds found during sesame cultivation include: *Cynodon dactylon*, *Dactyloctenium aegyptium*, *Cyperus rotundus*, *Amaranthus spinosus*, *Eleusine indica*, *Digera arvensis*, *Physalis minima*, *Trianthema portulaca*, *Leucas aspera*, *Digitaria sanguinalis* and *Cenchrus biflorus*. Weed management poses a considerable challenge, as weeds vie with sesame plants for essential resources such as water, light, space, and nutrients, ultimately resulting in diminished yields and financial returns. Improving the use efficiency of nitrogen, phosphorus, and potassium (NPK) fertilizers can also be achieved through effective weed management practices. Hand weeding, although common, is labor-intensive, expensive, and strenuous, particularly during peak agricultural periods when labor is scarce and wages are high. Herbicides usage is viable, time-saving, easier, economical, and timely solution for weed control with greater efficacy than manual weeding, especially where labor shortages exist during crucial field operations. Herbicides allow for consistent and extended weed control, improving overall crop health and yield (Bhadauria *et al*. 2012). Hence, this experiment was undertaken with an objective to identify effective herbicides and optimum nitrogen level for managing weeds to enhance the productivity of sesame and to study herbicides residual effects on succeeding chickpea (*Cicer arietinum* L.).

MATERIALS AND METHOD

The study was conducted at the Instructional Farm of the College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, during the kharif seasons of 2022 and 2023, and the rabi seasons of 2022-23 and 2023-24. The farm is located on Sri Ganganagar Road at a latitude of 28.100° N and a longitude of 73.350° E, with an elevation of 234.7 meters above mean sea level. According to the ‘Agro-ecological Region Map’ by the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Bikaner falls under Agro-ecological Region No. 2 (M9E1) within the Hot Arid Eco-region, characterized by deep, sandy, coarse loamy desert soils with low water retention and a hot, arid climate. The annual rainfall ranges from 350 to 600 mm. Based on the NARP classification, Bikaner is categorized in Agro-climatic Zone I C (Hyper Arid Partially Irrigated Western Plain Zone) of Rajasthan, and as part of Agro-climatic Zone XIV (Western Dry Region) of India by the National Planning Commission. A split-plot design with three replications was used. There were 20 treatments combinations, with four nitrogen levels (control, 20, 40, and 60 kg/ha) assigned to the main plots and five weed control treatments: weed-free; pre-emergence application (PE) of pendimethalin at 750 g/ha; flumioxazin at 75 g/ha PE; post-emergence application (PoE) of imazethapyr 50 g/ha PoE and weedy check, designated to the subplots. The sesame variety RT-351 was planted at a row and plant spacing of 30 x 10 cm, utilizing a seed rate of 2.5 kg/ha. Following the sesame harvest, chickpea was seeded as a test crop during the rabi seasons to evaluate the residual effects of the treatments applied to sesame. Chickpea (GNG-1581) was sown at a row spacing of 30 x 10 cm, with a seed rate of 60 kg/ha.

The herbicides were applied using a knapsack sprayer with 500 liters of water per hectare. Weed density and weed dry weight (biomass) were recorded at 30, 60 days after seeding (DAS) by placing a quadrat of 0.5 m^2 randomly placed at two spots in each plot. Data on weed density and biomass were subjected to square root transformation before statistical analysis. Weed control efficiency (WCE) was estimated by using the formula: biomass of weeds in control plot- weeds biomass in treated plot/ weeds biomass in control plot. The effectiveness of weed control was assessed based on weed biomass and the sesame yield measured in kilograms per plot was adjusted to a moisture content of 12-14%. Subsequently, the weight was converted to kg/ha. The weed index was determined by comparing the grain yield from treatment plots with that from control plots. The uptake of nitrogen, phosphorus and potassium by weed at harvest was computed using the formula: Nutrient content in weed (%) x dry weight of weed (kg/ha) /100. To compute the net returns for each treatment, the total cultivation costs were deducted from the gross returns. Mean analysis was conducted employing Fisher’s method of analysis of variance, as outlined by Gomez and Gomez (1984). The identification of mean differences was performed through Duncan’s univariate test at a significance level of p 0.05.

RESULTS AND DISCUSSION

The nitrogen levels did not significantly affect the density of grassy, broad-leaved, or sedge weeds at 30, 60 DAS, or at harvest (**Table 1**) confirming the findings of Fazil *et al.* (2022). However, increasing nitrogen levels led to a significant rise in weed biomass. The highest biomass of grassy, broad-leaved, and sedge weeds was recorded with nitrogen 40 kg/ha, which was statistically comparable to the

60 kg N/ha. This increase in weed biomass can be attributed to the greater availability of nitrogen, which created a more favorable nutritional environment for weed growth as reported by Kumar *et al.* (2020). The total weeds biomass throughout the sesame growth period was significantly affected by nitrogen levels, with the highest weed biomass observed with 40 kg/ha N which was significantly higher than weedy check and 20 kg/ha N, but statistically similar with 60 kg/ha N. The nitrogen content and uptake by weeds increased with higher nitrogen levels as observed by Upasani *et al.* (2013). However, phosphorus and potassium content did not change significantly but their uptake did increase with nitrogen levels. Ihsanullah *et al.* (2023) also reported significant sesame seed yield improvement with increasing nitrogen levels, with the highest seed yield recorded at 40 kg N/ha, comparable to the yield at 60 N kg /ha.

All weed control treatments significantly reduced weed density and biomass at all stages of crop growth, minimizing nutrient depletion by weeds at harvest, compared to the heavily weed infested weedy check (**Tables 1** to **4**). The observed increase in both weed density and biomass in the weedy check was due to the continuous unchecked weed growth throughout the crop season and usage of available resources (Kakabouki *et al.* 2022). In plots treated with herbicides, weed density and biomass increased at successive stages due to the regeneration of existing weeds and the emergence of new seedlings later in the crop cycle as observed earlier by Dubey *et al.* (2010). Flumioxazin 75 g/ha PoE recorded the lowest weed density and the highest reduction in biomass of broad-leaved weeds at all growth stages. Flumioxazin was effective in controlling most of the weed species including grassy, broad-leaved, and sedges. Weed control treatments significantly reduced weed density and biomass at 30 and 60 DAS, and at harvest. Imazethapyr 50 g/ha was more effective than pendimethalin at 750 g /ha PE in managing weeds confirming the findings of Das (2015). The effectiveness of imazethapyr at 50 g/ha PoE in controlling weeds was due to its inhibition of acetolactate synthase (ALS), an enzyme necessary for the synthesis of the branched-chain amino acids valine, leucine, and isoleucine, which are essential for protein synthesis and plant growth. ALS inhibitors block cell division and reduce carbohydrate translocation in susceptible plants. Imazethapyr is absorbed through both roots and shoots, leading to a rapid decrease in weed populations. The post-emergence application of imazethapyr was the most effective strategy for managing broad-leaved, narrow-leaved, and overall weed growth. Symptoms such as plant stunting, chlorosis, and tissue necrosis appeared within 1 to 4 weeks after herbicide application.

The significant reduction in weed density and biomass at harvest, particularly with pendimethalin at 750 g/ha PE, may be due to prevented weed seed

Table 1. Effect of nitrogen levels and weed management treatments on weed density (no./m^2) in sesame

Treatment	Grassy weeds			Sedges			Broad-leaved weeds		
	At 30 DAS	At 60 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest
Nitrogen levels									
Control	*1.27 (**1.70)	2.28 (6.11)	1.94 (4.08)	1.69 (4.09)	1.88 (5.38)	1.72 (4.44)	2.10 (6.73)	2.45 (8.48)	2.28 (7.62)
20 kg/ha	1.39 (2.06)	2.42 (6.89)	2.04 (4.57)	1.76 (4.40)	2.01 (5.80)	1.82 (4.83)	2.23 (7.42)	2.70 (10.04)	2.41 (8.25)
40 kg/ha	1.51 (2.57)	2.58 (7.73)	2.19 (5.29)	1.89 (4.96)	2.19 (6.55)	2.05 (5.83)	2.31 (7.92)	2.83 (10.76)	2.53 (8.77)
60 kg/ha	1.60 (3.07)	2.70 (8.55)	2.26 (5.68)	1.97 (5.25)	2.33 (7.36)	2.16 (6.39)	2.35 (8.15)	2.96 (11.54)	2.61 (9.23)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed management treatment									
Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Pendimethalin 750 g/ha PE	0.71 (0.00)	2.22 (4.58)	1.93 (3.27)	1.38 (1.43)	1.59 (2.12)	1.47 (1.75)	2.66 (6.71)	2.94 (8.26)	2.90 (8.01)
Flumioxazin 75 g/ha PE	1.84 (3.03)	2.67 (6.79)	2.27 (4.75)	1.44 (1.65)	1.74 (2.62)	1.56 (2.03)	1.07 (0.65)	2.02 (3.79)	1.51 (1.93)
Imazethapyr 50 g/ha PoE at 25 DAS	1.20 (1.06)	2.39 (5.38)	2.10 (4.05)	1.25 (1.12)	1.57 (2.07)	1.30 (1.34)	1.43 (1.66)	2.06 (3.89)	1.71 (2.48)
Weedy check	2.77 (7.67)	4.50 (19.92)	3.52 (12.44)	4.35 (19.17)	4.92 (24.54)	4.63 (21.73)	5.37 (28.75)	5.93 (35.08)	5.48 (30.00)
LSD (p=0.05)	0.24	0.20	0.23	0.27	0.29	0.28	0.23	0.23	0.24

*Transformed to $\sqrt{x+0.5}$, ** Original values; PE = pre-emergence application; PoE = post-emergence application; DAS =days after seeding germination and controlled the growth of those already germinated (Sujithra *et al*. 2020). Pendimethalin was reported to control both grassy and small-seeded dicot weed species (Singh *et al*. 2018). It forms a thin layer on the soil surface, inhibiting weed seed germination. The pre-emergence application of pendimethalin disrupts microtubule formation in susceptible weed cells, essential for cell division, which reduces cell division, restricts weed emergence, and ultimately leads to weed death due to

Table 2. Effect of nitrogen levels and weed management treatments on weed biomass (g/m²) in sesame

Treatment	Grassy weeds			Sedges			Broad-leaved weeds		
	At 30 DAS	At 60 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest	At 30 DAS	At 60 DAS	At harvest
Nitrogen levels									
Control	*0.98 (**0.60)	3.22 (13.06)	2.58 (8.14)	1.47 (2.94)	2.72 (12.45)	2.39 (11.49)	1.70 (4.17)	4.87 (37.87)	4.85 (39.67)
20 kg/ha	1.17 (1.14)	3.38 (14.43)	3.09 (11.49)	1.70 (4.01)	2.91 (13.18)	2.79 (13.88)	2.07 (5.81)	5.35 (43.84)	5.18 (43.12)
40 kg/ha	1.27 (1.46)	3.69 (16.74)	3.48 (14.30)	1.81 (4.47)	3.18 (14.59)	3.55 (18.51)	2.16 (6.36)	5.71 (47.70)	5.67 (48.02)
60 kg/ha	1.30 (1.50)	3.86 (18.47)	3.78 (16.99)	1.89 (4.85)	3.42 (16.97)	3.80 (20.85)	2.21 (6.75)	5.99 (51.58)	6.03 (52.71)
LSD (p=0.05)	0.134	0.26	0.14	0.151	0.22	0.28	0.202	0.40	0.25
Weed management treatment									
Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Pendimethalin 750 g/ha PE	0.71 (0.00)	3.12 (9.52)	2.99 (8.67)	1.13 (0.85)	2.22 (4.67)	2.21 (5.04)	2.42 (5.66)	6.08 (36.94)	6.60 (43.69)
Flumioxazin 75 g/ha PE	1.39 (1.54)	3.88 (14.83)	3.64 (13.25)	1.31 (1.28)	2.54 (6.20)	2.62 (7.27)	1.05 (0.66)	4.05 (16.87)	3.45 (12.96)
Imazethapyr 50 g/ha PoE at 25 DAS	1.09 (0.75)	3.46 (11.83)	3.26 (10.93)	1.28 (1.18)	2.27 (4.92)	2.18 (5.28)	1.37 (1.48)	4.09 (17.00)	3.77 (14.18)
Weedy check	2.00 (3.60)	6.53 (42.21)	5.57 (30.79)	4.16 (17.02)	7.45 (55.18)	7.95 (63.32)	4.62 (21.07)	12.48 (155.43)	12.60 (158.58)
LSD (p=0.05)	0.113	0.22	0.17	0.13	0.26	0.28	0.181	0.34	0.31

*Transformed to $\sqrt{x+0.5}$, ** Original values; PE = pre-emergence application; PoE = post-emergence application; DAS =days after seeding

Table 3. Effect of weed management treatments on weed index and weed control efficiency (%) in sesame

Treatment	Weed index (%)			Weed control efficiency (%)		
	2022	2023	Pooled	2022	2023	Pooled
Weed free	0.00	0.00	0.00	100.00	100.00	100.00
Pendimethalin 750 g/ha PE	5.01	5.35	5.18	81.79	77.44	79.69
Flumioxazin 75 g/ha PE	96.89	97.14	97.01	86.39	85.13	85.78
Imazethapyr 50 g/ha PoE at 25 DAS	38.28	38.04	38.16	90.46	86.43	88.50
Weedy check	40.71	40.19	40.45	0.00	0.00	0.00

*PE = pre-emergence application; PoE = post-emergence application; DAS =days after seeding

Table 4. Effect of nitrogen levels and weed management treatments on nutrient content and uptake by weeds in sesame

Treatment	Nutrient content (%)			Nutrient uptake (kg/ha)		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
Nitrogen levels						
Control	0.83	0.258	0.538	6.59	2.14	4.35
20 kg/ha	1.01	0.272	0.564	9.00	2.60	5.09
40 kg/ha	1.16	0.284	0.582	12.24	3.19	6.18
60 kg/ha	1.17	0.291	0.595	13.83	3.61	7.13
LSD (p=0.05)	0.08	NS	NS	1.57	0.34	0.89
Weed management treatment						
Weed free	0.00	0.000	0.000	0.00	0.00	0.00
Pendimethalin 750 g/ha PE	1.29	0.348	0.677	7.84	2.08	4.01
Flumioxazin 75 g/ha PE	1.27	0.306	0.681	4.70	1.07	2.47
Imazethapyr 50 g/ha PoE at 25 DAS	1.26	0.320	0.707	3.88	0.95	2.08
Weedy check	1.39	0.407	0.784	35.65	10.33	19.88
LSD (p=0.05)	0.07	0.026	0.049	1.66	0.37	0.92

*PE = pre-emergence application; PoE = post-emergence application; DAS =days after seeding

Table 5. Effect of nitrogen levels and weed management treatments on sesame seed yield, net return, and B:C ratio of sesame

Treatment	Sesame seed yield (kg /ha)			Net return (₹/ha)			B:C ratio		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Nitrogen levels									
Control	350	355	353	12968	13902	13435	1.40	1.42	1.41
20 kg/ha	498	504	501	30494	32073	31283	1.94	1.97	1.96
40 kg/ha	590	597	594	41604	43463	42533	2.27	2.30	2.29
60 kg/ha	621	629	625	45224	47307	46265	2.37	2.40	2.39
LSD (p=0.05)	60	56	37	7462	7105	4587	0.20	0.22	0.13
Weed management treatment									
Weed free	807	817	812	55995	58926	57461	2.25	2.30	2.27
Pendimethalin 750 g/ha PE	766	773	770	66416	68802	67609	3.27	3.29	3.28
Flumioxazin 75 g/ha PE	25	23	24	-25535	-26469	-26002	0.11	0.10	0.10
Imazethapyr 50 g/ha PoE at 25 DAS	498	506	502	33126	34863	33994	2.14	2.17	2.15
Weedy check	478	488	483	32859	34808	33833	2.22	2.25	2.24
LSD (p=0.05)	44	45	31	5472	5631	3850	0.18	0.19	0.13

*PE = pre-emergence application; PoE = post-emergence application; DAS =days after seeding

insufficient food reserves, thus lowering weed biomass (Joshi *et al*. 2022). This timely intervention resulted in a significant reduction in weed biomass, maintaining a weed-free environment and minimizing competition (Manasa *et al*. 2022).

The least sesame yield loss due to weeds was recorded with pendimethalin at 750 g/ha PE, followed by flumioxazin at 75 g/ha PE and imazethapyr at 50 g/ha PoE at 25 DAS during both years. The weed index reflects the yield loss due to weeds under a given treatment compared to a weed-free plot. The highest yield loss, as indicated by the weed index, occurred in the weedy check due to severe weed infestation. In contrast, post-emergence herbicide treatments resulted in lesser yield compared to those applied pre-emergence, as the latter effectively controls weeds at an early stage, fostering a favorable environment for optimal crop establishment and growth as reported by (Yadav *et al*. 2018).

Nutrient concentrations and their depletion by weeds were significantly affected by the various weed control treatments applied. The weedy check recorded significantly higher uptake of nitrogen, phosphorus, and potassium compared to pendimethalin 750 g/ha PE, flumioxazin 75 g/ha PE, and imazethapyr 50 g/ha PoE at 25 days after sowing (DAS), as observed during both years and in pooled data. This can be attributed to the effectiveness of the herbicides in controlling weeds, allowing the crops to absorb more nutrients compared to the unchecked growth of weeds. Similar observations were reported by (Choudhary *et al*. 2017). In the weedy check plot, where weeds grew freely throughout the crop cycle and recorded maximum nutrient uptake by weeds (35.65 kg N, 10.33 kg P, and 19.18 kg K/ha), which was significantly higher than in other weed management treatments. On the contrary, the lowest nutrient uptake by weeds (3.88 kg N, 0.95 kg P, and 2.08 kg K/ha) was recorded with imazethapyr 50 g/ha PoE. Both imazethapyr 50 g/ha PoE and flumioxazin 75 g/ha PE proved equally effective in minimizing nitrogen, phosphorus, and potassium depletion by weeds, showing statistical parity with each other, while differing significantly from pendimethalin at 750 g/ha PE and the weedy check. The reduction in nutrient depletion by weeds under these treatments can be attributed to the corresponding decrease in weed biomass, due to effective weed control, and the competitive suppression exerted by the crop on weed growth. Similar findings were reported by Kumbar *et al*. (2014). The higher weed biomass in the weedy check plot is likely the primary cause of increased nutrient depletion by weeds as observed by Bhatia *et al*. (2012).

The improved yield with pendimethalin 750 g/ha PE can be attributed to recorded lower weed density and biomass and reduction in competition which ultimately promoted better crop growth and yield (Patel *et al*. 2023). Pendimethalin offers a distinct advantage due to its prolonged persistence in the soil compared to other pre-emergence herbicides. This extended duration of action provides sustained protection against weed competition, which positively affects growth, yield attributes, and overall yields.

Significantly maximum net returns and B:C ratio were observed with 40 kg/ha N (42533 ₹/ha and 2.29) over control and 20 kg/ha N, and this treatment was on par with 60 kg/ ha in this regard, on pooled mean basis (**Table 5**). The result is in conformity with findings of Kumar *et al*. (2009) and Sharongmangyang and Nongmaithem (2019). Pendimethalin 750 g/ha recorded highest net return (67,609 ₹/ha) and B:C ratio (3.28) than all other herbicidal treatments. The pendimethalin 750 g/ha increase additionally ₹/ha by 33776, 33615 and 10148 over weedy check, imazethapyr at 50 g/ha and weed free, respectively, on pooled data analysis. This might be due to low cost of pendimethalin coupled with good economic yield Weed free gave maximum gross return but has higher labor cost for weed management (Patel *et al*. 2023).

It may be concluded that the effective weed management and maximum sesame seed yield can be obtained with pendimethalin 750 g/ha PE, without any residual effect on the subsequent chickpea crop.

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RESEARCH ARTICLE

Comparative efficacy of herbicide-mixtures for efficient weed management and productivity enhancement of *pre-Kharif* greengram

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ABSTRACT

Early slow growing behaviour of short-duration greengram (*Vigna radiata* L. Wilczek) makes it a poor competitor against weeds and failure to take up timely weed control measures may lead to severe yield losses. Hence, the present study was taken up during the *pre-Kharif* seasons of 2022 and 2023 at Kalyani, West Bengal with an objective to assess different herbicide-mixes for their weed managing efficiency in greengram and improving productivity and profitability. Propaquizafop (2.5%) + imazethapyr (3.75%) w/w ME (propaquizafop + imazethapyr) 125 g/ha and quizalofop-ethyl (5% EC) + imazethapyr (10% SL) (quizalofop-ethyl + imazethapyr) 50+75g/ha at 15 days after sowing (DAS) were most effective against grasses. Clodinafop-propargyl (8%) + sodium-acifluorfen (16.5%) EC (clodinafop-propargyl + sodium-acifluorfen), irrespective of doses, significantly reduced growth of broad-leaved weeds. Imazamox (35%) + imazethapyr (35%) WG (imazamox + imazethapyr) 60 g/ha was most effective in controlling sedges. Clodinafop-propargyl + acifluorfen-sodium 245 g/ha, propaquizafop +imazethapyr 125 g/ha and quizalofop-ethyl+ imazethapyr (50+75 g/ha) showed similar efficacy in reducing overall weed growth recording higher weed control efficiency. Weed management with these treatments significantly increased greengram growth traits, greengram productivity and benefit cost ratio. The principal component analysis confirmed the superiority of those treatments. The identified effective herbicide-mixtures usage would help in successful inclusion of greengram in rice-wheat systems.

Keywords: Clodinafop-propargyl + acifluorfen-sodium, Imazamox + imazethapyr, Greengram, Propaquizafop + imazethapyr, Quizalofop-ethyl + imazethapyr, Weed management

INTRODUCTION

Greengram [*Vigna radiata* (L.) Wilczek] ranks third among the prominent pulse crops in India after chickpea and pigeon pea. Every 100 g of nutrient-dense greengram seeds is enriched with 23.9 g of protein, 16.3 g of total dietary fibre, 3.32 g of ash, and 62.6 g of carbohydrate (USDA 2019). Additionally, the highly nutritive biomass of greengram makes it preferred choice for livestock feed. They are also widely grown as green manure or cover crop. Greengram can add significant nitrogen in soil by fixing 58-109 kg N/ha through symbiotic association with *Rhizobium* (Mehandi *et al.* 2019). The enhancement of soil nutrient status in pulse-based systems, along with the partial transfer of these advantages to the following crop, contributes to a reduced dependence on chemical fertilisers and assists in reducing greenhouse gas emissions. Pulses are also considered excellent crops for carbon sequestration than cereals because of their higher root biomass. Borase *et al.* (2020) found that including greengram in rice-wheat system increased soil organic carbon and microbial biomass carbon by 17% and 27%, resulting in improved soil enzyme activity. Addition of carbon-rich residues and substrates to soil facilitates diversified microbial proliferation in a pulse-based system. Therefore, inclusion of greengram into high input intensive cereal-based systems is a potential approach to establish a sustainable agro-food system.

One of the primary challenges faced by greengram farmers is weed infestation, with the extent of yield losses primarily being influenced by the composition and severity of the infesting weed flora. The critical crop weed competition period in greengram spans from 20 to 30 days after seeding (DAS). The early slow growing behaviour also makes it a poor competitor against weeds and failure to take up timely weed control measures may lead to high yield losses, occasionally reaching 90% (Azam *et al.* 2018). In India, hand weeding has been the traditional weed control measure but with summer temperatures rising to 50°C, it is becoming impossible to manually weed summer crops. The use of selective eco-safe

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herbicide-mixes can be a viable alternative for effectively managing weeds, limiting the spread or appearance of new weed species, and combat herbicide resistance. Few emerging novel post-emergence herbicides such as clodinafop-propargyl + acifluorfen-sodium, imazethapyr + imazamox, propaquizafop + imazethapyr and quizalofop-ethyl + imazethapyr were reported to effectively control weeds with a weed control efficiency of more than 87-95% in soybean and groundnut (Lakshmidevi *et al.* 2022, Sandil *et al.* 2015, Tripathi and Singh 2022). However, information on bio-efficacy of these herbicides in greengram is relatively scanty. Hence, the present experiment was taken up to identify suitable effective and economical broad-spectrum herbicide-mix to manage weeds in greengram and improve greengram productivity economically.

MATERIALS AND METHOD

The field experiment took place at District Seed Farm (AB Block), Kalyani, under Bidhan Chandra Krishi Viswavidyalaya, West Bengal, during the pre-*Kharif* season of 2022 and 2023. The farm is located at approximately $22^0$93'N latitude and $88^0$53'E longitude, with an average elevation of 9.75 m above mean sea level (MSL). The soil had a clay loam texture and a pH of 7.2. The recorded amounts of nitrogen (N), phosphorus (P), and potassium (K) were 250.5 kg/ha, 33.8 kg/ha, and 178.0 kg/ha, respectively. The current study utilised a randomised complete block design. Nine different weed management treatments were evaluated in summer greengram (cv 'IPM 205-7') which include: pre-emergence application (PE) of imazethapyr 10% SL (imazethapyr) 75 g/ha; post-emergence application (PoE) of imazethapyr 75 g/ha; clodinafop-propargyl (8%) + sodium-acifluorfen (16.5%) EC (clodinafop-propargyl + sodium-acifluorfen) 183.5 g/ha PoE; clodinafop-propargyl (8%) + sodium-acifluorfen (16.5%) EC (clodinafop-propargyl + sodium-acifluorfen) 245 g/ha PoE; propaquizafop (2.5%) + imazethapyr (3.75%) w/w ME (propaquizafop + imazethapyr) 125 g/ha PoE; quizalofop-ethyl (5% EC) + imazethapyr (10% SL) (quizalofop-ethyl + imazethapyr) 50+75g/ha PoE; imazamox (35%) + imazethapyr (35%) WG (imazamox + imazethapyr) 60 g/ha PoE ; hand weeding twice; unweeded check. Imazethapyr 75 g/ha (pre) was applied within 24 h of sowing, whereas the rest of the treatments having herbicide sprays were applied at 15 DAS. Two hand weedings were taken up on 20 and 35 days after seeding (DAS). All herbicide-mixes were ready-mixes, except quizalofop-ethyl + imazethapyr, which was a tank-mix. All the treatments were replicated thrice. The recommended seed rate of 25 kg/ha, with a plant spacing of 10 cm and a row spacing of 30 cm was adopted. Nitrogen (N), phosphorus (P) and potassium (K) were added at sowing time at the rate of 20, 40, and 40 kg/ha, respectively. A knapsack sprayer with a capacity of 16 litres and flat fan nozzles was used to apply herbicide. The spray volume employed was 500 litres/hectare. Thinning was done at 15 DAS to ensure even crop stand. Data on various growth parameters of weeds and crops were collected at 30, 45, and 60 DAS. Weed control efficiency (WCE), weed control index (WCI) and weed index (WI) were calculated according to Singh *et al*. (2018). Additionally, yield and yield related characters were recorded during harvest. Crude protein was estimated by multiplying seed nitrogen concentration (Jackson 1973) with 6.25. The benefit-cost ratio (B:C) was calculated by dividing the gross income by the cost of cultivation. The statistical analysis was done on the pertinent experimental data using analysis of variance (ANOVA) for randomised complete block design (RCBD). An ANOVA was conducted specifically for the weed density and dry matter (biomass) data, following a square root transformation ($\sqrt{x+0.5}$). The ANOVA of the experimental data showed no statistically significant change (p=0.05) among the years, treatments, and interactions between years and treatments. Hence, the study presents the mean data from two consecutive years. The treatment means were compared at p=0.05 using the Least Significant Difference (LSD) method. SPSS version 25 software was utilised to calculate the necessary regression models. The principal component analysis was done using the PCA function of FactoMineR package in R software version 4.4.0.

RESULTS AND DISCUSSION

Weeds response

The most prominent grassy weeds during the experimental period were *Cynodon dactylon, Setaria glauca*, *Leptochloa chinensis*, *Eleusine indica*, *Imperata cylindrica*, and *Digitaria sanguinalis*. The broad-leaved weeds included *Phyllanthus niruri*, *Euphorbia hirta*, *Parthenium hysterophorus* and *Digera muricata*. The only sedge weed was *Cyperus rotundus*. Throughout the experimental period, grassy weeds ranked first in dominance followed by broad-leaved weeds and sedges (**Table 1**). The experimental crop was included in a rice-based system in a lowland situation, which likely led to a prevalence of grassy weeds. According to Walia and Singh (2006), grassy weeds dominated the widely practiced intensive cereal-based systems in India.

Hand weeding twice had significantly lowest density of grasses, broad-leaved and sedges (**Table 1**). Out of the various tested herbicides, propaquizafop + imazethapyr 125 g/ha PoE and quizalofop-ethyl + imazethapyr 50+75g/ha PoE were most efficient in suppressing grassy weeds. They reduced grass weed density by 84.2-85.5% and 82.3-84.7% compared to weedy check on 25 and 45 DAS, respectively. Clodinafop-propargyl + sodium-acifluorfen at 245 g/ha significantly lowered (79.6–84.5% compared to weedy check) broad-leaved weed density among the evaluated herbicides. No significant difference occurred in broad-leaved density between lower dose (183.5 g/ha) and higher dose (245 g/ha) of clodinafop-propargyl + sodium-acifluorfen on 25 DAS. However, on 45 DAS, application of higher dosage resulted in a significant decline in broad-leaved weed density by 22.2% as compared to its lower dose. Imazamox + imazethapyr at 60 g/ha, caused most significant reduction in sedge population compared to all other herbicide treatments. This ready-mix registered 50.0-54.7% lower sedge density than weedy check. Also, all the treatments comprising imazethapyr were statistically comparable in their ability to control sedge density.

Hand weeding twice had the lowest weed biomass of all weed types. Among the tested herbicides, propaquizafop + imazethapyr recorded the lowest grass biomass on 25 DAS, which was closely followed by quizalofop-ethyl + imazethapyr 50+75g/ha PoE and clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE (**Table 2**) which reduced grassy weed biomass by 83.2-85.4%, as compared to weedy check. Almost a similar trend was noted on 45 DAS as well. Clodinafop-propargyl + sodium-acifluorfen at 245 g/ha recorded the highest efficacy against broad-leaved weeds, as evident from their significantly lower biomass. Increasing the dosage of clodinafop-propargyl + sodium-acifluorfen from 183.5 g/ha to 245 g/ha reduced the broad-leaved weeds biomass by 22.9-33.9%. Herbicides containing imidazolinone significantly reduced sedge biomass on 25 DAS, with no significant difference between them. However, on 45 DAS, imazamox-imazethapyr was most effective in suppressing sedge biomass.

Hand weeding twice registered the highest weed control efficiency (WCE) and weed control index (WCI) of 95.1-95.2 and 97.1-97.4% during the crop growing period (**Table 1** and **2**). Among the various tested herbicides, propaquizafop + imazethapyr and quizalofop-ethyl + imazethapyr had considerably higher WCE of 77.0-77.6% on 25 DAS and 71.7-73.5% on 45 DAS. The next best was clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE, which also consistently recorded a comparatively higher WCE of 70.5-74.1% during the crop life cycle. Following almost a similar trend, WCI in these three herbicide-mixes ranged from 79.2-80.1% and 75.2-78.1% on 25 and 45 DAS, respectively. They also recorded substantially lower weed index (WI) of 10.1-14.1%. Herbicides having higher WCI and WCE but lower WI exhibit greater efficiency in limiting weed growth.

Table 1. Weed density (no./m^2) under different weed control treatments in greengram (mean of two years)

Treatment	30 DAS				45 DAS				WCE (%)	
	Grasses	Broad-leaved	Sedges	Total	Grasses	Broad-leaved	Sedges	Total	25 DAS	45 DAS
Imazethapyr 75 g/ha PE	5.89 (34.2)	4.34 (18.4)	2.77 (7.2)	7.76 (59.8)	6.64 (43.6)	5.54 (30.2)	3.75 (13.6)	9.37 (87.4)	65.8	60.3
Imazethapyr 75 g/ha PoE	5.64 (31.4)	4.16 (16.8)	2.91 (8.0)	7.53 (56.2)	6.92 (47.4)	5.48 (29.6)	3.80 (14.0)	9.56 (91.0)	67.8	58.6
Clodinafop-propargyl + sodium-acifluorfen 183.5 g/ha	5.09 (25.4)	3.56 (12.2)	3.56 (12.2)	7.09 (49.8)	6.09 (36.6)	4.70 (21.6)	4.18 (17.0)	8.70 (75.2)	71.5	65.8
Clodinafop-propargyl + sodium-acifluorfen 245 g/ha	4.66 (21.2)	3.30 (10.4)	3.75 (13.6)	6.76 (45.2)	5.59 (30.8)	4.16 (16.8)	4.20 (17.2)	8.08 (64.8)	74.1	70.5
Propaquizafop + imazethapyr 125 g/ha	3.78 (13.8)	4.18 (17.0)	2.98 (8.4)	6.30 (39.2)	4.64 (21.0)	5.37 (28.4)	3.64 (12.8)	7.92 (62.2)	77.6	71.7
Quizalofop-ethyl + imazethapyr (50+75g/ha)	3.94 (15.0)	4.25 (17.6)	2.84 (7.6)	6.38 (40.2)	4.32 (18.2)	5.24 (27.0)	3.67 (13.0)	7.66 (58.2)	77.0	73.5
Imazamox + imazethapyr 60 g/ha	5.30 (27.6)	3.79 (13.8)	2.51 (5.8)	6.91 (47.3)	6.27 (38.8)	4.97 (24.2)	3.15 (9.4)	8.53 (72.4)	73.0	67.1
Hand weeding twice	2.21 (4.4)	1.87 (3.0)	1.22 (1.0)	2.98 (8.4)	2.39 (5.2)	2.02 (3.6)	1.58 (2.0)	3.36 (10.8)	95.2	95.1
Unweeded check	9.77 (95.0)	8.21 (67.0)	3.64 (12.8)	13.24 (174.8)	10.92 (118.8)	9.10 (82.4)	4.39 (18.8)	14.85 (220.0)	-	-
LSD (p=0.05)	0.3	0.27	0.23	0.46	0.36	0.36	0.27	0.56		

*Data square root transformed. Values in parentheses indicate the original weed count; WCE: Weed control efficiency; PE = pre-emergence application; PoE = post-emergence application; DAS = days after seeding

In the current study, herbicide mix comprising imazethapyr and propaquizafop /quizalofop-ethyl were found to effectively check grassy weed population and density. The ready-mix clodinafop-propargyl + acifluorfen-sodium also demonstrated significant efficacy against grasses. The "fops" herbicides present in these herbicide-mixes, *viz.* propaquizafop, quizalofop-ethyl, and clodinafop-propargyl, are aryloxy-phenoxypropionate herbicides. They are commonly employed for broad-spectrum management of a variety of annual and perennial grassy weeds. These herbicides specifically inhibit the functioning of the eukaryotic-type Acetyl-CoA-carboxylase enzyme in the chloroplasts of susceptible grasses (Takano *et al.* 2020). The ready-mix clodinafop-propargyl + acifluorfen-sodium at a higher dose showed maximum efficacy against broad-leaved weeds. The constituent acifluorfen-sodium of this ready-mix is a diphenyl-ether herbicide, which is reported to restrict the proliferation of broad-leaved weeds (Tang *et al.* 2020). It obstructs the function of protoporphyrinogen oxidase in susceptible plants, ultimately resulting in cell membrane rupture (Lewis *et al.* 2016). The ready-mix imazamox + imazethapyr effectively suppressed sedges. Plots treated with imazethapyr also showed a significant decline in sedge growth compared to the weedy check. Both imazethapyr and imazamox are classified as imidazolinone herbicides and are reported to control wide spectrum of weeds, especially grasses and broad-leaved weeds. They control weed growth by hindering the function of acetohydroxy acid synthase, which is a critical enzyme for production of branched-chain amino acids (Auria *et al.* 2022). However, it has been documented that both imazethapyr (Grichar 2002) and imazamox (USDA 2010) effectively manage sedges, as observed in this study. Since grasses were the pre-dominant weed type in the current experiment followed by broad-leaved weeds, herbicide-mixes targeted to control both these plant types were observed to be superior in managing overall weed growth.

Greengram response

Hand weeding twice recorded the tallest crop with highest leaf area index (LAI) throughout the crop growing period. The greengram plant height, and LAI with propaquizafop + imazethapyr and quizalofop-ethyl + imazethapyr were considerably higher than other herbicide treatments and no significant difference was found between them. However, they were statistically at par with clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE in terms of crop height on 50 DAS (**Table 3**). These two treatments recorded higher LAI values on the other two dates of observation as well, but were statistically at par with clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE and imazamox + imazethapyr on 30 DAS and clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE on 50 DAS.

Among the tested weed management interventions, hand weeding twice significantly augmented dry matter accumulation on 30 and 40 DAS (**Table 3**). On 50 DAS also, hand weeding twice recorded the highest biomass accumulation (327.2 g/m^2), but it was statistically equivalent with

Table 2. Weed biomass (g/m^2) under different weed control treatments in greengram (mean of two years)

Treatment	30 DAS				45 DAS				WCI (%)	
	Grasses	Broad-leaved	Sedges	Total	Grasses	Broad-leaved	Sedges	Total	25 DAS	45 DAS
Imazethapyr 75 g/ha PE	5.85 (33.8)	3.83 (14.2)	2.50 (5.8)	7.36 (53.7)	6.30 (39.2)	4.99 (24.5)	3.41 (11.2)	8.68 (74.9)	69.1	65.3
Imazethapyr 75 g/ha PoE	5.99 (35.4)	3.69 (13.1)	2.67 (6.6)	7.46 (55.1)	6.60 (43.1)	4.81 (22.7)	3.48 (11.6)	8.82 (77.5)	68.3	64.0
Clodinafop-propargyl + sodium-acifluorfen 183.5 g/ha	4.91 (23.6)	3.42 (11.2)	3.46 (11.5)	6.84 (46.3)	5.70 (32.0)	4.14 (16.6)	4.10 (16.3)	8.09 (65.0)	73.4	69.8
Clodinafop-propargyl + sodium-acifluorfen 245 g/ha	4.10 (16.3)	2.81 (7.4)	3.52 (11.9)	6.01 (35.6)	4.92 (23.7)	3.65 (12.8)	4.17 (16.9)	7.34 (53.4)	79.5	75.2
Propaquizafop + imazethapyr 125 g/ha	3.83 (14.2)	3.75 (13.6)	2.68 (6.7)	5.91 (34.5)	4.08 (16.2)	4.88 (23.3)	3.30 (10.4)	7.09 (49.9)	80.1	76.9
Quizalofop-ethyl + imazethapyr (50+75g/ha)	4.00 (15.5)	3.87 (14.5)	2.59 (6.2)	6.06 (36.2)	3.86 (14.4)	4.76 (22.1)	3.34 (10.7)	6.90 (47.2)	79.2	78.1
Imazamox + imazethapyr 60 g/ha	4.81 (22.7)	3.63 (12.7)	2.53 (5.9)	6.46 (41.3)	5.60 (30.9)	4.69 (21.5)	2.88 (7.8)	7.79 (60.2)	76.2	72.0
Hand weeding twice	1.61 (2.1)	1.55 (1.9)	1.02 (0.5)	2.24 (4.5)	1.76 (2.6)	1.70 (2.4)	1.30 (1.2)	2.59 (6.2)	97.4	97.1
Unweeded check	9.88 (97.3)	8.13 (65.7)	3.36 (10.8)	13.19 (173.8)	10.96 (119.7)	8.98 (80.3)	3.99 (15.4)	14.69 (215.4)	-	-
LSD (p=0.05)	0.38	0.29	0.19	0.51	0.34	0.33	0.23	0.51		

*Data square root transformed. Values in parentheses indicate the original weed dry matter; WCI: Weed control index; PE = pre-emergence application; PoE = post-emergence application; DAS = days after seeding clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE, propaquizafop + imazethapyr and quizalofop-ethyl + imazethapyr. Although the biomass with these three treatments on 30 and 40 DAS were significantly lower than the hand weeding, the values were significantly higher than the other tested herbicides.

Reduced crop-weed competition with application of clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE, propaquizafop + imazethapyr and quizalofop-ethyl + imazethapyr, as also evident from their substantially higher WCE and WCI in this study, might have improved resource utilization by the crop, which eventually led to crop height, biomass accumulation and leaf area development. Maji *et al*. (2020) also observed a significant decrease in leaf area index and crop growth traits as weed density increased. Intense weed pressure can adversely affect leaf traits such as leaf water potential, turgor pressure, stomatal conductance, and photosynthesis (Singh *et al.* 2022).

Nodulation

Hand weeding twice recorded the highest nodule number (36.4 nos./plant), which was closely followed by propaquizafop + imazethapyr and (35.6 nos./plant), clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE (35.0 nos./plant), and quizalofop-ethyl + imazethapyr (34.8 nos./plant) (**Table 3**). No significant difference was noted between these treatments. The nodule weights in these treatments were also statistically equivalent and varied between 33.9-36.3 mg/plant. Weed suppression in these treatments might have reduced weed-microbe competition for soil resources (Kato-Noguchi 2022), which likely led to improved nodulation. By limiting the growth of weeds, it is also possible to promote root growth through the efficient utilisation of soil nutrients. This, in turn, can offer sufficient infection sites for *Rhizobium* mediated nodulation. The unweeded check recorded significantly lower nodulation traits compared to all the other treatments. Allelochemicals exuded by the roots of weeds hinder nodulation (Chaniago *et al*. 2012). This might have led to poor nodulation characteristics in the weedy check treatment of the current study.

Greengram yield attributes, yield, and protein content

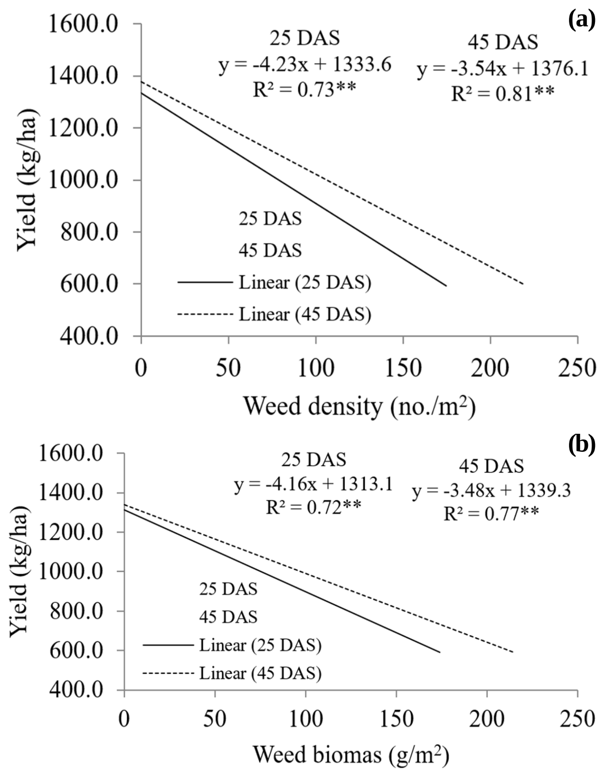
Hand weeding twice produced considerably higher number of pods/plant and seeds/pod (**Table 4**). Among the herbicidal measurements, quizalofop-ethyl + imazethapyr recorded highest pods closely followed by propaquizafop + imazethapyr and clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE. The pod-bearing capacities of these three treatments were noted to be statistically equivalent. Clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE recorded the highest number of seeds/pod among the herbicidal treatments, and it was statistically comparable to clodinafop-propargyl + sodium-acifluorfen) 183.5 g/ha PoE. No significant difference in seeds/pod was noted among the imazethapyr-constituting treatments. The herbicide treatments containing imazethapyr had significantly higher seed index in comparison to rest of the treatments. Interestingly, all the imidazolinone treated plots (22.5%-22.8%) had significantly lower protein content than hand weeding (24.4%). It has been reported that imazethapyr, by inhibiting acetohydroxy acid synthase, leads to a higher starch to protein ratio in seeds, resulting in larger seed size (Scarponi *et al.* 1997). This highlights the crucial need to determine the appropriate dosage of imidazolinone herbicides for each specific crop.

Hand weeding twice produced highest biological yield, with clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE, propaquizafop +

Table 3. Greengram growth parameters under different weed control treatments (mean of two years)

Treatment	Crop height (cm)			Leaf area index			Total dry matter (g/m^2)			Nodule no. /plant	Nodule weight (mg)
	30 DAS	40 DAS	50 DAS	30 DAS	40 DAS	50 DAS	30 DAS	40 DAS	50 DAS	40 DAS	
Imazethapyr 75 g/ha PE	14.9	26.4	34.5	1.05	1.96	2.50	121.2	188.6	244.4	29.6	22.0
Imazethapyr 75 g/ha PoE	15.6	27.7	34.8	1.02	2.04	2.58	123.1	184.8	245.3	30.0	23.1
Clodinafop-propargyl + sodium-acifluorfen 183.5 g/ha	17.4	32.0	39.2	1.10	2.31	2.93	136.7	216.0	293.1	31.8	28.5
Clodinafop-propargyl + sodium-acifluorfen 245 g/ha	18.4	35.1	46.9	1.17	2.29	3.29	155.5	231.2	309.6	35.0	33.9
Propaquizafop + imazethapyr 125 g/ha	21.9	37.6	47.6	1.21	2.62	3.56	147.6	226.7	304.8	35.6	36.3
Quizalofop-ethyl + imazethapyr (50+75g/ha)	21.5	38.2	49.3	1.24	2.70	3.41	159.0	230.9	302.5	34.8	34.8
Imazamox + imazethapyr 60 g/ha	19.0	32.3	41.4	1.15	2.37	3.05	137.8	211.4	280.7	33.0	30.1
Hand weeding twice	23.1	41.5	53.7	1.26	2.84	3.87	184.4	257.2	327.2	36.4	35.6
Unweeded check	12.8	22.8	30.0	0.89	1.68	2.14	106.9	159.1	208.9	20.2	18.7
LSD (p=0.05)	1.6	3.0	3.8	0.10	0.21	0.28	12.7	22.0	33.1	2.7	2.4

PE = pre-emergence application; PoE = post-emergence application; DAS = days after seeding



** Regression equation significant at $p \leq 0.01$.

Figure 1. Relationship between weed density and biomass and seed yield

imazethapyr, and quizalofop-ethyl + imazethapyr following closely behind (**Table 4**). These treatments exhibited statistically equivalent biological yields. Among the herbicidal treatments, application of quizalofop-ethyl + imazethapyr produced highest seed yield, which was statistically equivalent to propaquizafop + imazethapyr and clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE. A comparatively lower weed pressure and reduced competition for available resources in the herbicide-treated plots might have improved productivity. An inverse relationship between weed growth and yield is also apparent from regression analysis, which showed that weed density and weed biomass accounted for 73.0-81.0% and 72.0-77.0% variation in seed yield respectively (**Figure 1**). The hand weeding twice recorded the highest harvest index (HI) of 0.35. The HI in all the weed control measures *i.e.,* hand weeding twice and herbicidal treatments was statistically equivalent. This indicated that arresting weed growth offered favourable environment for resource utilization, which facilitated assimilation and redistribution of photosynthates from vegetative biomass to seeds.

Principal component analysis

A principal component analysis was performed on the different growth characters, yield attributing characters and yield of greengram along with WCE and WCI resulting from the different herbicide mixes (**Figure 2**). The first two principal components (PC 1 and PC 2) together accounted for 93.9% of the variability in the data with their individual contribution being 87.3% and 6.6% respectively. The contribution to PC 1 was the highest for yield, number of nodules per plant, total plant dry matter at 50 DAS and WCE at 45 DAS (9.5, 9.2, 9.0 and 8.8%). However, nodule dry weight per plant, plant height at 50 DAS, WCE and WCI at 25 DAS contributed the most to PC 2 (14.8, 14.2, 14.2 and 13.9%). The PCA in the present context helped to better visualise the difference between the treatments and the relatively more important characters contributing towards this difference were identified. The herbicide-mixes clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE, propaquizafop + imazethapyr, quizalofop-ethyl + imazethapyr (**Figure 2**) are in close proximity along the PC1 axis, having the highest positive values after hand weeding twice. Thus, apart from hand weeding

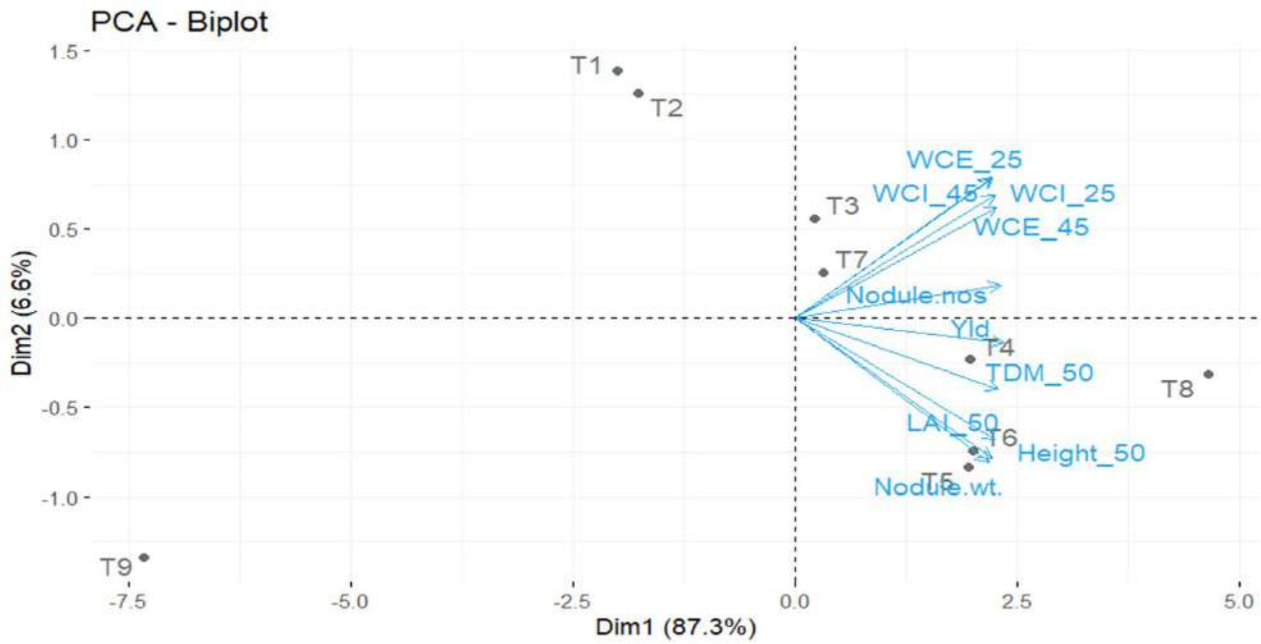
Table 4. Greengram yield traits, yield, crude protein and weed index under different weed control treatments (mean of two years)

Treatment	Pods/ plant	Seeds/ pod	Hundred seed weight (g)	Seed yield (kg/ha)			Biological yield (kg/ha)			Harvest index	Crude protein (%)	Weed index (%)
				2022	2023	Pooled	2022	2023	Pooled			
Imazethapyr 75 g/ha PE	7.8	7.4	3.30	836	942	889	2777	3009	2893	0.31	22.80	36.4
Imazethapyr 75 g/ha PoE	8.0	7.8	3.26	869	941	905	2719	2945	2832	0.32	22.60	35.1
Clodinafop-propargyl + sodium-acifluorfen 183.5 g/ha	9.4	9.2	2.89	1022	1064	1043	3407	3547	3477	0.30	23.80	25.2
Clodinafop-propargyl + sodium-acifluorfen 245 g/ha	10.4	9.8	2.97	1160	1232	1196	3626	3850	3738	0.32	23.90	14.2
Propaquizafop + imazethapyr 125 g/ha	10.8	7.2	3.32	1173	1271	1222	3553	3849	3701	0.33	22.70	12.4
Quizalofop-ethyl + imazethapyr (50+75g/ha)	11.5	7.6	3.31	1279	1229	1254	3763	3615	3689	0.34	22.80	10.1
Imazamox + imazethapyr 60 g/ha	9.6	7.8	3.33	1017	1125	1071	3178	3512	3345	0.32	22.50	23.2
Hand weeding twice	14.2	10.2	3.08	1437	1353	1395	4106	3866	3986	0.35	24.40	-
Unweeded check	6.0	6.6	2.60	549	467	508	2437	2209	2323	0.22	21.60	63.6
LSD (p=0.05)	1.29	0.9	0.24	179.3	189.2	125.35	442.2	467.5	446.96	0.05	1.44	

PE = pre-emergence application; PoE = post-emergence application

Table 5. Economic analysis under different weed control treatments in greengram (mean of two years)

Treatment	Gross returns (Rs. /ha)	Net returns (Rs./ha)	B:C ratio
Imazethapyr 75 g/ha PE	58301	20233	1.53
Imazethapyr 75 g /ha PoE	59350	21282	1.56
Clodinafop-propargyl + sodium-acifluorfen 183.5 g/ha	68400	30004	1.78
Clodinafop-propargyl + sodium-acifluorfen 245 g/ha	78434	39605	2.02
Propaquizafop + imazethapyr 125 g/ha/ha	80139	39645	1.98
Quizalofop-ethyl + Imazethapyr (50+75) g/ha	82237	42320	2.06
Imazamox + Imazethapyr 60 g/ha	70236	30992	1.79
Hand weeding twice	91484	46395	2.03
Unweeded check	33315	-2700	0.93



T1: imazethapyr 75 g/ha (PE), T2: imazethapyr 75 g/ha (PoE), T3: clodinafop-propargyl + sodium-acifluorfen 183.5 g/ha, T4: clodinafop-propargyl + sodium-acifluorfen 245 g/ha, T5: propaquizafop + imazethapyr 125 g/ha, T6: quizalofop-ethyl + imazethapyr (50+75 g/ha), T7: imazamox + imazethapyr 60 g/ha, T8: hand weeding twice, T9: unweeded check

Figure 2. PCA biplot of principal components (PC 1 and PC 2) for WCE, WCI, growth and yield characters in greengram (graph showing the top 10 variables based on contributions to PCs)

twice, these treatments had better performance especially in terms of those characters which contributed more to PC1, *viz*. yield, no. of nodules, WCE at 45 DAS, etc. and were on the same side (positive) of the PC 1. The herbicide treatments are clustered in 3 groups indicating similarity in performance of treatments within each group. Unweeded check remained on the far negative side on both axes due to poor performance than others.

Economics

Among all weed control treatments applied in the experiment, the highest net return was obtained with hand weeding twice (Rs. 46,395 /ha) followed by herbicidal treatment quizalofop-ethyl + imazethapyr (Rs. 42,320 /ha) (**Table 5**). A loss in crop production (Rs. -2700 /ha) recorded in unweeded check indicates that failure to manage weeds could result in significant economic losses. The maximum benefit-cost ratio was noted in treatment quizalofop-ethyl + imazethapyr (2.06), closely followed by hand weeding twice (2.03) and clodinafop-propargyl + sodium-acifluorfen 245 g/ha PoE (2.02). Intensive labour investment in the hand-weeded plots likely lowered the B:C ratio despite the edge earned in yields and net returns over other treatments.

Conclusion

The present study highlights the importance of timely weed treatment in greengram to improve crop growth and productivity by reducing weed-induced stress in the field. Successful adoption of greengram in grass-dominated cereal-based systems can be encouraged by using any of the following post-emergence broad-spectrum herbicide-mixtures, *viz*. clodinafop-propargyl + sodium-acifluorfen (245 g/ha), propaquizafop + imazethapyr (125 g/ha), and quizalofop-ethyl + imazethapyr (50+75 g/ha), as they are particularly effective against grassy weeds.

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RESEARCH ARTICLE

Effect of different tillage and weed management treatments on growth and yield of soybean

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ABSTRACT

A field experiment was conducted, during 2019-20 to 2021-22 at Akola, Maharashtra to study the effect of tillage (conventional, reduced, minimum and zero tillage) and herbicides (diclosulam, propaquizafop + imazethapyr, farmers practice and weedy check) on soybean productivity. The total weed biomass and soybean yield were significantly influenced by various tillage practices at all stages of crop growth. Conventional tillage recorded statistically significant minimum weed biomass, higher number of soybean pods/plant, soybean seed weight/m^2, soybean grain yield/ha and economic returns than rest of the tillage treatments. The next best response was recorded with reduced tillage followed by minimum tillage. The zero tillage recorded the highest weed biomass. Amongst herbicidal treatments tested, minimum weed biomass, maximum soybean yield and economic benefit was recorded with pre-emergence application (PE) of diclosulam 0.026 kg/ha followed by (*fb*) post-emergence application of (PoE) propaquizafop + imazethapyr 0.125 kg/ha.

Keywords: Diclosulam, Economics, Propaquizafop + imazethapyr, Soybean, Tillage, Weed management

INTRODUCTION

Soybean (*Glycine max* L.) is one of the important oilseeds as well as a leguminous crop. The area covered under soybean in India during the year 2024 was 13.50 M ha which produced 12.58 MT with productivity of 930 kg/ha. In Maharashtra the area under soybean cultivation was 51.59 lakh ha with a production of 84.38 lakh tonnes of soybean grains and productivity of 1635 kg/ha (www.krishi.maha.gov.in). It is an excellent source of protein and oil besides it contains high level of amino acids such as lysine, lucien, lecithin. Soybean contains approximately 40-45% protein and 18-22% oil and is a rich source of vitamins and minerals. Soybean contain40-45% protein hence called as the "Poor man's meat".

Tillage helps to prepare an appropriate seedbed for crop planting, which have several advantages such as loosening soil, regulating the circulation of water and air within the soil, increasing the release of nutrient elements from the soil for crop growth, and controlling weeds by burying weed seeds and emerged seedlings (Reicosky and Allmaras 2003). Conservation tillage techniques save time, energy, money and also help in improving the soil carbon status (Erenstein and Laxmi 2008). Assessing tillage's impact on soybean yields has been complicated by inconsistent weed control practices, often leading to lower yields in no-till systems compared to conventional tillage due to weed competition. Thus, adequate weed management is equally essential as tillage to realize optimal soybean yield. The tillage experiments are site specific and yield results are often non-repeatable even under the same soil conditions. While tillage changes soil characteristics, the effects are usually not of the magnitude to significantly affect emergence and early plant growth in experimental plots. The practical feasibility of the tillage practice would play a major role when it comes to disseminate the technology to farmer's field. Hence, identifying appropriate tillage and weed management practices will certainly be beneficial to the stakeholders of this region for sustainable soybean production. Therefore, an experiment was conducted to study the impact of both tillage and weed management practices on weeds and the productivity of soybean.

MATERIALS AND METHODS

The experiment was conducted at All India Coordinated Research Project (AICRP) on Weed Management, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during 2019-20 to 2021-22. Akola is situated in the Sub-tropical zone at the latitude of 22^{0}42' North longitude of 77^0 02' East. The altitude of the place is 307.41 meter above mean sea level. The

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soil of experimental plot was medium deep black with fairly uniform and leveled topography with slightly alkaline in reaction with medium status of organic carbon content, available nitrogen and phosphorous and fairly rich status of available potassium. The climate of Akola is semi-arid and characterized by three distinct season *viz.*, hot and dry summer from March to May, warm and rainy monsoon from June to October. Total rainfall of 774.1 mm was recorded during the crop growing season. Four tillage treatments were in main plots viz., conventional tillage (CT) – ploughing twice with harrowing tyne cultivator + harrowing with blade harrow; reduced tillage (RT) - harrowing with tyne cultivator + rototill; minimum tillage (MT) - rototill (rotavator) and zero tillage. The sub-plot treatments were five weed management practices viz; pre-emergence application (PE) of diclosulam 0.026 kg/ha; post-emergence application (PoE) of propaquizafop + imazethapyr 0.125 kg/ha at 15 days after seeding (DAS); diclosulam 0.026 kg/ha PE followed by (*fb)* propaquizafop + imazethapyr 0.125 kg/ha PoE at 30 DAS; weed free (hoeing twice 15 and 30 DAS + 1 hand weeding (HW) 20 DAS; and weedy check. The gross plot size of the sub plot was 70 m^2, while the gross plot size of the main plot was 3500 m^2. The soybean variety AMS 1001 during *Kharif* (June to October) was sown at row to row spacing of 45 cm and 20 cm. The application of herbicides was done as per the treatments with manually operated knapsack sprayer attached with a flat fan nozzle. The recommended practice of fertilizers application was followed to both the crops. The N, P and K were given in the form of urea, single super phosphate and muriate of potash, respectively in soybean 30:75:30 N, P and K kg/ha. Standard procedures were adopted to collect the data of recorded parameters. The data recorded for different characters in this study were analyzed by following analysis of variance procedure as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weed flora

The major weed flora during *Kharif* season in soybean in the experimental field composed of *Cyperus rotundus, Commelina benghalensis, Euphorbia geniculate, Boerhavia diffusa, Parthenium hysterophorus, Phyllanthus niruri, Portulaca oleracea, Cynodon dactylon, Dinebra arabica, Digera arvensis, Amaranthus viridis, Euphorbia hirta, Abutilon indicum, Abelmoschus moschatus, Ageratum conyzoides, Alternanthera triandra, Panicum* spp., *Ischaemum pilosum, Digitaria sanguinalis, etc.* Both broad- and narrow-leaved weeds were observed.

Weed biomass and weed indices

The weed dry matter (weed biomass) was significantly influenced by various tillage practices. At 20 DAS, significantly lowest weed biomass was recorded with conventional tillage which was followed by reduced tillage and minimum tillage. The zero tillage recorded the highest weed biomass. At 40 DAS, the treatment of conventional tillage registered significantly lowest weed biomass and conversely, zero tillage treatment recorded highest weed biomass. Highest weed control efficiency was recorded in treatment of conventional tillage followed by minimum tillage. In this study, zero tillage showed the lowest weed control efficiency and the highest weed index, while conventional tillage demonstrated the lowest weed index, followed by reduced tillage.

Amongst herbicide treatment, the lowest weed biomass was observed with diclosulam 0.026 kg/ha PE up to 20 DAS, as diclosulam application resulted in better weed control at initial stage by inhibiting weed seed germination and seedling development. The pre-emergence herbicide shows its efficacy up to 20 DAS. However, diclosulam 0.026 kg/ha PE *fb* propaquizafop + imazethapyr 0.125 kg/ha PoE showed its superiority by recording least weed biomass. Maximum weed control efficiency and lowest index were noted with weed free where hoeing and hand weeding practices were carried out and found statistically superior at all the growth stages. The second-best treatment was diclosulam 0.026 kg/ha as PE *fb* propaquizafop + imazethapyr 0.125 kg/ha as PoE.

Soybean yield and yield attributes

Conventional tillage proved significantly superior in number of pods, weight of seed per m^2, test weight and seed yield than all the treatments due to maximum depth of tillage operation which resulted in highest root proliferation and subsequently easy availability of moisture and nutrients. Monsefi (2009) reported that the yield attributes in soybean was significantly influenced by the tillage and crop establishment treatments and maximum for these traits were recorded in conventional tillage than zero tillage. The second-best treatment was reduced tillage which was recorded significantly higher yield than minimum tillage and zero tillage. The lower seed yield with treatments of minimum tillage (consisting only one rototill) and zero tillage (no tillage) where the soil was undisturbed could be attributed to the inferior value of plant growth and yield attributing characters.

It indicates that soybean plants did not respond well to shallow tillage. Soybean grown in a conventional tillage system has yield advantage over soybean grown in a reduced, minimum and no-tillage system. The results are in agreement with Guy and Oplinger, (1989) and Singh *et al.* (1998).

Weed free treatment recorded significantly higher number of pods/plant, weight of seed/m^2, maximum test weight, seed yield over rest of the herbicidal treatments which in turn was found at par with treatment diclosulam 0.026 kg/ha PE *fb* propaquizafop + imazethapyr 0.125 kg/ha PoE. Weedy check showed lowest number of pods/plant. These treatments remain significantly superior over treatments diclosulam 0.026 kg/ha PE and propaquizafop + imazethapyr 0.125 kg/ha PoE. Weed check treatment recorded lowest number of pods/plant, test weight and seed yield than herbicidal treatments. The similar result was recorded with Susmita Panda *et al.* (2015) and Rajkumari *et al.* (2015).

Economics

Conventional tillage treatment, due to its consistency in improving the soil characteristics, provided an ideal ground for prolific crop growth, which ultimately triggered the yield potential of

Table 1. Weed biomass, weed control efficiency and weed index as influenced by various tillage and weed management treatments in soybean (mean of 3 years)

Treatment	Weed biomass (g/m^2)			Weed control efficiency (%)			Weed index (%)
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS	
Main plot- tillage							
Conventional tillage (1 Plo + 2 Hr by Tc + 1 Hr by Bd)	16.9(4.17)	27.5(5.30)	34.8(5.94)	64.88	60.28	55.44	5.70
Reduced tillage (1Hr by Tc +1 rototill)	20.7(4.60)	34.2(5.89)	42.2(6.54)	56.92	50.65	45.95	16.37
Minimum tillage (1 rototill)	26.9(5.23)	41.3(6.47)	49.7(7.08)	44.00	40.45	36.41	24.10
Zero tillage (no tillage)	36.2(6.06)	49.8(7.10)	57.8(7.64)	24.59	28.13	25.96	39.31
LSD (p=0.05)	0.24	0.25	0.28	--	--	--	--
Sub plot- weed management							
Diclosulam 0.026 kg/ha PE	20.5(4.58)	46.6(6.86)	59.4(7.74)	57.32	32.80	23.97	28.39
Propaquizafop + imazethapyr 0.125 kg/ha PoE upto 15 DAS	33.9(5.86)	44.3	54.3	29.47	36.19	30.54	21.55
Diclosulam 0.026 kg/ha PE *fb* propaquizafop + imazethapyr 0.125 kg/ha PoE up to 30 DAS	16.6(4.13)	30.3(5.55)	40.0(6.37)	65.53	56.36	48.76	7.96
Weed free (2 hoeing at 15 and 30 DAS + 1 hand weeding at 20 DAS)	4.2(2.18)	5.5(2.45)	5.1(2.36)	91.15	92.08	93.52	0.00
Weedy check	48.0(6.97)	69.4(8.36)	78.1(8.87)	0.00	0.00	0.00	48.20
LSD (p=0.05)	0.12	0.18	0.25	--	--	--	--
Interaction(A×B)							
LSD (p=0.05)	0.05	0.05	0.07	--	--	--	--

Data are subjected to square root transformation ($\sqrt{x + 0.5}$) and original data presented in parentheses; Plo –Ploughing; Hr- Harrow; Tc- Tyne cultivator; Bd- Blade; PE= pre-emergence application; PoE= post-emergence application; DAS= days after seeding

Table 2. Number of pods/ plants, seed weight/m^2, test weight and seed yield of soybean as influenced by various tillage and weed management treatments (mean of 3 years)

Treatment	No. of pods/ plant	Seed weight/m^2 (g)	Test weight (g)	Seed yield (kg/ha)
Main plot- tillage				
Conventional tillage (1 Plo +2 Hr by Tc +1Hr by Bd)	40.48	445	13.36	2414
Reduced tillage (1Hr by Tc +1 rototill)	37.32	406	12.87	2138
Minimum tillage (1 rototill)	35.31	374	11.92	1941
Zero Tillage (no tillage)	30.12	327	10.92	1532
LSD (p=0.05)	2.42	11.51	0.48	186
Sub plot- weed management				
Diclosulam 0.026 kg/ha PE	32.26	403	11.82	1828
Propaquizafop + imazethapyr 0.125 kg/ha 15 DAS	36.76	352	12.13	2007
Diclosulam 0.026 kg/ha PE *fb* propaquizafop + imazethapyr 0.125 kg/ha PoE 30 DAS	42.22	426	12.38	2357
Weed free (2 hoeing 15 and 30 DAS + 1 hand weeding 20 DAS)	44.19	455	12.89	2612
Weedy check	22.59	304	10.38	1287
LSD (p=0.05)	3.05	7.26	0.40	185
Interaction (A× B)				
LSD (p=0.05)	NS	15.62	NS	NS

Plo –Ploughing; Hr- Harrow; Tc- Tyne cultivator; Bd- Blade; PE= pre-emergence application; PoE= post-emergence application; DAS= days after seeding

Table 3. Economics of soybean as influenced by different tillage and weed management treatments (mean of 3 years)

Treatment	Gross monetary returns (Rs/ha)	Cost of cultivation (Rs/ha)	Net monetary returns (Rs/ha)	Benefit Cost ratio
Main plot- tillage management				
Conventional tillage (1 ploughing +2 Hr by Tc +1Hr by Bd)	95353	42820	52533	2.23
Reduced tillage (1Hr by Tc +1 rototill)	84451	39257	45194	2.15
Minimum tillage (1 rototill)	76670	37502	39168	2.04
Zero tillage (no tillage)	60514	34604	25910	1.75
LSD (p=0.05)	2905	--	2905	--
Sub plot- weed management				
Diclosulam 0.026 kg/ha PE	72206	37409	34797	1.93
Propaquizafop + imazethapyr 0.125 kg/ha PoE 15 DAS	79277	37915	41361	2.09
Diclosulam 0.026 kg/ha PE *fb* propaquizafop + imazethapyr 0.125 kg/ha PoE 30 DAS	93102	39960	53141	2.33
Weed free (2 hoeing 15 and 30 DAS + 1 hand weeding 20 DAS)	103174	42814	60360	2.41
Weedy check	50837	34630	16206	1.47
LSD (p=0.05)	2163	--	2163	--
Interaction (AXB)				
LSD (p=0.05)	4586	--	4586	--

Plo –Ploughing; Hr- Harrow; Tc- Tyne cultivator; Bd- Blade; PE= pre-emergence application; PoE= post-emergence application; DAS= days after seeding

soybean, and subsequently offered highest economic return as compared to the input cost incurred towards cultivating this crop; which had reflected in obtaining the highest gross monetory return (GMR) and net monetory return (NMR) both being statistically similar with each other; as a result of its higher productivity owing to better soil and plant characters, as observed throughout the investigational period. It was followed by treatments minimum tillage and significantly lowest GMR and NMR was recorded with zero tillage could be ascribed to its lower productivity as compared to cost of cultivation. Even after undertaking the intensive tillage with expensive operation of deep tillage through tyne harrow, blade harrow and planking, the greater B:C value was observed with reduced and minimum tillage and proved marginally superior over conventional tillage. The zero tillage, recorded lowest B:C (1.96).

Among various weed management treatments, the highest return and maximum B:C was noticed with treatment weed free as a result of more productivity and best weed management through cultural practices as observed throughout the study period, which was closely followed by treatment diclosulam 0.026 kg/ha PE *fb* propaquizafop + imazethapyr 0.125 kg/ha up to 30 DAS where sequential application of PE and PoE herbicides were done and lowest return was recorded with treatment weedy check. Weedy check recorded the minimum B:C. Similarly, Chaudhari *et al*. (2020) also reported the higher net returns with application of imazethapyr + propaquizafop 125 kg/ha PoE in soybean.

It was concluded that in swell and shrink type of soils use of conventional tillage practices i.e. ploughing+ two harrowing by tyne harrows + a blade harrow or reduced tillage *i.e.* 1 harrow by tyne cultivator + 1 rototill in soybean was found optimum. The sequential application of diclosulam 0.026 kg/ha PE *fb* propaquizafop + imazethapyr 0.125 kg/ha PoE at 30 DAS was found effective in managing weeds and increasing yield as well as economic returns in soybean.

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RESEARCH ARTICLE

Efficacy of herbicides and their time of application on field dodder (*Cuscuta*) in lucerne

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ABSTRACT

Parasitic weed *Cuscuta* is a serious problem in lucerne and other crops has negative impacts on the growth and yield of lucerne. Hence, effective control of *Cuscuta* in lucerne is necessary to reduce yield losses. Considering the seriousness of the problem, an experiment was conducted during *Rabi* seasons of the 2020-21 and 2021-22 on loamy sand soil at the farm of AICRP-Weed Management, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat. Pre-emergence application (PE) of pendimethalin 680 g/ha; pendimethalin + imazethapyr 640 g/ha; and pendimethalin + imazethapyr 800 g/ha were found phytotoxic to lucerne crop. The post-emergence application (PoE) of fluazifop-p-butyl + fomesafen 250 g/ha was also found phytotoxic to lucerne crop and showed burning effect on leaves of lucerne. Among different treatments, pendimethalin 680 g/ha applied at 10 days after sowing (DAS) significantly reduced the length and fresh weight of *Cuscuta* at 60 DAS with higher *Cuscuta* control efficiency (99.44%) and green fodder yield of lucerne at 60 DAS without any phytotoxic effect on lucerne.

Keywords: *Cuscuta*, Fluazifop-p-butyl + fomesafen, Lucerne, Pendimethalin, Pendimethalin + imazethapyr, Phytotoxicity

INTRODUCTION

Lucerne/Alfalfa (*Medicago sativa* L.) is an important forage crop with high yields and nutritional value for the dairy industry across the world. The high protein and low lignin contents of the species make it highly desirable within the animal feedstock industry (Noroozi *et al.* 2022). In India, lucerne is predominantly cultivated in subtropical and tropical climatic conditions as a major *rabi* fodder crop and is estimated to cultivated under 1.0 Mha area (Chauhan *et al*. 2017). Gujarat state is having the highest area under lucerne cultivation followed by Rajasthan, Maharashtra, Punjab, Haryana, Madhya Pradesh, Uttar Pradesh, Tamil Nadu and Karnataka (Roy *et al*. 2020). Weeds have serious impacts on the economical production of lucerne as they severely decrease the forage yield and nutritive value. Dodder (*Cuscuta* spp.) also reduces the quality lucerne seed.

Dodder, also known as *Akashbel* or *Amarbal,* is a parasitic angiosperm belonging to the family *Cuscutaceae*. It is a serious parasitic weed in lucerne, which reduces crop yield and can kill its host plant. Dodders are obligate parasitic plants consisting of yellow twining stems that produce small clusters of white flowers. Dodder is a holo-parasitic plant that attaches to the stems and leaves of broad-leaved crops in many agricultural regions of the world. Dodder does not produce chlorophyll, therefore, it exhibits no photosynthetic activity and acquires essential resources such as moisture, nutrients and carbohydrates by attaching to the aerial tissues of host plants through haustoria due to the lack of roots and leaves Garcia *et al*. (2014). Mishra (2012) reported that *Cuscuta* caused detrimental effect on lucerne seed yield (85.5-95.3% loss), even at density of 0.25 plants/m^2 (1 plant/4m^2). Lucerne is a very sensitive host to dodder infection because of slow germination and establishment. Heavy contamination of dodder without control leads to significant yield losses ranging between 50 and 80% (Arregi *et al*. 2001 and Saric-Krsmanovic *et al*. 2015). Manual removal and frequent inter-row cultivation before the parasite attaches the host plant are the usual control measures but they are laborious and often not effective methods. Therefore, effective and selective herbicide is required to control the *Cuscuta* without damaging its host plant. Hence, the present study was undertaken with an objective to identify the effective herbicides for control of *Cuscuta* in lucerne.

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MATERIALS AND METHODS

A field experiment was carried out during *Rabi* seasons of 2020-21 and 2021-22 on loamy sand soil at the farm of AICRP-Weed Management, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat State. The experiment was laid out in randomized block design with three replications and nine treatments, *viz*. pre-emergence application (PE) of pendimethalin 38.7% CS (pendimethalin) 680 g/ha, pendimethalin 680 g/ha at 10 days after seeding (DAS), pendimethalin 30% + imazethapyr 2% EC pre-mixed (PM) (pendimethalin + imazethapyr) 640 g/ha PE, pendimethalin + imazethapyr (PM) 800 g/ha PE, post-emergence application (PoE) of imazethapyr10% SL (imazethapyr) 50 g/ha, imazethapyr 35% + imazamox 35% WG (PM) (imazethapyr + imazamox) 70 g/ha PoE, fluazifop-p-butyl 11.1% + fomesafen 11.1% SL (PM) (fluazifop-p-butyl + fomesafen) 250 g/ha PoE, propaquizafop 2.5% + imazethapyr 3.75% ME (PM) (propaquizafop + imazethapyr) 125 g/ha PoE and weedy check. The recommended seed rate of 15 kg/ha of lucerne cv. "*Anand Lucerne 2*" was manually sown in previously open furrows, with the help of kudali, keeping the row spacing of 30 cm. The crop was sown on 9th November, 2020 and 1st November 2021 and was harvested on 9th May 2020 and 2021. Seeds of *Cuscuta* (5 g/18m^{-2} plot area) were mixed with lucerne seeds at the time of sowing. After sowing, the seeds were covered with soil manually and irrigation was given for better germination of the seeds. Herbicides were applied as per the treatment by using battery operated knapsack sprayer fitted with flat-fan nozzle by mixing in 500 and 375 litre of water/ha for pre-emergence and post emergence application of herbicide, respectively. Visual phytotoxicity (%) of herbicides applied in lucerne was recorded based on 0-10 scale at 10 and 20 days after herbicide application (DAHA). Observation on fresh weight and length of *Cuscuta* were taken randomly from 0.25 m^2 quadrat from net plot area in each treatment and fresh weight was converted into g/m^2 and length was converted into (m/m^2) at 60 DAS. Green forage yield of lucerne was harvested from net plot area of each treatment at 60 DAS and converted into t/ha. Data on various observations recorded during the experimental period was statistically analysed as per the standard procedure and weed data were transformed by square root transformation ($\sqrt{x+1}$) and transformed data were subjected to ANOVA analysis (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Effect on *Cuscuta*

Pendimethalin 680 g/ha at 10 DAS, pendimethalin + imazethapyr 640 g/ha PE and pendimethalin + imazethapyr 800 g/ha PE significantly reduced the length, fresh weight at 60 DAS and seed yield of *Cuscuta* as compared to other treatments (**Table 1**). Pendimethalin 0.5-1.5 kg/ha PE was reported to control *Cuscuta* in niger (Mishra *et al*. 2005) with higher *Cuscuta* control efficiency and more than 94% decrease in seed yield of *Cuscuta*. Fluazifop-p-butyl + fomesafen 250 g/ha PoE recorded higher seed yield of *Cuscuta* and it was at par with propaquizafop + imazethapyr 125 g/ha PoE, imazethapyr 50 g/ha PoE, pendimethalin 680 g/ha PE and imazethapyr + imazamox 70 g/ha PoE. Other herbicidal treatments recorded significantly lower fresh weight, length and seed yield of *Cuscuta* as compared to control plot. Imazethapyr inhibits amino acid biosynthesis, causing plant mortality and this mode of action has been found to be particularly effective in suppressing growth of *Cuscuta* in lucerne. Noroozi *et al*. (2022) observed that imazethapyr 100 g/ha provided significant reduction in the density (90%) and biomass (98%) of dodder in alfalfa.

Phytotoxicity

Mean data on phytotoxicity of applied herbicides on lucerne indicated that application of pendimethalin 680 g/ha PE, pendimethalin + imazethapyr 640 g/ha PE and pendimethalin + imazethapyr 800 g/ha PE were found phytotoxic to lucerne crop and poor germination was observed in treated plot as compared to untreated check. Liu *et al*. (1990) reported that pendimethalin inhibited the cell division and formation of spindle microtubulus in the cells of germinated *Cuscuta* seedlings. However, pendimethalin PE was found phytotoxic to berseem and lucerne. Fluazifop-p-butyl + fomesafen 250 g/ha PoE was also found phytotoxic to lucerne crop and showed burning effect on leaves of lucerne but recovered after 10 days of application (**Table 3**).

Effect on lucerne

Lucerne plant stand (at 15 DAS) and plant height (at 60 DAS) was significantly lowest with pendimethalin + imazethapyr at both 800 or 640 g/ha (**Table 2**). Further, pendimethalin 680 g/ha also showed significantly lower plant stand and plant height as compared to other herbicidal treatments. Mishra (2012) also observed that pendimethalin 750

Table 1. Length, Fresh weight and seed yield of *Cuscuta* as influenced by different treatments

Treatment*	Length of *Cuscuta* (m/m^2) at 60 DAS			Fresh weight of *Cuscuta* (g/m^2) at 60 DAS			*Cuscuta* control efficiency (%)			Seed yield of *Cuscuta* (g/m^2)		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Mean	2020-21	2021-22	Pooled
Pendimethalin 680 g/ha PE	9.86 (96.3)	9.46 (88.7)	9.66 (92.5)	8.57 (72.7)	6.36 (39.7)	7.47 (56.2)	85.04	94.11	89.58	51.8	20.5	36.2
Pendimethalin 680 g/ha at 10 DAS	1.00 (0.00)	3.52 (11.4)	2.26 (5.72)	1.00 (0.00)	2.71 (6.43)	1.85 (3.22)	100	99.05	99.53	0.00	8.57	4.28
Pendimethalin + imazethapyr (PM) 640 g/ha PE	1.00 (0.00)	4.69 (21.0)	2.84 (10.5)	1.00 (0.00)	3.89 (14.2)	2.44 (7.08)	100	97.89	98.95	0.00	8.77	4.38
Pendimethalin + imazethapyr (PM) 800 g/ha PE	1.00 (0.00)	2.99 (8.13)	1.99 (4.07)	1.00 (0.00)	2.43 (5.13)	1.71 (2.57)	100	99.24	99.62	0.00	8.70	4.35
Imazethapyr 50 g/ha PoE	15.5 (245)	13.4 (180)	14.4 (213)	13.7 (189)	11.5 (132)	12.6 (161)	61.11	80.42	70.77	45.6	28.1	36.8
Imazethapyr + imazamox 70 g/ha PoE	18.1 (333)	14.1 (201)	16.1 (267)	16.5 (275)	13.1 (175)	14.8 (225)	43.41	59.20	51.31	43.5	26.6	35.1
Fluazifop-p-butyl + fomesafen 250 g/ha PoE	15.7 (255)	13.8 (189)	14.7 (222)	14.5 (211)	18.6 (349)	16.6 (280)	56.58	48.22	52.40	45.4	35.1	40.3
Propaquizafop + imazethapyr 125 g/ha PoE	11.3 (129)	10.5 (109)	10.9 (119)	10.5 (108)	9.64 (92.4)	10.0 (100)	77.78	86.29	82.04	45.8	28.0	36.9
Weedy check	24.2 (588)	26.3 (692)	25.3 (640)	22.0 (486)	25.8 (674)	24.0 (580)	-	-	-	92.4	69.2	80.8
LSD (p=0.05)	3.60	2.10	1.61	2.34	1.89	1.17	-	-	-	9.37	8.63	4.93

Note: Data subjected to ($\sqrt{x+1}$) transformation. Figures in parentheses are means of original values. ; *PE = pre-emergence application; PoE = post-emergence application; DAS = days after seeding

Table 2. Plant stand, plant height and green fodder yield of lucerne as influenced by different treatments

Treatment*	Reduction in seed yield of *Cuscuta* over control (%)			Plant stand (no./m row length) at 15 DAS			Plant height (cm) at 60 DAS			Green fodder yield (t/ha) at 60 DAS		
	2020-21	2021-22	Mean	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Pendimethalin 680 g/ha PE	43.94	70.38	57.16	25.2	46.9	36.0	48.6	52.4	50.5	13.0	8.13	10.6
Pendimethalin 680 g/ha at 10 DAS	100.00	87.62	93.81	39.7	78.7	59.2	60.3	63.6	62.0	22.8	12.2	17.5
Pendimethalin + imazethapyr 640 g/ha PE	100.00	87.33	93.66	9.07	28.1	18.6	38.40	37.9	38.2	7.00	8.90	7.95
Pendimethalin + imazethapyr 800 g/ha PE	100.00	87.43	93.71	8.13	24.6	16.4	36.13	32.7	34.4	6.57	8.53	7.55
Imazethapyr 50 g/ha PoE	50.65	59.39	55.02	41.1	78.4	59.8	52.5	56.4	54.5	20.0	11.7	15.8
Imazethapyr + imazamox 70 g/ha PoE	52.92	61.56	57.24	41.5	77.9	59.7	53.5	57.5	55.5	22.7	9.83	16.3
Fluazifop-p-butyl + fomesafen 250 g/ha PoE	50.87	49.28	50.07	40.3	78.9	59.6	42.2	46.2	44.2	12.7	3.70	8.18
Propaquizafop + imazethapyr 125 g/ha PoE	50.43	59.54	54.99	42.4	80.9	61.7	51.3	54.2	52.7	19.4	11.8	15.6
Weedy check	-	-	-	43.3	79.9	61.6	59.2	59.9	59.5	18.9	3.90	11.4
LSD (p=0.05)	-	-	-	5.58	10.0	4.45	5.66	4.73	2.86	6.51	2.42	2.69

*PE = pre-emergence application; PoE = post-emergence application; DAS = days after seeding

Table 3. Phytotoxicity of applied herbicides on lucerne (mean of two years)

Treatment	Phytotoxicity Score (0-10 scale)		Remarks
	10 DAHA	20 DAHA	
Pendimethalin 680 g/ha PE	3	1	Poor germination
Pendimethalin 680 g/ha at 10 DAS	0	0	-
Pendimethalin + imazethapyr 640 g/ha PE	4	2	Poor germination and Stunted growth
Pendimethalin + imazethapyr 800 g/ha PE	4	2	Poor germination and Stunted growth
Imazethapyr 50 g/ha PoE	0	0	-
Imazethapyr + imazamox 70 g/ha PoE	0	0	-
Fluazifop-p-butyl + fomesafen 250 g/ha PoE	4	0	Burning of leaves
Propaquizafop + imazethapyr 125 g/ha PoE	0	0	-
Weedy check	0	0	-

*PE = pre-emergence application; PoE = post-emergence application; DAS = days after seeding; DAHA = days after herbicide application g/ha PE significantly reduced the lucerne plant population leading to decreasing green fodder yield of lucerne. Significantly higher green fodder yield (17.5 t/ha) at 60 DAS was recorded with pendimethalin 680 g/ha at 10 DAS but remained at par with imazethapyr + imazamox 70 g/ha PoE, propaquizafop + imazethapyr 125 g/ha and imazethapyr 50 g/ha PoE. Mishra (2012) observed that pendimethalin applied at 14 DAS was safe for lucerne emergence as compared to its application at 7 DAS and pendimethalin 14 DAS was also effective in reducing *Cuscuta* emergence leads to recorded maximum green fodder yield of lucerne.

Conclusion

Pendimethalin 680 g/ha applied at 10 DAS significantly reduced the length and fresh weight of *Cuscuta* at 60 DAS with higher *Cuscuta* control efficiency (99.44%) and green fodder yield of lucerne at 60 DAS without any phytotoxic effect on lucerne. Hence, pendimethalin 680 g/ha application at 10 DAS may be used for managing *Cuscuta* in lucerne.

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RESEARCH ARTICLE

Weed management in *Rabi* onion

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ABSTRACT

A field experiment was conducted to evaluate the efficacy of different herbicides for controlling weeds in onion (*Allium cepa* L.) during *Rabi* 2019 and 2020. The experiment was laid out in randomized complete block design with seven weed control treatments, *viz*. pre-emergence application (PE) of oxyfluorfen 199.75 g/ha, post-emergence application (PoE) of quizalofop-ethyl 50 g/ha, quizalofop-ethyl + oxyfluorfen 50 g/ha PoE, quizalofop-ethyl + oxyfluorfen 75 g/ha PoE, quizalofop-ethyl + oxyfluorfen 100 g/ha PoE, hand weeding twice 30 and 60 days after transplanting (DAT) and unweeded control. Quizalofop-ethyl + oxyfluorfen 100 g/ha PoE provided effective weed control with highest bulb yield (31.13 t/ha), highest net returns (Rs. 184.90 $\times10^3$/ha) and B: C ratio (2.48). The un-weeded control recorded the lowest net returns (Rs. 80.03 $\times10^{3/}$ha) and benefit: cost ratio (1.63).

Keywords: Economics, Onion, Quizalofop-ethyl + oxyfluorfen, Weed management

INTRODUCTION

The bulbous vegetable onion (*Allium cepa* L var. *aggregatum*) is the most important species of *Allium* group and is regarded as the single most important vegetable spices as it forms an indispensable part of many diets, both vegetarianand non-vegetarian. Onion is valued for its bulbs having characteristic odour, flavor and pungency. Onion is regarded as a highly export oriented crop and earns a valuable foreign exchange for India.It is also a good source of minerals phosphorus and calcium. Besides this, it is also good source of proteins, carbohydrates, fats, thiamine, niacin and ascorbic acid. India is the second largest onion growing country with average yield of 16.2 t/ha. India is the second largest producer of onion in the world, next to China with an area of 1.43 million hectares and production of 26.15 million tones, but the productivity is low (16.2 t/ha) as compared to other countries (Anonymous 2020).

Weeds are one of the most important factors known to causesignificant reduction in onion yield which has direct correlation with weed competition. Onion exhibits greater susceptibility to weed competition as compared to other crops due to its inherent characteristics such as their slow growth, small stature, shallow roots and lack of dense foliage (Dhananivetha *et al.* 2017). In addition, their long growing season allows several successive flushes of weeds. Weeds compete with the crop plants for nutrients, water, space and light resulting in losses in yield, quality and value of the crop through increased production and harvesting cost. A loss in yield due to weed infestation ranged from49-86 % in onion (James and Harlen 2010).

Hand weeding, a conventional method of weed control is effective but it is time consuming, cumbersome and under many situations becomes uneconomical. The predominant choice for weed control in onion is the use of herbicides. Currently herbicides with greater efficacy and environmental safety are becoming available for effective control of weeds in field crops. Hence, the present study was planned to evaluate the efficacy of pre- and post-emergence herbicides on weed growth and yield in onion toidentify practically effective and economically feasible weed management method to suit to needs of farmers.

MATERIALS AND METHODS

The field experiment was conducted at Krishi Vigyan Kendra, Nurmahal, Jalandhar, Punjab to study the efficacy of different herbicides for controlling weeds in onion during the year 2019 and 2020 in *Rabi* season. Krishi Vigyan Kendra, Nurmahal, Jalandhar is geographically situated at 31°09'N latitude, 75°59' E longitude and at an altitude of about 237 m above

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mean sea level. The experimental site was sandy loam in texture, low in organic carbon (0.31) with available nitrogen (195 kg/ha), high in available phosphorus (28.7 kg/ha) and medium in available potassium (151 kg/ha) in 0-15 cm soil depth. Experiment was laid out in randomized complete block design and replicated thrice. The treatments consists of: pre-emergence application (PE) of oxyfluorfen 199.75 g/ha; post-emergence application (PoE) of quizalofop-ethyl 50 g/ha, quizalofop-ethyl + oxyfluorfen 50 g/ha PoE; quizalofop-ethyl +oxyfluorfen 70 g/ha PoE, quizalofop-ethyl +oxyflourfen100 g/ha PoE, hand weeding twice 30 and 60 days after transplanting (DAT) and unweeded control.

The nursery of onion (cv. PRO-6) was sown on raised beds using seed rate 10 kg/ha in last week of October in both the experimental years. The onion seedlings were transplantedin first fortnight of January during both the years following row to row and plant to plant spacing of 15cm and 7.5 cm, respectively. The crop was raised as per the recommended package of practices by Punjab Agricultural University, Ludhiana except weed control treatments. Oxyfluorfen 199.75 g/ha was applied within three days of transplanting as pre-emergence, while other treatments were post-emergence applied after 25 days after transplanting (DAT). The gross plot size for each treatment was 25 m^2. The data on weed density (number/m^2), and weeds biomass (dry matter) (g/m^2) were recorded atharvest. Weed control efficiency (WCE) was determined by followingformula.

$$WCE = \frac{(WD_C - WD_T) \times 100}{WD_C}$$

Where WD_C = Weed density (no./m^2) in control plot

WD_T = Weed density (no./m^2) in treated plot.

The number of weeds from one square meter were counted using quadrat of 1 m^2 randomly placed in each plot at 60 DAT. Later weeds were uprooted from sampling area from each treatment; sun dried for about 9–10 days and the dry weight (biomass) of the weeds was recorded. The data on fresh bulb weight (g), plant height (cm), bulb diameter (cm) and onion yield (t/ha) were recorded at harvest. The bulbs were uprooted manually in the first week of May during 2020 and last week of April during 2021. The data was statistically analyzed by standard analysis of variance technique for RBD described by (Gomez and Gomez 1984) comparisons were made at 5 per cent level of significance.

RESULTS AND DISCUSSION

Effect on weeds

Grassy and broad-leaved weeds were predominant weed flora in onion.Relative composition of weed species varied with the growth stages of onion. The weeds infested the experimental plots were: *Poa annua*, *Cyperus rotundus*, *Anagallis arvensis*, *Convolvulus arvensis*, *Lepidium sativum* and *Medicago denticulata* (**Table 1**). Relative proportion *Poa annua* in total weeds was high (48.0 %) *Cyperus rotundus* (17.0%), *Anagallis arvensis* (11.0%) and *Coronopus didymus* (9.0%), *Convolvulus arvensis* (7.0%), *Rumex dentatus* (5.0%) and *Medicago denticulata* (3.0%). The lowest weed density was recorded in weeding twice (30 and 60 DAT) followed by quizalofop-ethyl + oxyflourfen100 g/ha PoE. The maximum weed density was recorded in unweeded control plot followed by quizalofop-ethyl + oxyfluorfen 50 g/ha PoE and quizalofop-ethyl 50 g/ha PoE which are statistically at par quizalofop-ethyl + oxyfluorfen 70 g/ha PoE. It showed that some herbicidal treatments were found more effective than others. Similar results were reported by Sraw *et al.* (2016) in rabi onion. Highest weed control efficiency was recorded in hand weeded twice (90.0%) followed by treatment quizalofop-ethyl + oxyfluorfen 100 g/ha PoE (88.9%). It might be due to lack of competition for resources between crop and weeds due toeffective weed control. It was also observed that weed control efficiency varied from 77.5-88.9% in post-emergence application of quizalofop-ethyl 50 g/ha, quizalofop-ethyl + oxyfluorfen 50 g/ha, quizalofop-ethyl + oxyfluorfen70 g/ha and quizalofop-ethyl + oxyfluorfen 100 g/ha while it was 68.8% with oxyfluorfen 199.75 g/ha PE. Similar results were also recorded by Ganesh *et al.* (2022). Though weeds were controlled more efficiently and bulb yield production was highest hand weeding twice but its cost of cultivation was also higher because of the higher human labour requirement and their higher wages. Similar results were also recorded by Kalapure *et al.* (2013).

Table 1. Weed flora at experimental site

Scientific name	Weed category	Proportion of total weeds (%)
Poa annua	Grass	48
Cyperus rotundus	Sedge	17
Anagallis arvensis	Broad-leaved	11
Coronopus didymus	Broad-leaved	9
Convolvulus arvensis	Broad-leaved	7
Rumex dentatus	Broad-leaved	5
Medicago denticulata	Broad-leaved	3

Table 2. Effect of different weed control treatments on weed density, weed biomass and weed control efficiency at harvest (pooled data of two years)

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	Weed control efficiency (%)
Oxyfluorfen 199.75 g/ha PE	40.3	38.8	68.8
Quizalofop-ethyl 50 g/ha PoE	45.0	27.9	77.5
Quizalofop-ethyl + oxyfluorfen 50 g/ha PoE	47.0	24.3	80.4
Quizalofop-ethyl + oxyfluorfen70 g/ha PoE	44.7	20.7	83.4
Quizalofop-ethyl + oxyfluorfen 100 g/ha PoE	30.3	13.8	88.9
Hand weeding twice at 30 and 60 DAT	13.7	12.4	90.0
Unweeded control	87.7	124.5	-
LSD (p=0.05)	3.3	4.8	4.9

*PE=pre-emergence application; PoE= post-emergence application; DAT=days after transplanting

Table 3. Effect of different weed control treatments on growth and yield contributing characters and bulb yield of onion (pooled data of two years)

Treatment	Plant height (cm)	Bulb weight (g)	Bulb diameter (cm)	Bulb yield (t/ha)		
				2019	2020	Pooled
Oxyfluorfen 199.75 g/ha PE	62.1	64.7	4.5	29.49	29.51	29.50
Quizalofop-ethyl 50 g/ha PoE	63.5	71.5	5.3	29.97	29.77	29.87
Quizalofop-ethyl + oxyfluorfen 50 g/ha PoE	65.5	70.4	4.4	29.92	29.78	29.85
Quizalofop-ethyl + oxyfluorfen 70 g/ha PoE	67.1	70.3	5.7	29.99	30.30	30.11
Quizalofop-ethyl + oxyfluorfen 100 g/ha PoE	69.4	73.5	5.8	31.08	31.18	31.13
Hand weeding twice at 30 and 60 DAT	70.8	72.4	4.7	30.87	31.27	31.07
Unweeded control	43.5	39.3	3.1	20.41	20.03	20.22
LSD (p=0.05)	2.8	3.7	0.4	0.21	0.23	0.22

*PE=pre-emergence application; PoE= post-emergence application; DAT=days after transplanting

Table 4. Economics analysis of different weed control treatments

Treatment	Gross income (Rs×10^3/ha)	Net returns (Rs×10^3/ha)	B:C ratio
Oxyfluorfen 199.75 g/ha PE	285.0	145.59	2.04
Quizalofop ethyl 50 g/ha PoE	298.5	171.31	2.34
Quizalofop-ethyl + oxyfluorfen 50 g/ha PoE	298.5	172.67	2.37
Quizalofop-ethyl + oxyfluorfen 70 g/ha PoE	301.1	175.06	2.46
Quizalofop-ethyl + oxyfluorfen 100 g/ha PoE	311.3	184.90	2.48
Hand weeding twice at 30 and 60 DAT	310.7	129.53	1.80
Unweeded control	202.2	80.03	1.65

*PE=pre-emergence application; PoE= post-emergence application; DAT=days after transplanting

Effect on onion

Maximum onion plant height and higher bulb yield was recorded in hand weeded twice followed quizalofop-ethyl + oxyfluorfen 100 g/ha PoE and quizalofop-ethyl + oxyfluorfen 70 g/ha PoE (**Table 3**) In the present study, bulb diameter did not show significant difference amongst all the treatments. Bulb yield is final adjective from farmers point to fetch better price in market. During both the year of significantly higher bulb yield (31.13 t/ha) was recorded in quizalofop-ethyl + oxyfluorfen 100 g/ha PoE which was at par with hand weeding twice at 30 and 60 DAT. Minimum onion bulb yield was recorded in untreated control. Sraw *et al.* (2016) also reported that the efficacy of post emergence herbicides in term of yield and monetary return which is ultimate goal of all vegetable growers. Similar findings were observed by Barla and Upasani (2019), Sahoo and Tripathy (2019) and Hembrom *et al.* (2023).

Gross income was calculated from average price of onion prevailing market from which net returns per season were calculated in both experimental seasons. The highest net returns (Rs. 311300) and B:C ratio (2.48) was recorded with quizalofop-ethyl + oxyfluorfen at 70 g/ha PoE while minimum B:C ratio (1.65) was with un-weeded plot. Kalhapure *et al* (2014) also reported that post-emergence application of premix of oxyfluorfen + quizalofop-ethyl effectively control important grass and broad-leaved weeds in seed production onion with higher yield and monetary returns. These results also support findings of Kumari*et al.* (2019) and Singla and Singh (2020).

The application of quizalofop-ethyl + oxyfluorfen 100 g/ha gave the highest bulb yield and highest net returns of Rs 184.90 ×10^3/ha with B:C ratio 2.48 due to effective weed management. Hand weeding twice although gave better control of weeds, but it can only be practiced at small holder farmers onion fields and not on large scale cultivation in the state like Punjab, as the labour is very scarce, expensive and limited.

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RESEARCH ARTICLE

Effect of pre- and post-emergence herbicides on growth and yield of chia (*Salvia hispanica* L.)

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ABSTRACT

A field experiment was conducted during *Rabi* seasons of 2021-22 and 2022-23 at Research Farm of Dr. B.R. Choudhary Agricultural Research Station, Mandor, Agriculture University, Jodhpur with an objective of identifying suitable weed management practices in chia crop. The treatments comprised of post-emergence application (PoE) of bentazon 500 g/ha and 750 g/ha at 30 days after seeding (DAS), fluazifop–p-butyl 100 g/ha and 200 g/ha PoE at 30 DAS, pre-emergence application (PE) of sulfentrazon 50 g/ha and 75 g/ha, pendimethalin 200 g/ha and 400 g/ha PE, weed free and weedy check. A randomized block design with three replications was used. Bentazon 750 g/ha PoE recorded significantly lower total weed density, total weeds biomass, and maximum weed control efficiency (12.4, 83.4, 79.7 and 85.4 % at 30, 60, 90 and at harvest, respectively) with minimum reduction in yield due to weed competition. Among pre-emergence herbicides, sulfentrazon 75 g/ha and pendimethalin 400 g/ha were found statistically equally effective in controlling weeds in chia. It was concluded that bentazon 750 g/ha PoE can be used for managing weeds in chia.

Keywords: Bentazon, Chia, Pendimethalin, Sulfentrazon and Weed management

INTRODUCTION

Chia (*Salvia hispanica* L.) is a medicinal and edible plant from the Lamiaceae family and is native to Mexico and Guatemala (Ixtaina *et al.* 2008). Worldwide, central Mexico, Guatemala, Australia, South America and Argentina are the main producers of chia seeds. Chia seeds have become very popular nowadays due to the health benefits of eating their seeds. Chia seeds have many uses, mostly health-related. Chia seeds contain protein (15-25%), fat (30-30%), carbohydrates (26-41%) and total dietary fibre (18-30%). Chia seeds are a source of minerals (calcium, phosphorus, potassium and magnesium), vitamins (thiamine, riboflavin, niacin, folate, ascorbic acid and vitamin A) and antioxidant compounds (Anon 2022). It's seeds are considered the best source of omega-3 fatty acids and a good source of bioactive and polyphenolic compounds that help prevent inflammation, improve cognition, and reduce fat cholesterol in the human body (Punia and Dhull 2019). Cultivation of chia seeds in India began with small-scale cultivation in Madhya Pradesh, Andhra Pradesh, Gujarat, Maharashtra, Karnataka, Rajasthan, Haryana and Himachal Pradesh. The popularity of chia crop has also increased in Rajasthan and recently it has been included in the package of practices in agro-climatic zone Ia of Rajasthan. It grows in parts of Jalore, Jodhpur, Chittorgarh and Bhilwara districts in Rajasthan. Chia plants can grow up to 1.0 to 1.5 m tall, with leaves approximately 1.5 to 3.0 inches long and 1 to 2 inches wide and arranged near the stem. Chia seeds produce small white or purple flowers (3 to 4 mm) that facilitate self-pollination (Bresson *et al.* 2009). The seeds are black, brown and white, black, oval-shaped and 1 to 2 mm thick. Chia seeds can grow in many soil and climate types, but sandy loam soil is best for high yields.

There are many yield limiting factors in commercial cultivation of chia including infestation of weeds which causes yield loss due to competition in chia depending on the type, intensity and duration of competition. Competition for resources during the initial period is a major limitation to chia's productivity (Kumar *et al.* 2024). Weed interference can lead to low seed yield and subsequently lower the quality of the yields (Finch-Savage 2020). Forty-five days after Chia shoot emergence is considered the most critical period for competition (De Goes Maciel *et al.* 2019). Hand weeding 3-4 weeks after planting is often used to control weeds in chia. However, rising wages and labour shortages are forcing people to look for alternatives. Herbicides are an important tool used to control weeds in today's agriculture; they are effective against most, if not all, weeds (Mishra *et al.*

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2016, Karkanis *et al.* 2018). It would be economical for growers to choose proper crop management with effective and economical herbicides and other management methods. Currently, no recommended practices have been established for growing chia in the Western Arid Plains (Ia) region. Therefore, in order to increase chia productivity by weed control, this study was carried out to determine the effective pre- and post-emergence herbicides to manage weeds in chia crop.

MATERIALS AND METHODS

The experiment was conducted at Research Farm of Agricultural Research Station, Mandor, Agriculture University, Jodhpur during *Rabi* season of 2021-22 and 2022-23 to find out suitable effective herbicide for chia crop. The treatments comprised of post-emergence application (PoE) of bentazon 480 G/L SL (bentazon) 500 g/ha at 30 days after seeding (DAS), bentazon 750 g/ha 30 DAS, fluazifop-p-butyl 11.1% SL (fluazifop-p-butyl) 100 g/ha at 30 DAS, fluazifop–p-butyl 200 g/ha at 30 DAS, pre-emergence application (PE) of sulfentrazon 4 SC (39.6%) (sulfentrazon) 50 g/ha, sulfentrazon 75 g/ha, pendimethalin CS (38.7%) (pendimethalin) 200 g/ha PE, pendimethalin 400 g/ha PE, weed free and weedy check. Treatments were laid out in randomized block design with three replications. The seeds of chia genotype Jodhpur Chia 1 (JC 1) were sown in 20 and 25 October, 2021 and 2022 respectively by using *kera* method with spacing 30×10 cm and depth 3 cm. The soil of the experimental area was sandy loam in texture, neutral to slight saline in reaction (pH 8.2) having 1.3 g/kg organic carbon, 174.0 kg/ha available nitrogen, 22.2 kg/ha available phosphorus and 325.0 kg/ha available potassium. Recommended dose of 40-23-15 NPK kg/ha was applied through urea, single super phosphate and muriate of potash. 30 kg N and PK fertilisers were applied through basal dose and remain N as top dressing at 40 DAS. All the observations were recorded and recommended package of practices suggested by Agriculture University, Jodhpur were used except management of weeds. Data were analyzed using standard statistical procedures as suggested by Panse and Sukhatme (1978).

Total weed density and weed dry weight (biomass)

Weed samples from two randomly selected spots in each plot were taken at 30, 60, 90 DAS and at harvest stages with the help of 0.25 m^2 (0.5 m x 0.5 m) quadrat and the average density (no./m^2). was calculated. The samples collected were subjected to sun drying for sufficient time and weighed to compute average dry matter (biomass) (g/m^2). Data were transformed ($\sqrt{x+0.5}$) as recommended by Blackman and Roberts (1950) before statistical analysis.

Weed control efficiency (%)

In order to evaluate the weed management treatments for their efficacy, weed control efficiency of each treatment was computed by using the following formula given by Mani *et al.* (1973).

$$\text{WCE (\%)} = \frac{DM_C - DM_T}{DM_C} \times 100$$

Whereas,

DMC = Dry matter yield of weeds (weed biomass) in weedy check plot,

DMT = Dry matter yield of weeds (weed biomass) in treated plot

Weed index (%)

Weed index is defined as the magnitude yield reduction due to presence of weeds in comparison with weed free check. In other words, weed index expresses the competition offered by weeds measured by per cent reduction in yield owing to their presence in the field. Weed index was calculated by using following formulae.

$$\text{Weed index (\%)} = \frac{X - Y}{X} \times 100$$

Whereas,

X = Total yield from the weed free check

Y = Total yield from the treatment

The statistical analysis was done using MS excel program.

RESULTS AND DISCUSSION

The species wise relative weed density in weedy check at 30 DAS indicates the predominance of *Asphodelus tenuifolius* Cav. (40.0%), *Chenopodium album* L. (22.9%), *Chenopodium murale* (L.) S. Fuentes, Uotila & Borsch (17.1%), *Cyprus rotundas* L. (11.4%) and *Cirsium arvensis (L.) Scop.* (8.6%).

Total weed density (no./m^2)

Application of sulfentrazon 50 g/ha PE recorded 72% lower weed density compared to weedy check while sulfentrazone 75 g/ha PE recorded 78.9% lower weed density than weedy check (**Table 1**). Pendimethalin 200 g/ha PE and pendimethalin 400 g/ha PE recorded 72% and 74% lower weed density respectively than weedy check at 30 DAS. Among post-emergence herbicides, bentazon 750 g/ha applied at 30 DAS recorded significantly lower total weed density at 60 DAS of chia. Fluazifop –p-butyl 200 g/ha was superior than bentazone 500 g/ha and fluazifop –p-butyl 100 g/ha. Among pre-emergence herbicides, sulfentrazone 75 g/ha and pendimethalin 400 g/ha were found equally effective and recorded significantly lower total weed density than weedy check at 60 DAS of chia. Weed free and weedy check treatment, respectively recorded minimum and maximum density of total weeds at 60 DAS of chia.

Weed biomass

Sulfentrazon 50 g/ha and 75 g/ha PE reduced the total weed biomass by 77.7% and 84.5% (**Table 1**), respectively over weedy check. There was 76% reduction in total weeds biomass with pendimethalin 200 g/ha PE. The increased dose of pendimethalin 400 g/ha PE caused greater reduction in total weed biomass (81%), over weedy check**.** All the pre-emergence herbicides were found equally effective. Among post-emergence herbicides, bentazon 750 g/ha PoE at 30 DAS recorded significantly lower total weeds biomass in chia and was superior over rest of the treatments except weed free.

Weed control efficiency (%)

The maximum weed control efficiency was recorded with bentazon 750 g/ha PoE which was followed by pendimethalin 400 g/ha PE and sulfentrazon 75 g/ha PE and fluazifop–p-butyl 200 g/ha PoE at 60 DAS.

Weed index (%)

The least reduction in yield was recorded with bentazon 750 g/ha PoE followed by bentazone 500 g/ha PoE, sulfentrazone 75 g/ha PE, pendimethalin 400 g/ha PE and sulfentrazone 50 g/ha PE. Fluazifop–p-butyl 100 and 200 g/ha PoE and pendimethalin 200 g/ha PE were found lesser effective and recorded greater reduction in yield of chia in comparison to rest of the treatments.

Chia yield

The increase in chia seed yield was more with post-emergence herbicide application compared to pre-emergence herbicide application. Bentazone 750 g/ha PoE increased yield significantly, followed by bentazone 500 g/ha PoE, sulfentrazone 75 g/ha PE and pendimethalin 400 g/ha PE (**Table 3**). These

Table 1. Total weed density and biomass as influenced by various weed management treatments (pooled two years data)

Treatment	Total weed density (no./m^2)				Total weeds biomass (g/m^2)			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
Bentazon 500 g/ha PoE 30 DAS	(15.4)3.9	(3.6)2.0	(2.9)1.8	(3.5)2.0	(15.8)4.0	(6.9)2.7	(3.1)1.9	(3.9)2.11
Bentazon 750 g/ha PoE 30 DAS	(15.4)4.0	(2.1)1.6	(2.3)1.7	(2.5)1.7	(16.3)4.1	(4.0)2.1	(2.6)1.7	(2.8)1.82
Fluazifop-p-butyl 100 g/ha PoE 30 DAS	(16.5)4.1	(4.0)2.1	(4.7)2.2	(5.0)2.3	(17.9)4.3	(7.8)2.9	(5.6)2.4	(5.9)2.51
Fluazifop-p-butyl 200 g/ha PoE 30 DAS	(14.9)4.0	(3.0)1.9	(4.5)2.2	(4.5)2.2	(17.2)4.2	(5.9)2.5	(5.3)2.4	(5.2)2.38
Sulfentrazon 50 g/ha PE	(4.9)2.3	(4.7)2.3	(4.4)2.2	(5.1)2.3	(5.0)2.3	(9.3)3.1	(5.1)2.4	(6.0)2.53
Sulfentrazon 75 g/ha PE	(3.7)2.0	(3.8)2.1	(3.5)2.0	(4.0)2.1	(3.8)2.1	(7.3)2.8	(4.0)2.1	(4.6)2.25
Pendimethalin 200 g/ha PE	(5.3)2.3	(4.9)2.3	(6.2)2.5	(6.4)2.5	(5.3)2.4	(9.6)3.2	(7.6)2.8	(7.8)2.87
Pendimethalin 400 g/ha PE	(3.9)2.2	(4.5)2.2	(4.0)2.1	(4.6)2.2	(4.4)2.2	(8.7)3.0	(4.6)2.3	(5.5)2.44
Weed free	(0.0)0.7	(0.0)0.7	(0.0)0.7	(0.0)0.7	(0.0)0.7	(0.0)0.7	(0.0)0.7	(0.0)0.71
Weedy check	(17.5)4.2	(20.4)4.5	(11.8)3.5	(17.8)4.2	(18.6)4.4	(24.2)5.0	(12.7)3.6	(19.4)4.46
LSD (p=0.05)	0.45	0.41	0.58	0.37	0.36	0.49	0.59	0.28

*The values in the parenthesis are square root transformed values; PoE = post-emergence application; PE = pre-emergence application; DAS = days after seeding

Table 2. Weed control efficiency, and weed index of chia crop as influenced by different weed management treatments. (pooled two years data)

Treatment*	Weed control efficiency (%)				Weed index (%)
	30 DAS	60 DAS	90 DAS	At harvest	
Bentazon 500 g/ha PoE 30 DAS	14.9	71.6	75.3	79.7	15.5
Bentazon 750 g/ha PoE 30 DAS	12.4	83.4	79.7	85.4	10.2
Fluazifop-p-butyl 100 g/ha PoE 30 DAS	3.7	67.7	56.1	69.8	31.8
Fluazifop-p-butyl 200 g/ha PoE 30 DAS	7.6	75.7	58.1	73.1	27.9
Sulfentrazon 50 g/ha PE	72.9	61.6	59.7	69.0	26.1
Sulfentrazon 75 g/ha PE	79.7	69.9	68.8	76.2	16.8
Pendimethalin 200 g/ha PE	71.4	60.2	40.3	59.9	38.5
Pendimethalin 400 g/ha PE	76.5	63.8	63.6	71.7	20.7
Weed free	100.0	100.0	100.0	100.0	0.0
Weedy check	0.0	0.0	0.0	0.0	53.6

*PoE = post-emergence application; PE = pre-emergence application; DAS = days after seeding

Table 3. Seed yield and ancillary characters affected by different weed management treatments (pooled two years data)

Treatment*	Seed yield (kg/ha)			Straw yield (kg/ha)	Biomass yield (kg/ha)	Harvest index	Plant height (cm)
	2022	2023	Pooled				
Bentazon 500 g/ha PoE 30 DAS	469	472	471	1561	2031	0.23	74.1
Bentazon 750 g/ha at 30 DAS	495	505	500	1604	2104	0.24	75.2
Fluazifop-p-butyl 100 g/ha PoE 30 DAS	382	377	380	1316	1696	0.22	67.7
Fluazifop-p-butyl 200 g/ha PoE 30 DAS	417	385	401	1365	1766	0.23	68.2
Sulfentrazon 50 g/ha PE	434	390	412	1429	1840	0.22	68.5
Sulfentrazon 75 g/ha as PE	467	460	463	1555	2018	0.23	69.1
Pendimethalin 200 g/ha PE	371	314	342	1218	1560	0.22	67.8
Pendimethalin 400 g/ha PE	460	423	441	1511	1952	0.23	69.2
Weed free	554	560	557	1723	2279	0.24	76.2
Weedy check	291	226	258	950	1209	0.22	65.5
LSD (p=0.05)	76.22	52.66	89.43	274.53	311.28	NS	6.50

*PoE = post-emergence application; PE = pre-emergence application; DAS = days after seeding

treatments are comparable to each other and superior over fluazifop-p-butyl 100 g/ha PoE, fluazifop-p-butyl 200 g/ha PoE and pendimethalin 200 g/ha PE. The increase in yield and its traits may be due to reduced weed competition with the use of herbicides before crop initiation and subsequent reduced competition for nutrients and other growth factors with post-emergence herbicides. These practices reduce competition between crops and plants, thus saving more nutrients for crops and allowing crops to grow better (Maciel *et al.* 2018).

Bentazon 750 g/ha PoE and sulfentrazon 75 g/ha PE efficiently controlled the weeds and produced higher yield of chia. Hence, they can be used for weed control in chia crop.

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RESEARCH ARTICLE

Validation of bioherbicidal activity of *Kluyvera intermedia* against *Echinochloa crus-galli*

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ABSTRACT

Weeds in rice fields compete with crops for essential resources, causing severe yield losses based on weed infestation levels and control measures. The current study, conducted at Mahatma Gandhi University, Kottayam, Kerala, India, during June 2023 and March 2024, aims to assess the potentiality of *Kluyvera intermedia* as a bacterial biocontrol agent against *Echinochloa crus-galli* (L.) P. Beauv. (barnyard grass), the common weed of rice fields. Of the 127 bacterial isolates, the bacterial strain *Kluyvera intermedia* MA2 efficiently controlled *Echinochloa crus-galli*. The treated plants showed chlorosis after the first 3 days of application of bacteria and complete death of the plant in 7 days. The study's second objective was to identify the active compound responsible for the herbicidal activity of *Kluyvera intermedia*. The characterization of the active compounds via HR LC-MS/MS (Q-TOF) analysis revealed phthalic acid esters, pyrazine derivatives, and quinoline derivatives as bioactive compounds. Molecular docking studies with antioxidant enzymes revealed significant interactions between phthalic acid esters and key amino acid residues: SER173, ARG38, and ALA134 of ascorbate peroxidase; VAL372 and SER374 of glutathione reductase. Propylpyrazine showed strong binding with PRO367 of catalase, ILE93 of glutathione S-transferase, ARG31 of ascorbate peroxidase, and ASP466 of glutathione reductase. Additionally, 6-methylquinoline interacted notably with ALA253 of catalase. Biochemical, enzymatic, and antibiotic profiling identified the bacterium as an IAA-producing, gram-negative and rod-shaped strain. It demonstrated susceptibility to eight antibiotics and the ability to produce several enzymes, including cellulases, catalases, phenylalanine deaminases, and proteases.

Keywords: Biocontrol, *Echinochloa crus-galli*, *Kluyvera intermedia*, Microbial bioherbicide, Rice, Weed management

INTRODUCTION

Bioherbicides include chemical residues derived from natural sources like fungi, bacteria, and plant extracts with herbicidal roles. They could be advantageous over chemical herbicides, as they are a sustainable and environmentally friendly option for weed control (Duke *et al*. 2024). Unlike synthetic herbicides, bioherbicides are biodegradable and less likely to lead to weed resistance. Methyl indole-3-acetate, an auxin analog purified from *Bacillus altitudinis* was successful in suppressing the growth of wild oats (*Avena fatua* L.) (Ma *et al*. 2024). An aromatic polyketide called julichromes isolated from a Streptomyces species showed inhibitory activities against *Amaranthus retroflexus Setaria viridis*, *Portulaca oleracea* and *Chenopodium album* (Ling *et al*. 2023). *Streptomyces gardneri* producing anthraquinone exhibited 100% herbicidal activity against several weeds (Umurzokov *et al*. 2022). *Bacillus weidmannii* obtained from diseased wheat seeds were found to deliver Cry proteins that constrained the growth of ryegrass (Eigharlou *et al*. 2024).

Echinochloa crus-galli (L.) P. Beauv., commonly known as barnyard grass is highly autogamous annual weed in rice paddy fields causing more than 80% loss (Rao 2021). Both *Echinochloa* spp. and rice belong to the family Graminae. Moreover, they share common biological characteristics, nutrient demand, and growth periods resulting in intense competition for resources (Wu *et al*. 2022). The contemporary methods to control this weed include mechanical removal and herbicide use. However, the unjudicious use of herbicides has led to the emergence of herbicide resistance in barnyard grass (Damalas and Koutroubas 2023). The presence of herbicide residues in the environment directly intimidates ecological security and biodiversity.

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Acknowledging these aspects, this study aims to assess the potential of *Kluyvera intermedia* as a bacterial biocontrol agent to control *Echinochloa crus-galli* (L.) P. Beauv.

MATERIALS AND METHODS

Sample collection and isolation of bacteria

The soil samples were collected from different areas in the state of Kerala, India, and outside the State. The collected samples included sandy soils (coastal plains) (Alappuzha, Thiruvananthapuram), alluvium soil (Kottayam), riverine alluvial soils (river banks), laterite soil (Kottayam), black soil (Palakkad), and special group soils (Mangrove soil from Kannur and Desert soil from Rajasthan). Different soil bacteria were obtained by serial dilution and plating on different nutrient media (Nutrient broth, Lura-Bertani broth, King's B broth, and Tryptone Soya Broth; Himedia Laboratories, India). The well-isolated colonies of different bacteria were maintained in the respective culture media slants from which they were obtained and stored at 4^0C for further screening studies.

Screening of isolates for herbicidal activity

Growth of the weeds: Seeds of *Echinochloa crus-galli* were surface sterilized with 70% alcohol for 20 seconds followed by 30-second wash in 3.25% (v/v) NaOCl. The seeds were thoroughly washed with sterile distilled water and given an acid wash with 1N HCl for 30 seconds to break the dormancy and induce germination. The seeds were planted in pots, with one seedling in each pot at a depth of 14cm and filled with solarized soil. The seeds were allowed to germinate and grow into seedlings. Fully grown plants of about 50 cm in height were used for screening purposes.

Assessment of herbicidal activity: Individual colonies of the bacterial isolates were grown in nutrient broth to obtain an optical density of 1 OD at an absorbance of 600 nm. The culture supernatants obtained by centrifugation at 10000 rpm for 10 minutes were used for the treatment. Forty ml of the culture supernatant was treated with the weed plant for 7 days along with control plants treated with sterile distilled water. The plants were observed for morphological changes (chlorosis, necrosis) and finally, complete death as an indication of positive herbicidal activity. A scale by the European Weed Research Council (2010) was used to visually rate the herbicidal effectiveness of different bacteria on the weed plant (Mugehu and Chandiposha 2014) **(Table 1)**. The assessment was done for two seasons, June 2023 and March 2024 at the Mahatma Gandhi University campus in Kottayam, Kerala, India.

Table 1. Ratings as per the European Weed Research Council (2010)

Category number	Percentage of Weed Kill	Herbicidal effectiveness on weeds
1	100	Complete kill
2	97.5-99.9	Excellent
3	95-97.5	Good
4	90-95	Adequate
5	85-90	Just inadequate
6	75-85	Poor
7	65-75	Very poor
8	33-65	Useless
9	0-33	Almost no effect

Herbicide Effectiveness of different bacterial isolates

Name of the isolate	Category number based on the Effectiveness on *Echinochloa cruss-galli*
Pseudomonas sp	5
Streptococcus sp	6
Staphylococcus sp	5
Kluyvera intermedia MA2	2

Identification of potential isolates

Bacterial isolates showing herbicidal activity were identified using biochemical and molecular characterization. The genomic DNA was isolated using NucleoSpin® Tissue Kit (Macherey-Nagel, Germany) following the manufacturer's instructions. The 16S rDNA PCR amplification was carried out in a thermal cycler (GeneAmp PCR System 9700, Applied Biosystems, U.S.A.) using the primers 16S-RS-F:5′ -CAGGCCTAACACATGCAAGTC-3′ and 16S-RS-R:5′ -GGGCGGWGTGTACAAGGC-3′. The sequencing was carried out in ABI 3500 DNA Analyzer (Applied Biosystems, U.S.A). Sequence alignment and required editing of the obtained sequences were carried out using Geneious Pro v5.1(Kearse *et al.* 2012).

Identification and characterization of active herbicidal component

Growth of weeds: The method for growing and maintaining weed plants is the same as mentione above except that the seeds were allowed to germinate and grow into seedlings in 4-5 leaved stages for experimental use.

Extraction of active compound: Crude metabolites were extracted from the bacterial supernatant by partitioning with a double volume of organic solvents such as hexane, petroleum ether, chloroform, and ethyl acetate in the order of polarity in a separating funnel. The organic phase was collected and dried using a rotary evaporator at 60^0C. The residues collected from each solvent were dissolved in 1% DMSO and used for further analysis for the presence of an active compound.

Testing the efficacy of crude metabolites: The plant seedlings were treated with five replicates of solvent-extracted active components along with suitable controls (distilled water and DMSO) and kept for seven days. The plants were observed for any morphological changes to mark the signs of the herbicide effect. The extract showing promising herbicidal activity was analyzed via HR LC-MS/MS (Q-TOF) to identify the active compound present.

In silico docking studies: The biologically active compounds identified from the crude extract of the isolate were subjected to molecular docking to determine possible interactions with antioxidant enzymes: catalase (PDB ID:5GKN), glutathione-s-transferase (PDB ID:1GNW), ascorbate peroxidase (PDB ID:2XI6), and glutathione reductase (PDB ID:2HQM). The 3D structures of the active compounds were obtained from the PubChem online data server. AutoDock Vina analyzed the molecular interaction between the ligand and the receptor using the PyRx virtual screening tool. The proteins were prepared by AutoDock Tools 1.5.7 (Scripps Research Institute, USA) before docking by removing water molecules and adding polar hydrogens and Kollmann charges. Binding affinities and hydrogen bond interactions were recorded for each enzyme. PyMol (Schrodinger) was used to visualize the crystal structure of complexes.

Characterization of the isolate

Antibiotic profiling: The Kirby- Bauer Disc diffusion test was performed to determine the antibiotic resistance of the test bacteria against 14 antibiotics. Lawn cultured bacterial isolate on Mueller Hinton Agar was treated with different antibiotics, incubated at 30°C for 24 hours, and observed for their zone of inhibition patterns.

Enzyme profiling: The potential isolate was screened for the production of different enzymes including amylase, chitinase, phosphatase, urease, cellulase, catalase, phenylalanine activity, and protease activity by growing them in selective media. Amylase activity was screened on starch medium and after incubation for about 21-24 hrs at 37^0C, the plates were exposed to an iodine solution to check for clear zones around the test bacteria. Chitinase activity was evaluated in the chitin medium and the formation of halo zones was identified as positive for chitinase activity. Phosphatase production was determined in the Sperber medium, continuously checking for clear zones at 48, 72, 120, 144, and 168 hrs respectively due to hydrolysis. A change in the color of the medium from yellow to red was considered positive for urease production. Bacterial inoculated phenylalanine agar slants post incubation are treated with 10% $FeCl_3$ solution and observed for a sudden change in color to green marking a positive reaction. Cellulase activity is screened in a carboxymethylcellulose (CMC-Na) flooded with 0.2% aqueous Congo Red solution and destained by 1M NaCl to see a yellow halo surrounding the bacteria as a positive reaction. The test bacteria were inoculated into a 30% skim milk agar to study protease activity. The formation of clear zones was positive for protease activity.

RESULTS AND DISCUSSION

Biological control is an efficient and environmentally friendly substitute for or in addition to conventional herbicides. Microbial biocontrol agents (BCA) have been created in recent decades for treating bacterial and fungal infections because biological control is an emerging potential alternative. The use of microbial bioherbicides including deleterious rhizospheric bacteria has gained attention for the past many years. Therefore, exploring different bacteria present in different soil types may uncover a novel bioherbicide agent.

Isolation, screening, and identification of potential isolates

Out of the 127 morphologically distinct bacterial isolates obtained, only 4 different bacteria showed positive herbicidal properties against *Echinochloa crus-galli*. They were identified as *Pseudomonas sp*., *Streptococcus* sp., *Kluyvera intermedia* MA2, and *Staphylococcus sp* by molecular characterization. According to the ratings by the European Weed Research Council (2010), *Kluyvera intermedia* strain MA2 showed excellent weed control compared to other bacterial isolates and was selected for further study. The weed plant leaves showed necrosis and chlorosis within 3 days of bioherbicide treatment and the plant was completely damaged after 7 days **(Figure 1)**. The bacteria were identified morphologically, biochemically, and by molecular techniques **(Figure 2. A, B)**. The nucleotide

Figure 1. *Echinocloa crus-galli* plants before and after treatment with *Kluyvera intermedia* MA2.
A. Control: *Echinocloa crus-galli* plants after 7 days of treatment. **B.** Test: *Echinocloa crus-galli* plants before treatment. **C**. Test: *Echinocloa crus-galli* plants after 7 days of treatment with *Kluyvera intermedia* MA2.

sequence of the isolate was deposited in the Genbank with accession number OR399149. The culture has also been deposited in the National Centre for Cell Science (NCCS), Pune, Maharashtra, India (Accession number: MCC5423).

Identification and characterization of active components with herbicidal activity

Microorganisms work in immense ways to alter the soil ecosystem rendering numerous methods for weed control. Many rhizospheric bacteria are found to suppress weed growth by reducing its biomass, and seed production, while some inhibit weeds using their biometabolites. The hexane extracts obtained from *Kluyvera intermedia strain MA2* showed herbicidal activity against *Echinochloa* seedlings. After completing the seven-day experiment, chlorosis and necrosis were consistently seen in the test plants treated with the hexane extract. The absence of any chlorosis and necrosis in the control seedlings ruled out the possibility of the negative action of hexane. The HR LC-MS/MS (Q-TOF) analysis of the *Kluyvera intermedia* strain MA2 extract showed many bioactive compounds. Of these compounds, 6-methylquinoline, propylpyrazine, and phthalic acid mono-2-ethyl hexyl ester are previously reported to have herbicidal properties (Lawrance *et al*. 2019), (Huang *et al*. 2021), (Rybakova *et al*. 2016) **(Figure 3)**. In a previous study quinoline derivatives from *Pseudomonas aeruginosa* H6 showed herbicidal activity against *Pennisetum purpureum*, *Oryza sativa*, *Pisum sativa*, and *Amaranthus spinosum* (Lawrance *et al.* 2019). The herbicidal potential of numerous derivatives of pyrazine, such as analogs of pyrazinamide, and pyrazinoic acid has been established to have 95% control over *Echinochloa crus-galli* (Armel *et al.* 2024). This also supported the action of *Kluyvera intermedia* against *Echinocloa crus-galli* as noted in our study. Physiological studies have revealed that concentration of phthalic acid esters significantly contributed to the increased levels of antioxidant enzyme superoxide dismutase in tobacco plants. Increased antioxidant enzymes suggest oxidative damage in plant systems due to reactive oxygen species. It may indicate that phthalic acid mono-2-ethyl hexyl ester obtained from *Kluyvera intermedia* MA2 might induce oxidative damage in *Echinochloa* plants, rendering their growth inhibition. The utilization of bacterial secondary metabolites for effectively eradicating weeds has proved to be competent in sustainable agriculture. Herbicidal metabolites from *Bacillus velezensis* are efficient in controlling Egyptian broomrape *Orobranche aegyptiaca* (He *et al*. 2022).

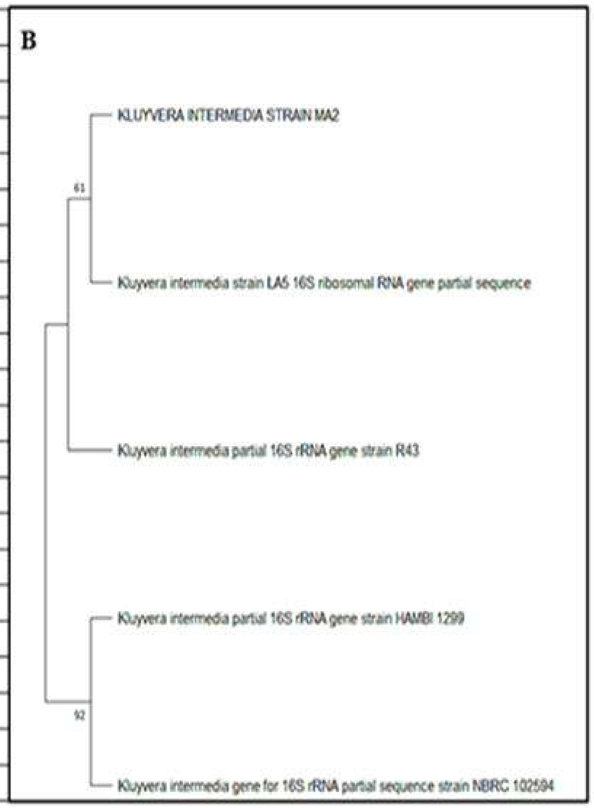
Molecular docking of the bioactive compounds 6-methylquinoline, propylpyrazine, and phthalic acid mono-2-ethyl hexyl ester obtained from *Kluyvera intermedia* strain MA2 revealed the probable interactions of these compounds with the antioxidant enzymes catalase, ascorbate peroxidase, glutathione -s-transferase and glutathione reductase. The ligands phthalic acid mono-2-ethyl hexyl ester and propylpyrazine showed hydrogen bonds with enzymes catalase, glutathione-s-transferase, ascorbate peroxidase, and glutathione reductase. However, 6-methylquinoline showed no interactions with glutathione-s-transferase, ascorbate peroxidase, and glutathione reductase **(Figure 4)**.

The phthalic acid mono-2-ethyl hexyl ester-catalase complex showed H-bond interactions with ASN243, LYS242, and HIS210, while propylpyrazine and 6-methylquinoline complexes with catalase exhibited single H-bond interactions with PRO367 and ALA253 respectively. In the complexes made by both phthalic acid mono-2-ethyl hexyl ester and propylpyrazine with glutathione-s-transferase, one H-bonds were made each by the two ligands with GLN72 and ILE93 of the enzyme. The structural complex of phthalic acid mono-2-ethyl hexyl ester with ascorbate peroxidase showed strong H-bond interactions with the active site residues ARG38 and ALA134 respectively. In molecular docking studies, binding energy is attributed to the strong interaction between a target and a ligand molecule. The more negative the binding affinity is, the stronger the attachment (López-Camacho *et al*. 2016). This study revealed negative binding energy for all the antioxidant enzymes indicating a stronger interaction possibility. The formation of H-bonds also constitutes the global binding energy of the ligand-protein

A

Colony morphology	Size	Medium
	Margin	Irregular
	Opacity	Opaque
	Surface	Wrinkled
	Colour	Creamy (not white)
Cell characters	Gram's reaction	Gram negative
	Shape	Rod
	Motility	Motile
	Endospores	+
Biochemical characters	Indole	-
	Methyl red	+
	Vogues Proskauer	+
	Citrate utilisation	+
	H_2S production	-
	Gelatin Hydrolysis	-
	Oxidase	-
	Catalase	+
	Urease	-
Fermentation	Glucose	+
	Sucrose	+
	Galactose	+
	Sorbitol	+

B



C

Enzyme	Activity
Amylase	-
Chitinase	-
Phosphatase	-
Urease	-
Lipase	-
Cellulase	+
Catalase	+
Phenylalanine deaminase	+
Protease	+

Antibiotics (µg/disc)	Resistant/Sensitive	Zone of Inhibition (mm)
Rifampicin[15]	Resistant	14
Cefipime[30]	Resistant	-
Amikacin[10]	Sensitive	22
Amoxyclav[10]	Resistant	7
Penicillin[10]	Resistant	-
Cefoperazone[75]	Intermediate	18
Tetracyclin[10]	Sensitive	26
Chloramphenicol[10]	Sensitive	21
Gentamycin[10]	Sensitive	26
Erythromycin[15]	Sensitive	28
Streptomycin[10]	Sensitive	23
Ampicillin[10]	Resistant	-
Cefixime[5]	Resistant	-
Imipenem[10]	Sensitive	22

Figure 2. A. Morphological and Biochemical Characteristics of *Kluyvera intermedia* strain MA2. **B**. Phylogenetic tree showing *Kluyvera intermedia* strain MA2 and other similar sequences from the same genus. **C**. Enzyme profile and Antibiotic profile of *Kluyvera intermedia* strain MA2.

Sl No.	Name of the compound	Retention time	Formula	Polarity
1.	6-methylquinoline	5.105	$C_{10}H_9N$	M+ H+
2.	Propylpyrazine	5.596	$C_7H_{10}N_2$	M+H+
3.	Phthalic acid mono-2-ethyl hexyl ester	19.708	$C_{16}H_{22}O_4$	M+H+

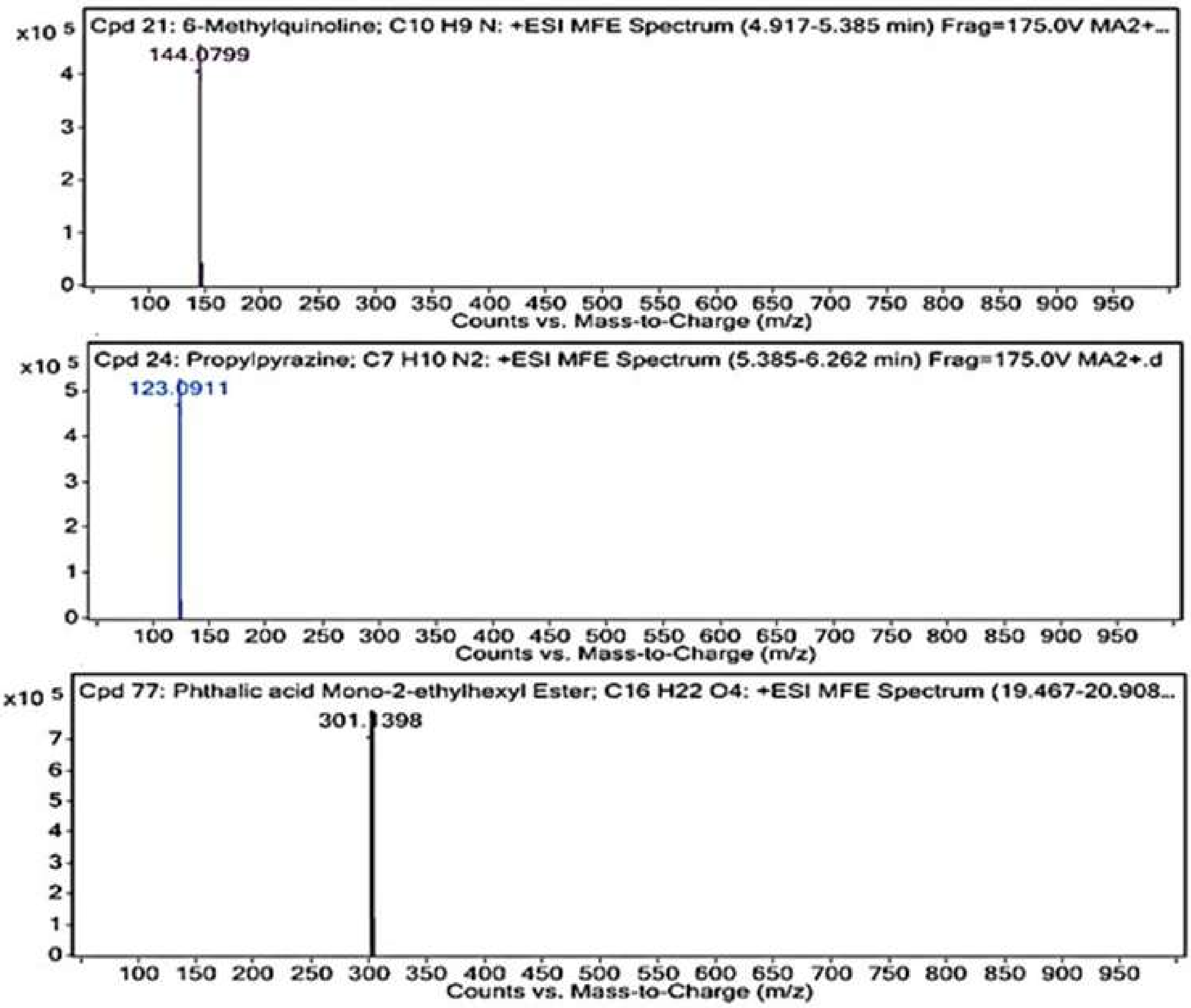


Figure 3. HR LC-MS/MS (Q-TOF) profile of active compounds from *Kluyvera intermedia* MA2 showing bioherbicidal activities

complexes. It was evident from the crystal structures the formation of H-bonds among the various complexes formed between the antioxidant enzymes and the ligands.

Plants constitute a multilevel and intricate system of antioxidant operations to tackle reactive oxygen species in their growth environment (Dumanovic *et al.* 2021). Molecular docking studies can reveal possible conformational changes to the protein and ligand that may disrupt the natural structure of the enzymes by adhering to various amino acid residues. The global binding energy of the antioxidant enzymes with all the bioactive compounds was negative indicating stronger interactions with each other. The highest value was attributed as -8.2 kcal/mol for glutathione-s-transferase-phthalic acid mono-2-ethyl hexyl ester complex. However, the binding energy is low for the same ligand with ascorbate peroxidase but it has stronger H-bond interactions with active site residues ARG38 and

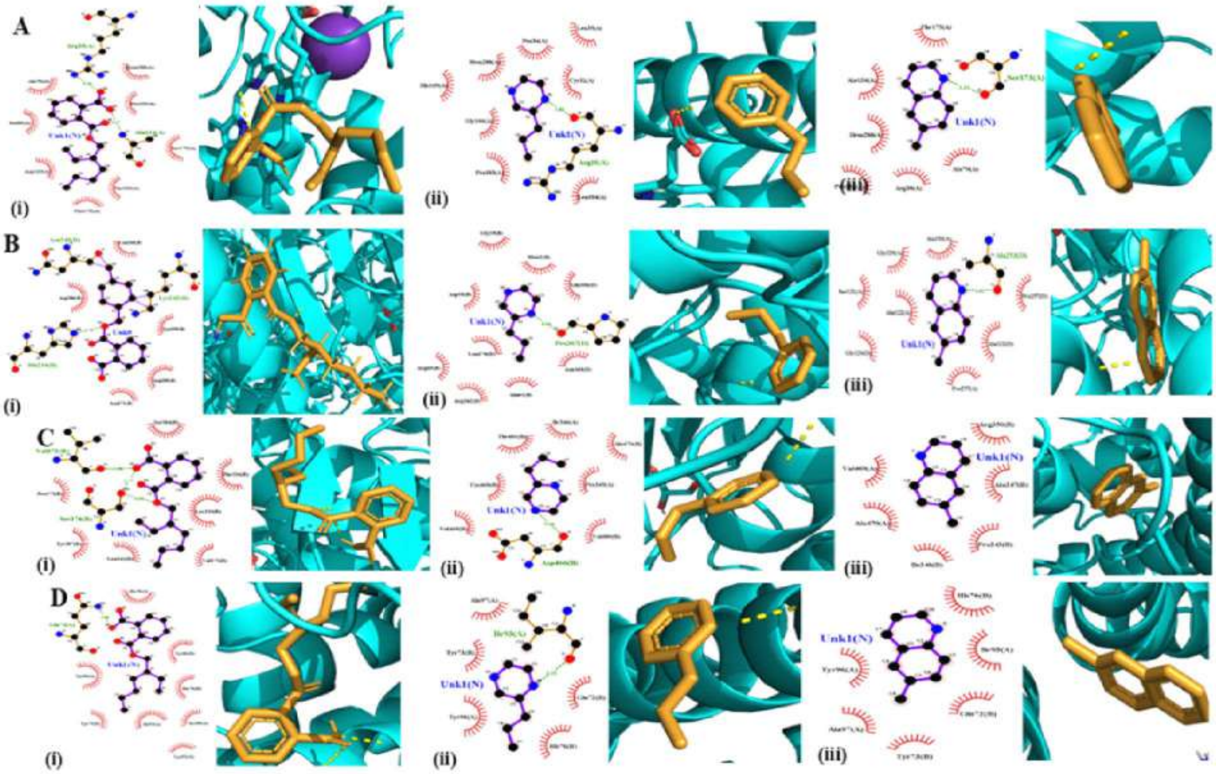


Figure 4. Visualization of bioactive compounds in complex formation with antioxidant enzymes representing 2D and 3D structures. (A) Ascorbate peroxidase, **(B)** Catalase, **(C)** Glutathione reductase, and **(D)** Glutathione-s-transferase [**(i)** phthalic acid mono-2-ethyl hexyl ester, **(ii)** propylpyrazine, and **(iii)** 6-methylquinoline]

ALA134 of the enzyme. 6-methylquinoline also interacts with the active site residues of ascorbate peroxidase at SER173 with a binding energy of -5.5 kcal/mol. Moreover, 6-methyl quinoline does not show any H-bonds with glutathione-s-transferase or glutathione reductase but has a negative binding affinity of -7.2 and -5.9 kcal/mol respectively. Negative binding energy indicates a favorable interaction. However, visualization of the 2D/3D structures reveals no formation of H-bonds with glutathione-s-transferase and glutathione reductase. Even though H-bonds signify a stronger attachment negative binding energy of the ligand with the enzymes suggests that it might be due to weaker hydrophobic interactions, electrostatic interactions, conformational changes of the protein and/or ligand, or Van der Waals forces of attraction (Schiebel et al. 2018). A better understanding of the physiology of antioxidant enzymes can only be gained after monitoring the level of these enzymes in bioherbicide-treated plants for a particular period.

The antibiotic resistance profile of the isolate MA2 revealed that the bacteria were susceptible to seven antibiotics namely Amikacin[10], Tetracyclin[10], Chloramphenicol[10], Gentamycin[10], Erythromycin[15], Streptomycin[10], Imipenem[10], resistant to six of them being Rifampicin[15], Cefipime[30], Amoxyclav[10], Penicillin[10], Ampicillin[10], Cefixime[5], and intermediate with Cefoperazone[75] (all µg/disc). The enzyme profiling of the isolate MA2 detected positive cellulase, catalase, phenylalanine deaminase, and protease activity **(Figure 2.C)**. Antibiotic profiling of any bacteria is relevant as the resistance of organisms to antibiotics can cause severe health hazards and is essential to cognize the susceptibility range of the organism you are handling (Maugeri *et al.* 2019).

The recent advances in biotechnology enable researchers to design or recreate biological enzymes to be utilized in various processes. By understanding the various enzymes a bacteria can produce, new ways for their synthesis might develop (Kieliszek *et al*. 2021). The enzyme profiling of isolate MA2 revealed that it produces cellulases, catalases, phenylalanine deaminases, and proteases. In tandem with the ability of microbes to promote plant growth, the production of metabolites that induce deleterious effects on weed plants has also been reported.

In this era of integrated weed management, biologically based control agents for weeds have gained virtue. These biological products are used directly or in a derived form as bioherbicides. In this study, aimed at identifying a bacterial biocontrol agent for effective control of *Echinochloa crus-galli*, the *Kluyvera intermedia* strain MA2 was recognized as a bioherbicide against barnyard grass. To our knowledge, this is the first report demonstrating the bioherbicidal property of *Kluyvera intermedia*. Chromatographic studies lead to identifying the active compounds behind the herbicidal action as phthalic acid mono-2-ethyl hexyl ester, propylpyrazine, and 6-methylquinoline. The *in silico* studies demonstrated the active compounds' possible interactions with the antioxidant enzymes catalase, ascorbate peroxidase, glutathione-s-transferase, and glutathione reductase. This suggests the use of the product of *Kluyvera intermedia* as an effective bioherbicide in the future after meticulous studies on their mechanism of action, toxicity on aquatic organisms, soil microflora, cell lines, *etc*.

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RESEARCH ARTICLE

Estimation of GR_{50} values of sulfosulfuron + metsulfuron (ready mix) and sulfosulfuron against herbicides resistant *Phalaris minor Retz*. in Punjab

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ABSTRACT

Two separate field experiments were conducted at the experimental farm of the Department of Agronomy, Lovely Professional University Phagwara, Punjab, during 2022-2023 and 2023-2024 to estimate the GR_{50} values of prominent herbicides, *viz*. sulfosulfuron + metsulfuron 30 g/ha and sulfosulfuron 25 g/ha against herbicide resistant populations of *Phalaris minor* collected from different districts of Punjab. Split Plot Design (SPD) was used with three replications. The sulfosulfuron + metsulfuron 30 g/ha, at recommended level caused significantly less mortality percentage resulting in significantly greater biomass of *P. minor* during both years as compared to its 2X dose. Among biotypes significantly less mortality was observed with Ropar biotype and significantly less biomass with Fazilka biotype as compared to Ferozepur and Ludhiana biotypes. The biomass of *P. minor* was also significantly higher with sulfosulfuron X level than 2X level of sulfosulfuron. Among all the biotypes significantly higher mortality and significantly less biomass was observed with Fazilka biotype as compared to other biotypes during both the years.

Keywords: Biotypes, $GR_{50,}$ Herbicide resistance, *Phalaris minor,* Sulfosulfuron, Sulfosulfuron + metsulfuron

INTRODUCTION

North western Indo-Gangetic plains (IGPs) of India comprising states of Haryana, Punjab, and western Uttar Pradesh contributes more than 50% of national wheat production (Soni *et al*. 2023). The weeds are the major biotic constraint in wheat production of this region. Wheat is infested by diverse weed flora but among them, *Phalaris minor Retz*. is a major problematic and mimicry weed of wheat (Kadam *et al*. 2021) in rice-wheat cropping system. It germinates in different flushes after wheat sowing and competes with the wheat for different resources.

In wheat herbicide application is recommended 35 days after seeding (DAS) for the control of grassy weeds and many alternative herbicides were used to manage the infestation of *P. minor* like isoproturon, fenoxaprop, clodinafop etc. These herbicides were used prominently and resistance to these herbicides also developed (Das *et al*. 2024). Sulfosulfuron and sulfosulfuron + metsulfuron were the alternatives herbicides, which were used by the farmers of Punjab from last many years (Cessna *et al*. 2015). These herbicides belong to sulfonylureas group which is very prone to resistance. These herbicides generally inhibit the activity of ALS (acetolactate synthase enzyme) (Adari *et al*. 2024). Now a days farmers are reporting a problem in some areas of Punjab that these herbicide are not giving satisfactory control of *P. minor* where these herbicides are being used (*Kaur et al*. 2023).

Estimation of GR_{50} (amount of herbicide required for the 50% growth reduction compared to control) of resistant population of *P. minor*, which indicates the level of resistance and time required for the occurrence of resistance in the *P. minor* population (Wei *et al*. 2016). Henceo, these herbicides were used at variable levels to assess their efficacy (Hooda *et al*. 2023). This study was made to estimate the GR_{50} values of sulfosulfuron and ready-mix formulation of sulfosulfuron + metsulfuron, so that their level of resistance in different biotypes of *P. minor* and also their efficacy can be assessed

MATERIALS AND METHODS

Two separate experiments were conducted during *Rabi seasons of* 2022-23 and 2023-24 at Agronomy Research Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab.

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The experimental site falls under the sub- tropic regions remain cool in winter and hot in summer, maximum rainfall in the month of July, August and September due to the south west monsoon. The temperature never goes below zero degree, however especially in the months of December and January it remains extremely cold. The highest temperature recorded was nearly 46^0 Celsius during the months of May and June. Different biotypes of *Phalaris minor* were collected in the year 2022 from the different districts of Punjab. *i.e*. village Mallan wala khas in Ferozepur district, village Mothapur in Ropar district, where sulfosulfuron + metsulfuron was used by the farmers since the last 5-6 years, and from village Islam wala in Fazilka district and from village Barewal in Ludhiana district where the sulfosulfuron was used by the farmers from since last 5-6 years. Both the experiments were laid out in Split Plot Design keeping herbicide dose in 5 main plots and biotypes in 4 sub plots with three replications.

The sowing of *P. minor* seeds was done manually on the 18th of November during 2022-23 and 2023-24 in adequate moist soil by maintaining 22.5cm row to row spacing. The gross plot size of $4.5m^2$ (1.5 ×3m) was kept for each treatment. The trial was conducted in *P. minor* seed free land and there was no addition of FYM, poultry or other organic manures because these could be the possible source of *Phalaris* seed contamination.

The herbicide application was done when the *P. minor* plants were in 3-4 leaf stage (which comes nearly 30-35 DAS). The graded levels of each of two herbicides were kept as 1/2X, X, 2X, 4X (X stands for recommended dose). One control treatment where no herbicide application was done was also kept with each herbicide treatment. The recommended dose (X) of Total (sulfosulfuron + metsulfuron) and Leader (sulfosulfuron) used were 30 and 25 g/ha, respectively. Herbicide application was done manually with the help of knap-sack sprayer which was fitted with flat fan nozzle and the herbicide application was done on area basis using 250 l/ha of water. The observations on *Phalaris minor*, like mortality (%), dry matter (biomass) (g/m²) and number of tillers per meter row length, and height (cm) were recorded 75 DAS when experiment was terminated.

RESULTS AND DISCUSSION

A-Mortality percentage

Visual observations were recorded on the mortality % of different treatments at the time of termination of experiments. The mortality percentage increased with increase in dose of sulfosulfuron + metsulfuron herbicide during both the years (**Table 2**). The mortality % in X dose was found at par with 1/2X dose but it was significantly less than 2X and 4X dose during both the years. Among the biotypes significantly less mortality % was recorded in Ropar biotype as compared to Ferozepur, Fazilka and Ludhiana biotypes with the application of sulfosulfuron + metsulfuron.

Similarly, the mortality percentage increased with increase in dose of sulfosulfuron but its performance was unsatisfactory and less than that of sulfosulfuron + metsulfuron herbicide. The performance of sulfosulfuron was very poor even at 4X level as indicated by *P. minor* biomass. Performance of sulfosulfuron herbicide was very poor among all biotypes except Fazilka biotype. The mortality percentage of Fazilka biotype was significantly more than all other all biotypes. The significantly less mortality percentage was found in Ferozepur, Ropar and Ludhiana biotypes as compared to Fazilka biotype.

Biomass of *Phalaris minor*

Sulfosulfuron+ metsulfuron herbicide reduced the biomass of *Phalaris minor* significantly during both the years and correspondingly with the increase in dose of herbicide from 1/2X to 4X (**Table 2** and **Figure 1**). However significantly higher biomass was found in unweeded (control) than all other level of herbicide during both the years. Among the biotypes

Table 1. Mortality (%) as influenced by *Phalaris minor* biotypes and different doses of sulfosulfuron + metsulfuron and sulfosulfuron

	Mortality %			
	Sulfosulfuron + metsulfuron		Sulfosulfuron	
	2022-23	2023-24	2022-23	2023-24
Main plots- herbicide doses				
Control	0.0	0.0	0.0	0.0
½ X	37.6	31.5	25.3	19.6
X	38.4	29.2	36.4	31.5
2X	52.9	47.4	42.2	39.6
4X	72.7	66.8	43.5	41.5
LSD (p=0.05)	13.9	3.5	9.4	6.5
Subplots- P. minor biotypes				
Ferozepur	49.3	40.4	5.0	0.0
Ropar	13.8	11.6	12.5	8.3
Fazilka	47.7	48.0	64.0	60.6
Ludhiana	50.6	46.6	36.4	30.5
LSD (p=0.05)	7.2	2.5	7.8	5.8

Table 2. Biomass of *Phalaris minor* as influenced by its biotypes and different doses of herbicides

	Biomass (g/m^2)			
	Sulfosulfuron + metsulfuron		Sulfosulfuron	
	2022-23	2023-24	2022-23	2023-24
Main plots- herbicide doses				
Control	128.08	139.8	142.6	135.4
½ X	20.2 (84.3)	22.2 (84.1)	61.9 (56.5)	64.6 (54.6)
X	16.2 (86.8)	15.4 (88.9)	52.1 (63.4)	62.2 (55.9)
2X	12.7 (90.1)	13.3 (90.4)	49.6 (65.2)	56.8 (60.1)
4X	6.9 (94.6)	11.8 (91.5)	49.0 (65.6)	54.5 (61.7)
LSD (p=0.05)	3.1	1.9	2.3	2.5
Sub plots- *P. minor* biotypes				
Ferozepur	31.3 (75.6)	36.4 (73.9)	125.6 (11.5)	124.0 (13.0)
Ropar	47.8 (62.8)	51.4 (63.2)	73.3 (48.5)	83.5 (41.4)
Fazilka	25.8 (79.9)	26.2 (81.2)	29.6 (79.2)	36.5 (74.4)
Ludhiana	43.0 (66.6)	41.0 (70.6)	55.7 (60.9)	64.5 (54.7)
LSD (p=0.05)	8.0	12.5	6.9	16.8

Data within parentheses represent percent decrease of biomass of *P. minor* over control

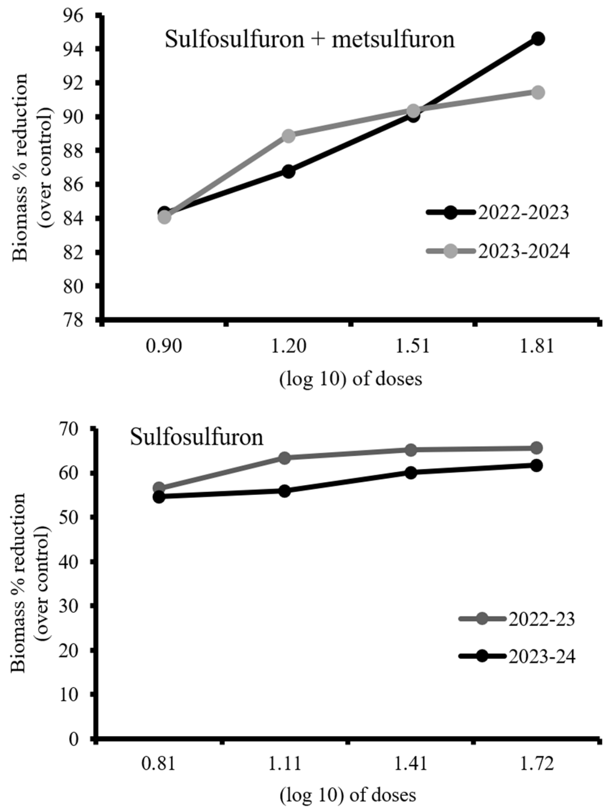

Figure 1. Percent reduction in biomass of *P. minor* with different doses of herbicides

significantly less biomass was recorded with Fazilka and Ferozepur biotypes as compared to others during both the years. The percent reduction in biomass of *Phalaris minor* at 1/2X dose was 84.3% and 84.1% less than unweeded (control) in the 1st and 2nd year which indicates that this herbicide is still reasonably effective even at 1/2X dose. Among the biotypes, the percent reduction in biomass of all 4- biotypes was more than 50% as compared to untreated indicating thereby that all biotypes are susceptible to this herbicide. However, Fazilka biotype during both years recorded significantly less biomass than other biotypes.

Sulfosulfuron herbicide reduced the biomass significantly more at X dose than at1/2 X during 2022-23 but at par during 2023-24, however it was significantly less than control (unsprayed). Biomass of *P. minor* at X dose was significantly more than 2X and 4X during both years (**Table 2** and **Figure 1**). Sulfosulfuron herbicide appeared less effective as compared to sulfosulfuron + metsulfuron because at the X level of herbicide dose it shows 63.4% and 55.9% reduction in growth of *Phalaris minor* during both the years. And the percent reduction in sulfosulfuron at X and 4X level were at par which shows that this herbicide was not capable to provide satisfactory control *of P. minor* populations even at their higher doses. Based on biomass percent reduction, it was observed that Ferozepur and Ropar district population was more resistant to sulfosulfuron than Fazilka district population which showed more susceptibility (79.2% and 74.4% reduction)

Number of *P. minor* tillers per meter row length

Number of tillers of *P. minor* were significantly more in unsprayed (control) during both the years when treated with sulfosulfuron + metsulfuron. During 2022-23 total tillers were at par among all herbicide levels except 1/2Xand during 2023-24, the recommended dose produced significantly more total tillers than its 2Xand 4X levels. Fazilka biotype produced significantly greater number of tillers than all other biotypes during both the years. Significantly higher numbers of tillers were observed in Ludhiana biotype as compared to other during 2022-23 and these were at par in Ferozepur, Ropar and Ludhiana biotypes. At the recommended dose of sulfosulfuron + metsulfuron, the percent decrease in number of tillers of *Phalaris minor* was less than 50% during both the years and complete mortality was not

Table 3. Number of *P. minor* tillers as influenced by different doses and biotypes

	No. of tillers of *P. minor* per meter row length			
	Sulfosulfuron + metsulfuron		Sulfosulfuron	
	2022-23	2023-24	2022-23	2023-24
Main plot- herbicide doses				
Control	26.2	26.9	50.3	61.0
½ X	15.1 (42.3)	24.3 (9.6)	46.8 (6.9)	58.8 (3.6)
X	13.2 (49.6)	16.5 (38.6)	33.5 (33.4)	46.6 (23.6)
2X	11.3 (56.8)	10.7 (60.2)	32.5 (35.3)	37.2 (39.0)
4X	8.8 (66.4)	8.2 (69.5)	30.5 (39.3)	36.8 (39.6)
LSD (p=0.05)	7.4	4.6	6.1	3.1
Sub plots- *P. minor* biotypes				
Ferozepur	15.8 (58.0)	17.1 (36.4)	55.0 (-9.3)	58.3 (4.4)
Ropar	15.1 (42.3)	20.2 (24.9)	40.0 (20.4)	57.6 (5.5)
Fazilka	11.0 (39.6)	9.9 (63.1)	16.3 (67.5)	23.2 (61.9)
Ludhiana	17.9 (31.6)	19.3 (28.2)	43.6 (13.3)	53.1 (12.9)
LSD (p=0.05)	2.3	3.4	3.9	3.5

Data in parentheses represents percent decrease of number of tillers over control

Table. 4. Height of *Phalaris minor* plants as affected by its biotypes and different dose of herbicides

	Phalaris minor plant height (cm)			
	Sulfosulfuron + metsulfuron		Sulfosulfuron	
	2022-23	2023-24	2022-23	2023-24
Main plots - herbicide doses				
Control	38.8	39.2	46.5	44.2
½ X	29.8 (23.1)	30.2 (22.9)	36.9 (20.6)	38.9 (11.9)
X	27.6 (28.8)	26.4 (32.6)	33.2 (28.6)	30.2 (31.6)
2X	25.7 (33.7)	21.0 (46.4)	32.0 (31.1)	23.5 (46.8)
4X	21.5 (44.5)	19.4 (50.5)	29.5 (36.5)	26.3 (40.4)
LSD (p=0.05)	2.2	2.0	5.6	2.5
Sub plots - P. minor biotypes				
Ferozepur	26.9 (30.6)	32.8 (16.0)	42.5 (8.6)	46.4 (4.9)
Ropar	33.6 (13.4)	32.5 (17.0)	38.4 (17.4)	39.0 (11.7)
Fazilka	24.2 (37.6)	20.6 (47.4)	28.7 (38.2)	25.6 (42.0)
Ludhiana	29.9 (22.9)	28.5 (27.2)	33.0 (29.0)	35.2 (20.3)
LSD (p=0.05)	3.9	1.6	7.0	1.6

Data within parentheses represent percent decrease in plant height over control

obtained even at 4X reflecting probably the beginning of resistance development Among the biotypes, the highest percent reduction was recorded in Ferozepur biotype (58.0%) during 2022-23 and Fazilka biotype (63.1%) during the 2023-24.

Number of tillers at X dose were significantly less than 1/2Xdose and were at par at 2Xand 4Xduring both the years. However, significantly higher number of tillers were recorded in unsprayed (control) than all other treatments. Among the biotypes, Fazilka biotype showed susceptibility to the sulfosulfuron herbicide. This biotype showed significantly a smaller number of tillers than all other biotypes during both years. Significantly higher numbers of tillers during both the years were recorded in Ferozepur biotype as compared to other biotypes. Whereas percent reduction in total tillers was not more than 50% even at its higher doses. At the 4X, the percent reduction was 39.3% and 39.6% during 2022-23 and 2023-24 indicating that *Phalaris minor* has developed resistance to this herbicide. Among the biotypes, Fazilka biotype recorded 67.5 and 61.9 % reduction during both the years. Whereas all other biotypes are having less than 50 % reduction. In general, the efficiency of sulfosulfuron + metsulfuron was more than sulfosulfuron.

Height of *Phalaris minor* plants (cm)

The plant height during both the years was significantly more in untreated (control) as compared to all other herbicidal treatments. Plant height during both the years at X dose was significantly more than 2Xand 4Xlevels. Among the biotypes, significantly less plant height was found in Fazilka biotype during both the years as compared to Ferozepur, Ropar and Ludhiana biotypes. During 2022-23 significantly less plant height was attained in Fazilka and Ferozepur biotypes, and in Fazilka biotype during 2023-24 as compared to other tested biotypes.

Sulfosulfuron herbicide at X level showed significantly less plant height than untreated (control) however it was at par at X, 2Xand 4X levels of sulfosulfuron during 2022-23. Among the biotypes, significantly higher plant height was found in Ferozepur biotype during both the years as compared to all other biotypes.

Conclusion

It may be concluded that with the recommended dose of sulfosulfuron + metsulfuron and sulfosulfuron, *P. minor* biotypes were not controlled satisfactorily. The performance of sulfosulfuron + metsulfuron was superior than that of sulfosulfuron. Only Fazilka biotype of *P. minor* was found susceptible to the sulfosulfuron and sulfosulfuron + metsulfuron while all other biotypes showed resistance to both tested herbicides.

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RESEARCH NOTE

Efficacy of pre-emergence herbicides in managing weedy rice in wet-seeded rice

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ABSTRACT

An experiment was conducted during 2023-2024 in a farmer's field with a history of severe infestation of weedy rice located in Thrissur district, Kerala. The objective of the study was to identify effective pre-emergence herbicides for managing weedy rice and improving rice yield in wet-seeded rice. Twelve treatments were included, *viz*. oxyfluorfen 0.15 kg/ha just prior to sowing (0 DBS); oxyfluorfen 0.15 kg/ha at 10 days after seeding (DAS); butachlor at two doses 1.25 kg/ha and 0.625 kg/ha 7 DAS; pendimethalin 1.5 kg/ha 7 DAS; pretilachlor 0.75 kg/ha 7 DAS; pyrazosulfuron-ethyl 0.03 kg/ha 7 DAS; pretilachlor 30% + pyrazosulfuron-ethyl 0.75% (pretilachlor + pyrazosulfuron-ethyl) 0.62 kg/ha 7 DAS; pendimethalin 24% + penoxsulam 1% (pendimethalin + penoxsulam) 0.625 kg/ha 7 DAS; butachlor 38.8% + penoxsulam 0.97% (butachlor + penoxsulam) 0.82 kg/ha 7 DAS; unweeded control and weed-free check. Spraying oxyfluorfen 0.15 kg/ha just prior to sowing of pre-germinated rice seeds resulted in the highest weedy rice control efficiency (73%) at 30 DAS with grain yield reduction of only 8% compared to the 69% in unweeded control. The next best effective herbicides were oxyfluorfen 0.15 kg/ha 10 DAS and butachlor + penoxsulam 0.82 kg/ha 7 DAS, which registered 12 and 17% rice yield reduction, respectively. Phytotoxicity was observed with oxyfluorfen and butachlor, but the rice recovered within two weeks.

Keywords: Butachlor + penoxsulam, Oxyfluorfen, Pre-seeding herbicide application, Red rice, Weed management

Direct-seeding has become the primary method for rice crop establishment in many Asian countries due to rising production costs, labour shortages, increasing wage rates, and limited water resources (Rao *et al*. 2007 and 2017). However, the proliferation of weeds, particularly weedy rice (*Oryza sativa* f. *spontanea*), presents a significant challenge in direct-seeded rice (DSR) systems (Chauhan and Johnson 2010; Abraham and Jose 2015). Weedy rice is widely distributed across commercial rice-growing regions in Asia, Africa, and Latin America, especially where direct-seeding practices are common. It has several competitive advantages, such as enhanced seed dormancy, seed shattering, and vigorous proliferation, leading to substantial yield loss, often ranging from 15% to 100%. The close anatomical and physiological similarities between weedy rice and cultivated rice make selective herbicide application difficult, necessitating alternative control strategies, such as modifying herbicide application timings and techniques.

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To explore effective management strategies, a study was conducted in Thrissur district, Kerala, India, during the 2023-2024 season. The aim of the experiment was to evaluate the efficacy of different pre-emergence herbicides in controlling weedy rice in wet-seeded rice (WSR) and to identify the most effective herbicide treatments for managing weedy rice and improving wet-seeded rice yield. The selected field, with a history of severe weedy rice infestation, had sandy clay loam soil and a pH of 5.93. The experiment was laid out in randomised block design (RBD), replicated thrice, with a plot size of 5 x 4m. There were twelve treatments *viz*. unweeded control (UWC), weed-free check (hand weeding), oxyfluorfen 23.5% EC (oxyfluorfen) 0.15 kg/ha at 0 days before to sowing (0 DBS), oxyfluorfen 0.15 kg/ha at 10 days after seeding (DAS); butachlor 50% EW (butachlor)1.25 kg/ha 7 DAS; butachlor 0.625 kg/ha 7 DAS; pendimethalin 30% EC (pendimethalin)1.5 kg/ha, pretilachlor 37% EW (pretilachlor) 0.75 kg/ha 7 DAS; pyrazosulfuron-ethyl 10% WP (pyrazosulfuron-ethyl) 0.03 kg/ha 7 DAS; pretilachlor 30% + pyrazosulfuron-ethyl 0.75% WG (pretilachlor + pyrazosulfuron-ethyl) 0.62 kg/ha 7 DAS; pendimethalin 24% + penoxsulam 1% SE (pendimethalin + penoxsulam) 0.625 kg/ha 7 DAS and butachlor 38.8% + penoxsulam 0.97% SE (butachlor + penoxsulam) 0.82 kg/ha 7 DAS. All the herbicides other than oxyfluorfen were applied on 7 DAS. The treatment with oxyfluorfen on the day of sowing was applied on puddled wet soil, and the pre-germinated rice seeds were sown immediately after spraying. Water was let into the herbicide-applied plot three days after spraying. In the weed-free check, initial hand weeding was done at 15 DAS, and periodic weeding was undertaken to keep the plot weed-free.

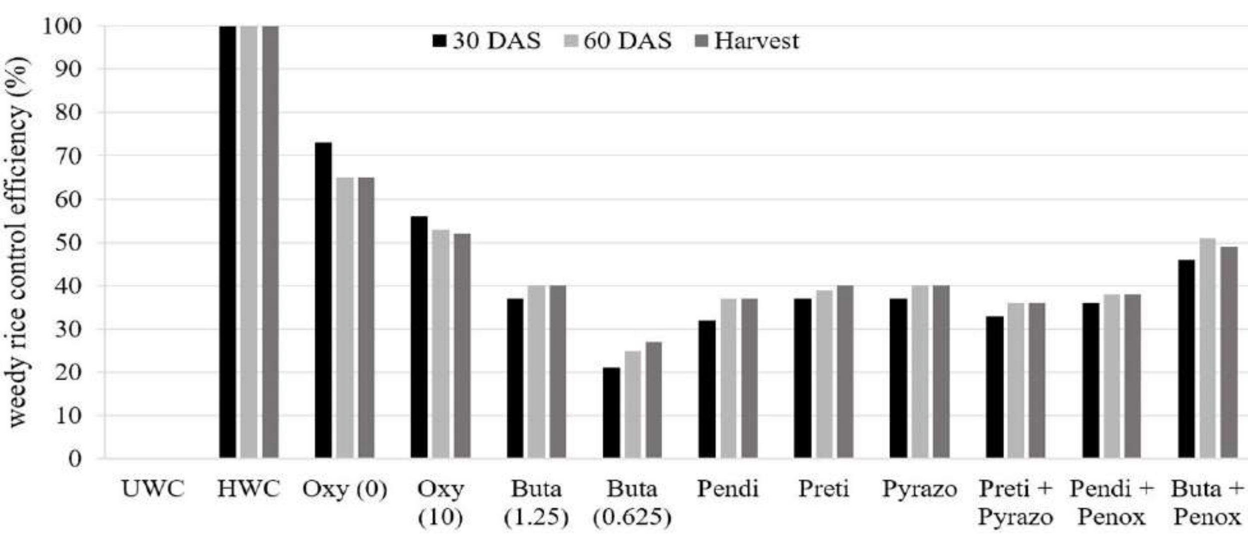
The phytotoxicity of herbicides was noted at 3, 7 and 14 days after herbicide application, using a phytotoxicity scoring scale from 0 to 5 as given by Thomas and Abraham (2007). Observation on plant height, number of tillers/m^2, grain and straw yield (kg/ha), were recorded. The data was analysed using the statistical package "GRAPES" (General R-based Analysis Platform Empowered by Statistics) developed by Gopinath *et al.* (2021). Data on parameters which showed wide variation were subjected to square root transformation [$\sqrt{x+0.5}$] to make the analysis of variance valid. Multiple comparisons among treatment means, where the F test was significant (at 5% level) were done with Tukey's HSD test (Honestly Significant Difference).

Effect on weedy rice and other weeds

The major weed flora of the experimental field was weedy rice (*Oryza sativa* f. *spontanea*). Other weeds included *Echinochloa* sp., *Fimbristylis miliacea*, *Ludwigia* sp., *Lindernia* sp. and *Sagittaria* sp.

Herbicide application had a significant effect on the density and biomass of weedy rice at 30 and 60 DAS and at harvest (**Table 1**). The hand-weeded plot was kept weed-free, and hence, no weedy rice was present in the field at all stages of observation. The weedy rice biotype found in the experimental plot had the same height as that of the cultivated variety even at heading stage. The grains were straw coloured and with awns ranging from 1.1 to 3.2 cm in length. The number of tillers per plant was also lower (2-3 tillers/plant) compared to typical weedy rice biotypes. Ngyuyen *et al.* (2023) documented that certain weedy rice lines display significant morphological similarities with cultivated rice, encompassing analogous growth periods, heights, husk pigmentation, and seed morphology.

Among the herbicides used, oxyfluorfen 0 DBS (on the same day of sowing) registered the lowest weedy rice density and biomass. It was statistically superior to all other herbicides due to the action of oxyfluorfen in preventing the germination of weedy rice from soil seed bank. Similar observations on the weedy rice control potential of oxyfluorfen was reported earlier by Hassan and Rao (1994) and Abraham and Jose (2015). The next best treatments were oxyfluorfen at 10 DAS and premix of butachlor + penoxsulam, respectively. The weedy rice density ranged from 17 no/m^2 with oxyfluorfen 0 DBS to 60 no/m^2 in unweeded control at 30 DAS. The weedy rice density showed a slight increase at rice harvest stage and ranged from 26 to 72 no/m^2. The weedy rice density and biomass were highest in the unweeded control at all growth stages.



UWC - unweeded control, HWC-weed-free check, Oxy (0) – oxyfluorfen at 0 DBS; Oxy (10) - oxyfluorfen at 10 DAS, Buta (1.25) - butachlor at 1.25 kg/ha; Buta (0.625) - butachlor (0.625 kg/ha), + penoxsulam; Pendi - pendimethalin, Preti - pretilachlor, Pyrazo – pyrazosulfuron-ethyl, Preti + Pyrazo - pretilachlor + pyrazosulfuron-ethyl, Pendi + Penox – pendimethalin + penoxsulam, and Buta + Penox - butachlor + penoxsulam; *DAS = days after seeding; DBS = days before seeding

Figure 1. Effect of weed management treatments on weedy rice control efficiency

Table 1. Effect of weed management treatments on weedy rice density and biomass

Treatment	Weedy rice density (no./m^2)			Weedy rice biomass (g/m^2)		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
Unweeded control	7.80^a (60.33)	8.21^a (67.00)	8.49^a (71.67)	11.50^a (131.71)	13.89^a (192.62)	16.64^a (276.6)
Weed free check (hand weeded)	0.71^g (0.00)	0.71^f (0.00)	0.71^f (0.00)	0.71^g (0.00)	0.71^f (0.00)	0.71^f (0.00)
Oxyfluorfen 0.15 kg/ha 0 DBS	4.22^f (17.33)	4.88^e (23.33)	5.11^e (25.67)	6.06^f (36.22)	8.18^e (66.46)	9.81^e (95.74)
Oxyfluorfen 0.15 kg/ha 10 DAS	5.30^e (27.67)	5.70^d (32.00)	5.99^d (35.33)	7.67^e (58.48)	9.53^d (90.33)	11.59^d (133.73)
Butachlor 1.25 kg/ha 7 DAS	6.23^{cd} (38.33)	6.42^c (40.67)	6.64^{bc} (43.67)	9.15^{cd} (83.19)	10.77^c (115.63)	12.94^c (167.07)
Butachlor 0.625 kg/ha 7 DAS	6.82^b (46.00)	7.08^b (49.67)	6.87^b (46.67)	10.22^b (103.91)	12.00^b (143.51)	14.27^c (203.02)
Pendimethalin 1.5 kg/ha 7DAS	6.49^{bc} (41.67)	6.55^c (42.33)	6.77^b (45.33)	9.46^c (89.01)	11.01^c (120.65)	13.25^c (174.98)
Pretilachlor 0.75 kg/ha 7DAS	6.23^{cd} (38.33)	6.44^c (41.00)	6.62^{bc} (43.33)	9.11^{cd} (82.49)	10.82^c (116.57)	12.91^c (166.14)
Pyrazosulfuron-ethyl 0.03 kg/ha 7 DAS	6.20^{cd} (38.00)	6.42^c (40.67)	6.62^{bc} (43.33)	9.11^{cd} (82.5)	10.78^c (115.76)	12.88^c (165.54)
Pretilachlor + pyrazosulfuron-ethyl 0.62 kg/ha 7 DAS	6.46^{bc} (41.33)	6.57^c (42.67)	6.84^b (46.33)	9.41^c (88.13)	10.97^c (123.93)	13.34^c (177.65)
Pendimethalin + penoxsulam 0.625 kg/ha 7DAS	6.28^{cd} (39.00)	6.54^c (42.33)	6.74^b (45.00)	9.18^c (83.86)	10.97^c (119.99)	13.13^c (171.91)
Butachlor + penoxsulam 0.82 kg/ha 7 DAS	5.90^d (34.33)	5.90^d (34.33)	6.29^{cd} (39.00)	8.49^d (71.62)	9.71^d (93.84)	11.84^d (139.77)

$\sqrt{x+0.5}$ transformed values, original values in parenthesis. In a column, means followed by common letters do not differ significantly at 5% level in Tukey's Test.; DAS = days after seeding; DBS = days before seeding

Table 2. Phytotoxicity of herbicides on rice

Treatment	Days after spraying		
	3	7	14
Oxyfluorfen 0.15 kg/ha 0 DBS	2	2	0
Oxyfluorfen 0.15 kg/ha 10 DAS	3	3	0
Butachlor 1.25 kg/ha 7 DAS	2	2	0
Butachlor 0.625 kg/ha 7 DAS	0	0	0
Pendimethalin 1.5 kg/ha 7 DAS	1	0	0
Pretilachlor 0.75 kg/ha 7 DAS	1	1	0
Pyrazosulfuron-ethyl 0.03 kg/ha 7 DAS	0	0	0
Pretilachlor + pyrazosulfuron-ethyl 0.62 kg/ha 7 DAS	0	0	0
Pendimethalin + penoxsulam 0.625 kg/ha 7 DAS	1	2	0
Butachlor + penoxsulam 0.82 kg/ha 7 DAS	2	2	0

Rating scale: 0 - No injury, 1 - Slight injury, 2- Moderate injury, 3- Severe injury, 4- Very severe injury, 5-Complete destruction; DAS = days after seeding; DBS = days before seeding

The highest weedy rice control efficiency (WCE) of 73% was recorded with oxyfluorfen applied on the day of sowing (before rice seeding) (**Figure 1**). At 60 DAS and harvest the WCE was slightly reduced to 65%, yet it remained the most effective treatment among all herbicides evaluated. Among the combination herbicides used, butachlor + penoxsulam recorded the highest WCE of 46, 51 and 49% at 30, 60 DAS and harvest, respectively. This can be attributed to the pre-emergent action of the herbicide. In situations where the herbicide is applied to the soil surface, rice seedlings exhibit selective advantages as pre-germinated seeds are sown above the herbicide layer (Jose 2015). Weedy rice seedlings, along with other weed seedlings that germinate through the herbicide-treated stratum, fail to establish, leading to a reduction in the weed population. Oxyfluorfen application on the day of sowing was found superior to all other herbicides, likely due to the fact that all other herbicides were sprayed one week after sowing of rice and hence weedy rice could emerge during the period of 0 to 6 days after sowing rice seeds.

Almost a similar trend of WCE as that of weedy rice was observed in the case of other weeds also, except that butachlor + penoxsulam registered a higher WCE of 81% compared to 51% with respect to weedy rice. In the case of weeds other than weedy rice, the pre-emergent application of oxyfluorfen recorded the highest weed control efficiency of 92% at 60 DAS. The next best treatment was butachlor + penoxsulam where WCE was 81%. Pendimethalin + penoxsulam, pyrazosulfuron-ethyl and oxyfluorfen at 10 DAS registered WCE ranging from 70–75%. Butachlor at a lower dose of 0.625 kg/ha resulted in a poor WCE (23%) and high weed dry matter production, which led to severe crop-weed competition.

Phytotoxicity

Spraying of oxyfluorfen at 10 DAS showed a higher phytotoxicity (**Table 2**). The appearance of tiny brownish spots and drying of leaf tips was noted. Oxyfluorfen is a selective herbicide that has both pre- and post-emergent action. The contact action of oxyfluorfen is well established, and it disrupts cell membranes and inhibits protoporphyrinogen oxidase, an enzyme essential for the biosynthesis of chlorophyll. This was in line with the findings of Abraham *et al*. (2010). Similarly, treatments such as oxyfluorfen on the day of sowing, butachlor and butachlor + penoxsulam also registered slight phytotoxicity. Butachlor generally induces mild toxicity in rice, leading to a notable reduction in pigment levels, along with alterations in chloroplast structure. Phytotoxicity of the combination herbicide butachlor + penoxsulam can also be attributed to the butachlor present in it, which constituted 38.8% of the active ingredient of the herbicide. At seven days after spraying also, the phytotoxicity score in all the treatments remained the same. However, by two weeks, plants in all treatments recovered, and no phytotoxicity could be observed.

Table 3. Effect of treatments on growth and yield parameters of wet-seeded rice

Treatment	No. of tillers/m^2		Panicles m^{-2}	Grains per panicle	Filled grains per panicle
	30 DAS	60 DAS			
Unweeded control	90.33^{f}	191.67^{i}	124.33^{i}	59.67^{f}	50.67^{e}
Weed free check (hand weeded)	285.79^{a}	571.67^{a}	471.00^{a}	113.00^{a}	108.00^{a}
Oxyfluorfen 0.15 kg/ha 0 DBS	258.72^{abc}	542.67^{b}	451.33^{b}	103.00^{ab}	95.67^{b}
Oxyfluorfen 0.15 kg/ha 10 DAS	245.95^{bc}	519.67^{c}	434.33^{c}	92.67^{bc}	85.33^{c}
Butachlor 1.25 kg/ha 7 DAS	237.67^{cd}	460.00^{f}	378.00^{ef}	84.67^{cd}	78.67^{c}
Butachlor 0.625 kg/ha 7 DAS	169.15^{e}	402.33^{h}	206.33^{h}	72.00^{e}	62.33^{d}
Pendimethalin 1.5 kg/ha 7 DAS	253.32^{abc}	481.00^{e}	389.33^{e}	86.33^{cd}	81.00^{c}
Pretilachlor 0.75 kg/ha 7 DAS	210.81^{d}	436.33^{g}	354.33^{g}	89.00^{cd}	83.67^{c}
Pyrazosulfuron-ethyl 0.03 kg/ha 7 DAS	238.43^{bcd}	455.67^{f}	374.33^{f}	84.67^{cd}	78.00^{c}
Pretilachlor + pyrazosulfuron-ethyl 0.62 kg/ha 7 DAS	237.02^{cd}	483.67^{e}	408.67^{d}	80.67^{de}	75.33^{c}
Pendimethalin + penoxsulam 0.625 kg/ha 7 DAS	242.29^{bcd}	484.67^{e}	414.67^{d}	86.67^{cd}	81.33^{c}
Butachlor + penoxsulam 0.82 kg/ha 7 DAS	272.9^{ab}	502.33^{d}	430.67c	92.00^{c}	85.00^{c}

In a column, means followed by common letters do not differ significantly at 5% level in Tukey's Test; *DAS = days after seeding; DBS = days before seeding

Table 4. Density (no./m^2) and biomass (g/m^2) of weeds other than weedy rice in wet-seeded rice at 60 DAS

Treatment*	Weed density (no./m^2)				Weed biomass (g/m^2)			
	G	S	B	Total	G	S	B	Total
Unweeded control	2.91^{a} (9.33)	6.14^{a} (37.33)	9.24^{a} (85.33)	11.5^{a} (132.00)	3.79^{a} (13.85)	2.60^{a} (6.29)	6.15^{a} (37.49)	7.62^{a} (57.63)
Weed free check (hand weeded)	0.71^{f} (0.00)	0.71^{e} (0.00)	0.71^{f} (0.00)	0.71^{g} (0.00)	0.71^{e} (0.00)	0.71^{d} (0.00)	0.71^{e} (0.00)	0.71^{g} (0.00)
Oxyfluorfen 0.15 kg/ha 0 DBS	1.34^{de} (2.33)	0.71^{e} (0.00)	1.94^{ef} (3.33)	2.47^{f} (5.67)	1.93^{d} (3.24)	0.71^{d} (0.00)	1.33^{de} (1.45)	2.26^{f} (4.70)
Oxyfluorfen 0.15 kg/ha 10 DAS	1.46^{de} (4.67)	1.76^{d} (2.67)	5.06^{bc} (25.33)	5.75^{bcd} (32.67)	2.70^{bc} (6.79)	0.83^{d} (0.19)	2.98^{cd} (8.91)	4.02^{de} (15.89)
Butachlor 1.25 kg/ha 7 DAS	2.26^{bc} (6.00)	2.92^{c} (8.00)	6.12^{b} (37.33)	7.18^{b} (51.33)	2.98^{b} (8.40)	1.61^{c} (2.08)	4.53^{abc} (20.15)	5.56^{bc} (30.55)
Butachlor 0.625 kg/ha 7 DAS	2.74^{ab} (9.00)	4.78^{b} (22.67)	8.34^{a} (69.33)	10.07^{a} (101.00)	3.53^{a} (12.02)	2.1^{b} (3.96)	5.33^{ab} (28.53)	6.69^{ab} (44.51)
Pendimethalin 1.5 kg/ha 7 DAS	1.56^{de} (4.33)	2.86^{c} (8.00)	4.91^{bc} (24.00)	6.04^{bc} (36.33)	2.52^{bc} (5.84)	1.52^{c} (1.84)	4.10^{bc} (16.60)	4.96^{cd} (24.28)
Pretilachlor 0.75 kg/ha 7 DAS	2.2^{bc} (6.00)	2.65^{cd} (6.67)	5.75^{bc} (33.33)	6.78^{b} (46.00)	2.97^{b} (8.33)	1.54^{c} (1.89)	4.50^{abc} (19.85)	5.52^{bc} (30.06)
Pyrazosulfuron-ethyl 0.03 kg/ha 7 DAS	1.23^{ef} (3.67)	0.71^{e} (0.00)	3.87^{cde} (14.67)	4.32^{de} (18.33)	2.37^{cd} (5.15)	0.71^{d} (0.00)	3.14^{c} (9.49)	3.88^{de} (14.64)
Pretilachlor + pyrazosulfuron-ethyl 0.62 kg/ha 7 DAS	1.86^{cd} (3.00)	0.71^{e} (0.00)	5.42^{bc} (29.33)	5.7^{bcd} (32.33)	2.17^{cd} (4.26)	0.71^{d} (0.00)	4.33^{bc} (18.71)	4.81^{cd} (22.97)
Pendimethalin + penoxsulam 0.625 kg/ha 7 DAS	1.87^{cd} (3.67)	0.71^{e} (0.00)	4.34^{bcd} (18.67)	4.75^{cde} (22.33)	2.36^{cd} (5.08)	0.71^{d} (0.00)	3.55^{bc} (12.17)	4.21^{cde} (17.24)
Butachlor + penoxsulam 0.82 kg/ha 7 DAS	1.34^{de} (2.33)	0.71^{e} (0.00)	2.92^{de} (8.00)	3.29^{ef} (10.33)	1.95^{d} (3.34)	0.71^{d} (0.00)	2.83^{cd} (7.52)	3.37^{ef} (10.86)

G - grasses, S - sedges, B - broadleaf weeds. $\sqrt{x+0.5}$ transformed values, original values in parenthesis. In a column, means followed by common letters do not differ significantly at 5% level in Tukey's Test.; DAS = days after seeding; DBS = days before seeding

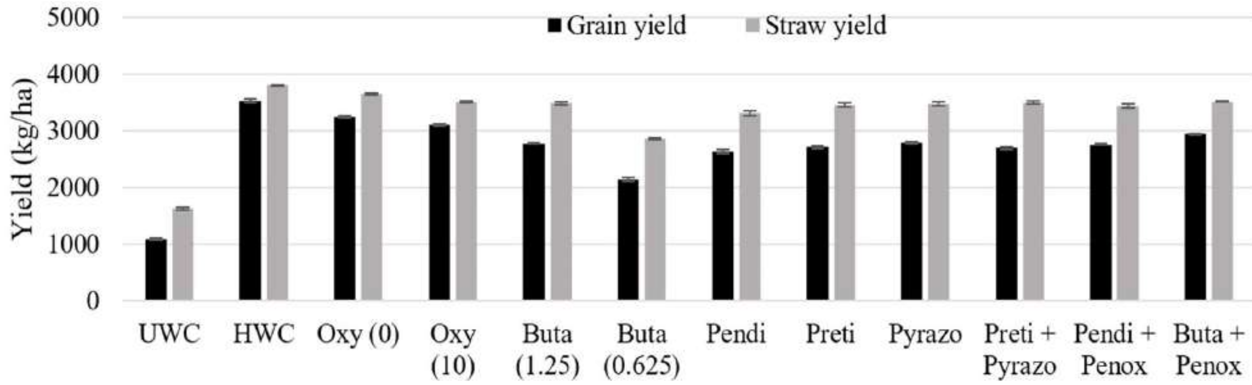


Figure 2. Effect of treatments on grain and straw yield of wet-seeded rice

UWC - unweeded control, HWC-weed-free check, Oxy (0) – oxyfluorfen at 0 DBS; Oxy (10) - oxyfluorfen at 10 DAS, Buta (1.25) - butachlor at 1.25 kg/ha; Buta (0.625) - butachlor (0.625 kg/ha), + penoxsulam; Pendi - pendimethalin, Preti - pretilachlor, Pyrazo – pyrazosulfuron-ethyl, Preti + Pyrazo - pretilachlor + pyrazosulfuron-ethyl, Pendi + Penox – pendimethalin + penoxsulam, and Buta + Penox - butachlor + penoxsulam; *DAS = days after seeding; DBS = days before seeding

Rice growth and yield

At all growth stages, oxyfluorfen 0 DBS and 10 DAS, butachlor + penoxsulam, and weed-free check registered taller plants with higher tiller number (**Table 3**). The higher tiller number with these treatments was due to the weed-free environment as evidenced by the lower density as well as dry matter production of weedy rice and other weeds (**Table 1** and **4**).

The efficient management of weeds favourably influenced yield parameters and yield (**Figure 2**). The weed-free check was statistically superior to all other treatments in terms of the number of panicles per unit area, number of filled grains per panicle, and grain and straw yield. The treatment of oxyfluorfen on the day of sowing resulted in almost double panicle number compared to the weedy check, which was inferior to all treatments due to severe competition induced by weedy rice and other weeds. Khodabaks (1999) observed that every increase of 1% population of weedy rice correlates with grain yield reduction of 6%. Among the herbicide treatments, oxyfluorfen on the day of sowing registered the highest grain yield (3247 kg/ha) and straw yield (3654 kg/ha), and was statistically superior to all other tested herbicides. Significant rice yield reduction (69%) was observed in the unweeded control when compared to weed free check. The oxyfluorfen applied before rice seeding recorded only 8% lesser yield than weed free (**Figure 2**).

The results demonstrated that the puddled soil application of oxyfluorfen 0.15 kg/ha immediately before broadcasting pre-germinated seeds in wet-seeded rice is highly effective for managing weedy rice, as it effectively prevents weedy rice germination. Oxyfluorfen 10 DAS and the premixed herbicide combination of butachlor + penoxsulam 7 DAS were identified as the next best treatment options for controlling weedy rice in wet-seeded rice.

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RESEARCH NOTE

Bio-efficacy of herbicide admixtures against composite weed flora in wheat under three methods of wheat seeding

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ABSTRACT

The field experiment was conducted with an objective to assess the bio-efficacy of herbicide admixtures against composite weed flora in wheat (*Triticum aestivum*) under three methods of wheat seeding. It was conducted at Students' Research Farm, Khalsa College, Amritsar during *Rabi* season of 2020-21 in split-plot design, replicated thrice, with three methods of sowing, *viz.* conventional tillage, super seeder and happy seeder in main plots and seven weed management treatments in sub-plots, *viz.* pinoxaden + clodinafop, fenoxaprop + metribuzin, metsulfuron-methyl + carfentrazone-ethyl + NIS, pendimethalin *fb* pinoxaden + metsulfuron-methyl, isoproturon + 2,4-D, weed free and weedy. Among the different methods of wheat seeding, greater weed density and biomass was observed in happy seeder sown wheat than the super seeder sown wheat, while the maximum weed density and biomass was observed in wheat sown with conventional tillage. Super seeder sown wheat recorded highest grain and straw yields as well as net return and B:C ratio. Among the various weed control treatments, pre-emergence application (PE) within 2 days after wheat sowing (DAS) of pendimethalin 900 g/ha followed by (*fb*) post-emergence application (PoE) at 35 DAS of pinoxaden + metsulfuron-methyl 60 g/ha enhanced of growth, yield and benefit cost ratio of wheat which was at par with weed free, pinoxaden + clodinafop-propargyl 70 g/ha PoE and fenoxaprop + metribuzin 110 g/ha and significantly better than metsulfuron-methyl 4 g/ha + carfentrazone-ethyl 25 g/ha (PoE), isoproturon 750 g/ha + 2,4-D 500 g/ha PoE as compared to weedy check. Pendimethalin 900 g/ha PE *fb* pinoxaden + metsulfuron-methyl 60 g/ha PoE recorded the maximum wheat grain (5.42 t/ha), net returns (Rs. 87373/-) and B:C ratio (2.04).

Keywords: Herbicide, Happy seeder, Methods of seeding, Pinoxaden + metsulfuron-methyl, Super seeder, Tillage, Weed management, Wheat

Wheat (*Triticum aestivum* L.) is a *Rabi* season crop which covers large area in world. In Punjab, the total area under wheat cultivation was 35.30 lakh hectares during 2020-21 with production of 171.8 lakh tonnes and an average yield of 4.87 t/ha (Anon 2021). Excessive tillage is used in the traditional method of wheat establishment, which involves greater time and energy (Tripathi *et al.* 2002). After transplanted rice is harvested, the seeding of wheat is typically postponed since conventional systems require extensive tillage to prepare the seed bed. This results in reduced crop duration, equivalent to an extent of 1.0-1.5% yield loss/hectare/day (Gathala *et al.* 2011).

A number of biotic and abiotic factors directly affect wheat crop productivity. Of them, weed infestation is the most limiting biological limitation. The yield losses of wheat vary between 17-30% annually (Rao and Chauhan 2015). Weed problem is one of the major barriers responsible for low productivity of wheat as weeds competes with the crop for moisture, nutrients, space, light etc. Wheat is infested by both grass and broad-leaved weeds. The dominant weeds noted in wheat field are *Phalaris minor*, *Rumex dentatus*, *Rumex spinosus*, *Chenopodium album*, *Anagallis arvensis*, *Avena fatua*, *Convolvulus arvensis*, *Euphorbia helioscopia* and *Cannabis sativa*. *Phalaris minor* is one of the very serious weeds in wheat and sometimes almost 100% crop losses have been reported by Singh and Singh (2005). Due to increased soil strength, the no-till wheat system under the rice wheat system decreased the infestation of *Phalaris minor*, but it increased the infestation of broad-leaved weeds such as *Medicago denticulate*, *Malva parviflora*, and *Rumex dentatus*. Hence, the use of herbicides could be the only way to check the weeds and improve the wheat yields. Weed management with herbicide usage increased grain yield as compared to weedy and hand weeding treatments (Amin *et al.* 2008). Combination of herbicides that manage both grassy and broad-leaved weeds was better than their sole application for

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weed control in wheat (Shahzad *et al.* 2016). Pre-mixed broad-spectrum herbicide is cost-effective against complex weed flora (Patel *et al.* 2017). In this study, the efficacy of combination of tank-mix or as pre-mix pre- and post- emergence herbicide were evaluated in sequence for managing weeds to attain higher growth and yield of wheat, under different methods of wheat establishment.

The field study was carried out during *Rabi* season of year 2020-2021 at Khalsa College, Amritsar (Location 31.63°E and 74.87°N, 234 meters above mean sea-level). A split plot design with three replications was used. The main plot treatments comprised of three sowing methods, *viz.* conventional tillage, super seeder and happy seeder whereas, treatments in sub plots include: post-emergence application (PoE) of pinoxaden + clodinafop-propargyl 70 g/ha; fenoxaprop + metribuzin 110 g/ha PoE; metsulfuron-methyl 4 g/ha + carfentrazone-ethyl 25 g/ha PoE + non-ionic surfactant (NIS); pre-emergence application (PE) of pendimethalin 900 g/ha followed by (*fb)* pinoxaden + metsulfuron-methyl 60 g/ha PoE; isoproturon 750 g/ha + 2,4-D 500 g/ha PoE; weed free and weedy check. The wheat variety "Unnat PBW343" was sown and recommended doses of fertilizers were applied. Pre-emergence application of herbicide was done with flood-jet nozzle by using a spray volume of 500 l/ha and post-emergence herbicides were sprayed with flat-fan nozzle using a spray volume of 375 l/ha. The pre-emergence application of herbicides was done within 2 days after sowing (DAS) and post-emergence herbicides were sprayed at 35 DAS Weedy check plots remained infested with native weeds till harvest. Observation on weed density and dry matter accumulation (weed biomass) were recorded using quadrat of 30 cm × 30 cm placed randomly at 4 places in each plot at 30, 60 and 90 days after herbicide application. Total number of weeds falling inside each quadrat were counted and cut at ground level for collecting weed biomass data. The sample were first dried in sun and after that oven dried at constant temperature 65 ^{0}C. The dried samples were weighed and expressed as weed biomass (g/m^2). Data on weeds were subjected to square-roots transformation to normalize their distribution. The grain yield recorded in kg/plot was finally converted into grain yield kg/ha and then into q/ha. The pair comparison of treatment mean was done using LSD value 5% level of significance.

Weed density

The weed density was not affected by wheat establishment methods (**Table 1**). However, amongst the weed management treatments, weed density was minimum with pendimethalin *fb* pinoxaden + metsulfuron followed by pinoxaden + clodinafop-propargyl, fenoxaprop + metribuzin, metsulfuron-methyl + carfentrazone-ethyl + NIS and isoproturon + 2,4-D. The percentage decrease in weed density, at wheat harvest, caused by weed management treatments was 93.46 %, 93.07%, 87.83%, 97.59%, 76.74% and 100% with pinoxaden + clodinafop-propargyl, fenoxaprop + metribuzin, metsulfuron-

Table 1. Effect of wheat seeding methods and weed management treatments on weed density and biomass of narrow-leaved weeds and broad-leaved weeds

Treatment	Weed density (no./m^2) (Narrow-leaved weeds) at 60 DAS	Weed density (no./m^2) (Broad-leaved weeds) at 60 DAS	Weed biomass (q/ha) (Narrow-leaved weeds)	Weed biomass (q/ha) Broad-leaved weeds)	Weed control efficiency (%)
Wheat seeding methods					
Conventional tillage	7.47(70.80)	4.18(20.88)	1.86(2.96)	1.84(3.01)	-
Super seeder	7.30(68.03)	3.86(18.08)	1.74(2.46)	1.83(2.95)	-
Happy seeder	6.72(60.56)	4.63(25.23)	1.62(1.96)	1.86(3.07)	-
LSD (p=0.05)	NS	NS	NS	NS	
Weed management treatment					
Pinoxaden + clodinafop-propargyl 70 g/ha PoE	7.30(53.49)	4.32(18.6)	1.74(2.20)	1.76(2.18)	91.82
Fenoxaprop + metribuzin 110 g/ha PoE	7.37(54.6)	4.40(19.39)	1.80(2.32)	1.80(2.32)	91.30
Metsulfuron-methyl 4 g/ha + carfentrazone-ethyl 25 g/ha PoE + non-ionic surfactant (NIS)	8.32(69.75)	4.23(17.86)	1.85(2.53)	1.72(2.03)	87.89
Pendimethalin 900 g/ha PE *fb* pinoxaden + metsulfuron-methyl 60 g/ha PoE	3.29(10.75)	3.08(9.15)	1.04(0.09)	1.009(0.02)	96.77
Isoproturon 750 g/ha + 2,4-D 500 g/ha PoE	11.53(132.05)	4.77(22.86)	1.96(2.98)	2.66(6.34)	76.55
Weed free	1(0)	1(0)	1(0)	1(0)	100
Weedy	13.84(194.53)	7.75(61.94)	2.79(7.13)	2.97(8.18)	0
LSD (p=0.05)	0.72	0.57	0.21	0.25	-

The original data in parentheses was subjected to $\sqrt{x+0.5}$ transformation; PE = pre-emergence treatment; PoE = post-emergence treatment; DAS = days after seeding methyl + NIS, pendimethalin *fb* pinoxaden + metsulfuron-methyl, isoproturon + 2,4-D and weed free, when compared with weedy check.

Weed biomass

Pendimethalin *fb* pinoxaden + metsulfuron-methyl recorded the lowest weed biomass of narrow and broad-leaved weeds, followed by pinoxaden + clodinafop, fenoxaprop + metribuzin, metsulfuron-methyl + carfentrazone-ethyl + NIS, isoproturon + 2,4-D and treatment at 60 DAS. The percentage decrease in weed biomass at wheat harvest was 87.44%, 82.35%, 76.57%, 99.30%, 29.42% and 100% with pinoxaden + clodinafop, fenoxaprop + metribuzin, metsulfuron-methyl + carfentrazone-ethyl + NIS, pendimethalin *fb* pinoxaden + metsulfuron-methyl, isoproturon + 2,4-D and weed free, respectively when compared with weedy check. The results are in conformity with Rana *et al.* 2017.

Wheat yield

Wheat seeding methods and herbicides treatments showed a remarkable effect on grain yield (Table 2.). Among sowing methods of wheat, super seeder sown wheat produced the highest grain yield, which was much higher than conventional tillage but statistically at par with happy seeder. However, the grain yield with wheat super seeder (4.77 t/ha) and happy seeder (4.28 t/ha) sown wheat differed significantly. According to Chhokar *et al.* (2007), surface retention of rice residue at 5.0 and 7.5 t/ha decreased weed biomass in wheat by 23.4- 30.3 and 35.5- 44.1%, respectively.

Weed free had the highest wheat grain and straw yield and it was significantly at par with pendimethalin *fb* pinoxaden + metsulfuron-methyl, pinoxaden + clodinafop and fenoxaprop + metribuzin and was significantly higher than other herbicide treatments. Walia *et al.* (2000) reported that metsulfuron-methyl enhanced wheat grain yield by 43.3 and 36.7% over weedy control. The wheat yield with isoproturon + 2,4-D and weedy check was significantly at par with each other. The wheat yield with fenoxaprop + metribuzin and metsulfuron + carfentrazone-ethyl + NIS was also significantly at par with each other. The weedy check produced the lowest grain yield. The percentage increase in grain yield of pinoxaden + clodinafop, fenoxaprop + metribuzin, metsulfuron-methyl + carfentrazone-ethyl + NIS, pendimethalin *fb* pinoxaden + metsulfuron-methyl, isoproturon + 2,4-D and weed free when compared with weedy check was 45.51%, 44.90%, 40.30%, 48.86%, 13.78% and 49.66%, respectively. Among the different weed control treatments weed free had the highest straw yield and it was significantly at par with pendimethalin *fb* pinoxaden + metsulfuron-methyl, pinoxaden + clodinafop and fenoxaprop + metribuzin, which were significantly higher than metsulfuron-methyl + carfentrazone-ethyl + NIS, isoproturon + 2,4-D and weedy check.

Economics

The economics of wheat production in terms of gross and net returns and benefit cost ratio were calculated to examine the economic feasibility and viability of the various treatments under investigation.

Table 2. Effect of wheat seeding methods and weed management treatments on wheat grain and straw yield, harvest index, total cost of production, net returns and benefit: cost ratio of wheat

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Total cost of production (Rs./ha)	Net returns (Rs./ha)	B:C ratio
Wheat seeding methods						
Conventional tillage	4.65	6.82	40.52	47554	66467	2.39
Super seeder	4.77	7.16	40.01	39958	77696	2.94
Happy seeder	4.28	6.24	40.70	38708	66213	2.71
LSD (p=0.05)	0.38	0.52				
Weed control treatment						
Pinoxaden + clodinafop-propargyl 70 g/ha PoE	5.09	7.44	40.77	42055	79204	1.88
Fenoxaprop + metribuzin 110 g/ha PoE	5.03	7.30	40.90	41805	78091	1.86
Metsulfuron-methyl 4 g/ha + carfentrazone-ethyl 25 g/ha PoE + non-ionic surfactant (NIS)	4.65	6.65	41.36	41830	68069	1.62
Pendimethalin 900 g/ha PE *fb* pinoxaden + metsulfuron-methyl 60 g/ha PoE	5.42	8.11	40.24	42630	87373	2.04
Isoproturon 750 g/ha + 2,4-D 500 g/ha PoE	3.22	4.95	39.39	41330	34952	0.84
Weed free	5.51	8.30	40.08	44930	87412	1.94
Weedy	2.77	4.31	39.13	39930	55724	1.48
LSD (p=0.05)	0.45	0.73				

PE = pre-emergence treatment; PoE = post-emergence treatment; DAS = days after seeding

Among different sowing methods, super-seeder sown wheat recorded highest net returns (Rs.77696/ ha) and similar results were also reported by Bishnoi *et al*. (2024). Among the various weed control practices weed free recorded highest net returns. Among different weed control treatments weed free recorded highest net returns.

Conclusion

It may be concluded that the higher wheat grain yield can be obtained with wheat seeding using super-seeder and weed management by pendimethalin 900 g/ha PE *fb* pinoxaden + metsulfuron-methyl 60 g/ha PoE for controlling complex weed flora in wheat and to increase wheat productivity.

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RESEARCH NOTE

Evaluation of herbicides for economical weed management with increased productivity of blackgram

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ABSTRACT

Field experiment was conducted during *Rabi* 2022-23 at Wetland farm of S.V. Agricultural College, Tirupati, Andhra Pradesh, India in a randomized block design. The objective was to evaluate and identify effective and economic herbicide treatment to manage weeds and improve productivity of blackgram (*Vigna mungo* L.). Nine weed management treatments were evaluated in RBD with three replications. Among the tested weed management treatments, lower weed density and biomass with higher weed control efficiency was recorded with pre-emergence application (PE) of diclosulam 20 g/ha followed by (*fb*)1 hand weeding (HW) at 15 days after seeding (DAS), and it was on par with HW twice at 15 and 30 DAS and the later was on par with post-emergence application (PoE) of fluazifop-p-butyl + fomesafen 222 g/ha and sodium-acifluorfen + clodinafop-propargyl 245 g/ha PoE. Significantly higher values growth parameters, yield attributes and yield of blackgram were recorded with HW twice at 15 and 30 DAS, which was however, on par with fluazifop-p-butyl + fomesafen 222 g/ha as PoE at 20 DAS and sodium-acifluorfen + clodinafop-propargyl 245 g/ha PoE at 20 DAS, while the later two treatments resulted in higher net returns and benefit-cost ratio. It was concluded that fluazifop-p-butyl + fomesafen 222 g/ha PoE or sodium-acifluorfen + clodinafop-propargyl 245 g/ha PoE at 20 DAS provide the most effective and economical weed management in blackgram.

Keywords: Blackgram, Economics, fluazifop-p-butyl + fomesafen, Herbicides, Sodium-acifluorfen + clodinafop-propargyl, Weed management

India is the world's largest producer and consumer of blackgram by contributing about 70% of the world's production. Blackgram accounts for 19% of area and 23% of production of pulse crops in India. India produces approximately 24.5 lakh tonnes of blackgram per year from 4.6 million hectares of land with an average productivity of 533 kg per hectare in 2021-22 (www.agricoop.nic.in).

Weed management is an important component of blackgram cultivation to ensure optimal crop growth and yield. The critical period of crop weed competition in blackgram is 20-40 DAS (Sivakumar *et al*. 2019). Adequate control of weeds cannot be achieved by using any one method or single herbicide. Further continuous usage of the same herbicide may lead to a shift in weed composition, favouring the growth of the weeds that are less susceptible to the herbicide being used. This may also lead to an increase in the diversity of weed species in the field making weed control more challenging. Under such circumstances, pre- and post- emergence herbicides applied in sequence or in combination will control the weeds very effectively. Ready-mix herbicides are formulated to target specific weed species for broad-spectrum weed control (Yadav *et al*. 2015; Mudalagiriyappa *et al*. 2022). They contain effective active ingredients and appropriate adjuvants that optimize weed control efficacy resulting in improved crop growth, yield and quality. Thus, the present study was undertaken to assess the effectiveness of different weed management treatments for broad-spectrum weed control and for higher productivity in blackgram.

A field experiment was conducted during *Rabi* season of 2022-23 at Wetland farm, S.V. Agricultural College, Tirupati, located at 13.5°N latitude and 79.5°E longitude with an altitude of 182.9 m above mean sea level in the Southern Agro-Climatic Zone of Andhra Pradesh, India. The soil was sandy loam in texture, neutral in soil reaction, low in organic carbon (0.26) and available nitrogen (172 kg/ha) and medium in available phosphorus (29 kg/ha) and potassium (193 kg/ha). The total rainfall received during the

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crop growth period was 211.6 mm in 12 rainy days. The experiment was laid out in a randomized block design with nine weed management treatments replicated thrice. Treatments include: pre-emergence application (PE) of diclosulam 20 g/ha followed by (*fb*) 1 hand weeding (HW) at 15 days after seeding (DAS); post-emergence application (PoE) of imazethapyr 50 g/ha at 20 DAS; quizalofop-p-ethyl + imazethapyr 98 g/ha PoE at 20 DAS; imazethapyr + imazamox 70 g/ha PoE at 20 DAS; propaquizafop + imazethapyr 125 g/ha PoE at 20 DAS; sodium-acifluorfen 16.5% EC + clodinafop propargyl 8% EC (sodium-acifluorfen + clodinafop-propargyl) 245 g/ha PoE at 20 DAS; fluazifop-p-butyl 11.1% SL + fomesafen11.1% SL (fluazifop-p-butyl + fomesafen) 222 g/ha PoE at 20 DAS, HW twice at 15 and 30 DAS and weedy check. Blackgram variety'*TBG-104*' was sown on 16.11.2024 and raised with recommended package of practices except for the weed management. Blackgram was harvested on 04.02.2023. The crop was fertilized with 20 kg N, 40 kg P and 20 kg K/ha. Entire dose of nitrogen was applied in the form of urea, phosphorus as single super phosphate and potassium as muriate of potash basally at the time of sowing. The weed population was counted with the help of 0.5m^2 quadrat placed randomly at two places in each plot and expressed as density (no./m^2). Different weed species collected for assessing the density of weeds were dried separately in a hot air oven at 65ºC till constant dry weight was reached and expressed as weed biomass (g/m^2). Due to large variations in values of weed density and biomass, the corresponding data was subjected to square root transformation $\sqrt{x+0.5}$ and the corresponding transformed values were used for statistical analysis as suggested by Gomez and Gomez (1984). Five randomly selected plants were tagged ineach treatment and from each replication in the net plot area and used for making observations on growth parameters and yield attributes at harvest of blackgram. The seed and haulm yield of blackgram were recorded based on the yield obtained from the net plot. Net returns were calculated by subtracting the cost of cultivation from the gross returns. Benefit-cost ratio was calculated after dividing gross returns with cost of cultivation.

Effect on weeds

Weed flora associated with blackgram belonged to thirteen taxonomic families, of which the predominant weed species noticed in the experimental field were: *Dactyloctenium aegyptium* and *Digitaria sanguinalis*, among grasses, *Cyperus rotundus* a sedge, *Boerhavia erecta, Commelina benghalensis* and *Euphorbia hirta*, among the broad-leaved weeds.

Weed management treatments tested in blackgram significantly influenced weed density and biomass and weed control efficiency (WCE) at the harvest of blackgram (**Table 1**). Among the different weed management treatments, lower density and biomass of grasses, sedges, broad-leaved weeds as well as total weeds and higher WCE were recorded

Table 1. Weed density and biomass at harvest of blackgram as influenced by different weed management treatments

Treatment	Weed density (no./m^2)*				Weed biomass (g/m^2)*				WCE (%)
	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	
Diclosulam 20 g/ha *fb* 1 HW at 15 DAS	6.57 (42.67)	6.48 (41.67)	6.28 (39.00)	11.13 (123.34)	4.14 (16.60)	4.16 (16.77)	3.98 (15.43)	7.02 (48.80)	70.36
Imazethapyr 50 g/ha PoE at 20 DAS	9.04 (81.33)	7.06 (49.67)	8.14 (66.00)	14.03 (197.00)	5.57 (30.67)	4.50 (19.87)	5.76 (32.73)	9.15 (83.27)	53.02
Quizalofop-p-ethyl + imazethapyr 98 g/ha PoE at 20 DAS	7.97 (63.00)	7.92 (62.67)	8.07 (64.67)	13.80 (190.34)	5.43 (28.97)	5.14 (25.97)	5.60 (31.00)	9.30 (85.94)	52.19
Imazethapyr + imazamox 70 g/ha PoE at 20 DAS	9.40 (88.00)	6.72 (44.67)	8.32 (69.00)	14.22 (201.67)	5.71 (32.47)	4.28 (17.90)	5.87 (34.00)	9.21 (84.37)	44.29
Propaquizafop + imazethapyr 125 g/ha PoE at 20 DAS	7.87 (61.67)	7.80 (60.33)	7.80 (60.33)	13.52 (182.33)	5.16 (26.17)	4.99 (24.47)	5.51 (30.00)	9.01 (80.64)	51.73
Sodium-acifluorfen + clodinafop-propargyl 245 g/ha PoE at 20 DAS	6.89 (47.00)	8.03 (64.00)	6.67 (44.00)	12.46 (155.00)	4.64 (21.20)	5.16 (26.17)	4.41 (19.00)	8.18 (66.37)	60.09
Fluazifop-p-butyl + fomesafen 222 g/ha PoE at 20 DAS	6.45 (41.33)	8.21 (67.00)	6.44 (41.00)	12.24 (149.33)	4.51 (20.13)	5.24 (27.00)	4.12 (16.47)	8.03 (64.00)	64.64
Hand Weeding twice at 15 and 30 DAS	6.66 (44.00)	6.84 (46.33)	6.71 (44.67)	11.63 (135.00)	4.55 (20.47)	4.37 (18.63)	4.39 (18.80)	7.63 (57.9)	65.01
Weedy check (control)	10.66 (113.67)	10.54 (110.67)	10.41 (108.33)	18.24 (332.67)	7.17 (50.77)	7.26 (52.23)	7.68 (58.57)	12.73 (161.57)	-
LSD (p=0.05)	0.82	0.72	0.88	0.88	0.50	0.44	0.43	0.63	

*Data in parentheses are original values, which were transformed to $\sqrt{x+0.5}$ and analyzed statistically; WCE: Weed control efficiency; DAS: Days after sowing, PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by BLW = broad-leaved weeds with diclosulam 20 g/ha PE *fb* 1 HW at 15 DAS, and it was on par with HW twice at 15 and 30 DAS and the later was in turn on par with fluazifop-p-butyl + fomesafen 222 g/ha PoE and sodium-acifluorfen + clodinafop-propargyl 245 g/ha PoE. This might be due to the dual mode of action of applied herbicides, which controls all types of weeds effectively during the critical period of crop weed competition as observed by Tamang *et al.* (2015) and Choudhary *et al.* (2012), Dhayal *et al.*(2022).

Phytotoxicity

Observations on phytotoxicity of pre- and post-emergence herbicides on blackgram were recorded at 10th and 15th day after herbicide application (DAH). All the applied herbicides did not show any phytotoxicity except with pre-emergence application of diclosulam 20 g/ha. It resulted in phytotoxicity rating of '1' indicating stunted growth, due to reduced intermodal length but no stand loss. This may be due to inhibition of ALS, a key enzyme responsible for biosynthesis of branched chain amino acids, which in turn reduced protein synthesis in meristematic tissues leading to stunted growth and discoloration of foliage. The crop plants started recovering from diclosulam phytotoxicity after 20 DAH and were completely recovered by 30 DAH. These results are in accordance with findings of Naveen *et al.* (2019) in groundnut and Jakhar and Sharma (2015) in soybean.

Effect on blackgram

Growth parameters of blackgram, *viz.* plant height, leaf area index and dry matter production and yield attributes, *viz.* number of filled pods/plant, number of seeds/pod and test weight and seed and haulm yield were significantly higher with HW twice at 15 and 30 DAS, which was at par with fluazifop-p-butyl + fomesafen 222 g/ha PoE and sodium-acifluorfen + clodinafop-propargyl 245 g/ha PoE (**Table 2**). This might be due to lower crop weed competition for growth resources throughout the crop growing period enabling the crop for maximum utilization of nutrients, moisture, light and space, which enhanced the vegetative and reproductive potential of the crop as reported by Yadav *et al.*(2015).

Economics

Higher gross returns were realized with HW twice at 15 and 30 DAS **(Table 2)**, which was at par with fluazifop-p-butyl + fomesafen 222 g/ha PoE and sodium-acifluorfen + clodinafop-propargyl 245 g/ha PoE, whereas highest net returns and benefit-cost ratio were recorded with fluazifop-p-butyl + fomesafen 222 g/ha PoE, which was at par with sodium-acifluorfen + clodinafop-propargyl 245g/ha PoE. The higher net returns and benefit cost ratio might be due to increased yield and reduced cost of cultivation as reported by Singh *et al.* (2014) and Aliveni *et al.* (2016).

Table 2. Growth, yield attributes, yield and economics of blackgram as influenced by different weed management treatments

Treatment	Plant height (cm)	Leaf area index	Dry matter production (t/ha)	No. of filled pods/ plant	No. of seeds/ pod	Test weight (g)	Seed Yield (kg/ha)	Haulm Yield (kg/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
Diclosulam 20 g/ha *fb* 1 HW at 15 DAS	23.1	0.97	920	9.1	4.0	37.7	527	1021	34872	8134	1.30
Imazethapyr 50 g/ha PoE at 20 DAS	26.1	1.00	959	9.2	4.1	38.5	575	1075	37950	15598	1.69
Quizalofop-p-ethyl + imazethapyr 98 g/ha PoE at 20 DAS	29.3	1.14	1240	11.6	5.9	38.6	836	1390	55154	31301	2.31
Imazethapyr + imazamox 70 g/ha PoE at 20 DAS	26.6	1.01	988	9.5	4.2	38.5	589	1132	38852	14960	1.63
Propaquizafop + imazethapyr 125 g/ha PoE at 20 DAS	30.1	1.16	1282	12.2	6.0	40.1	840	1410	55440	31158	2.28
Sodium-acifluorfen + clodinafop-propargyl 245 g/ha PoE at 20 DAS	34.0	1.30	1422	16.00	6.0	40.9	910	1410	60038	36306	2.52
Fluazifop-p-butyl + fomesafen 222 g/ha PoE at 20 DAS	35.1	1.33	1431	16.5	6.2	41.4	957	1490	63184	39722	2.69
Hand Weeding twice at 15 and 30 DAS	36.1	1.39	1446	17.6	6.5	41.8	971	1501	64064	34582	2.17
Weedy check (control)	20.4	0.83	810	7.0	3.0	36.1	343	798	22638	1156	1.05
LSD (p=0.05)	2.4	0.12	107	1.9	0.7	1.4	67	216	4402	4404	0.1

*DAS: Days after sowing; PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by.

In conclusion, fluazifop-p-butyl + fomesafen 222 g/ha PoE or sodium-acifluorfen + clodinafop-propargyl 245 g/ha PoE were found to be the most effective and economical weed management treatments to increase the productivity and the net returns in blackgram.

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RESEARCH NOTE

Non-chemical weed management evaluation in greengram

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ABSTRACT

A field experiment was conducted during *Kharif* season of 2022 at agricultural research block, School of Agricultural Sciences, Shri Guru Ram Rai University (SAS-SGRRU), Dehradun, Uttarakhand to study the effect of non-chemical weed management methods on weed growth and greengram (*Vigna radiata* L.) yield. The experiment was laid out in factorial randomized RBD comprising 2 factors replicated thrice. First factor, crop geometry comprised of 20 × 15 cm, 25 × 12 cm 30 × 10 cm spacing maintained between row to row and plant to plant, respectively. The second factor was non-chemical weed management treatments including: weedy check, hand weeding (HW) once at 20 days after seeding (DAS) + mulching, and hand weeding twice at 30 and 45 DAS. Crop geometry and weed management treatments significantly influenced all the growth parameters, yield attributes and yield of greengram, weed density and biomass. To improve the productivity of greengram by managing weeds effectively in the Doon valley area of Uttarakhand, hand weeding once at 20 DAS + mulching along with crop geometry of 30 cm × 10 cm may be recommended, as they recorded a significant improvement in growth and yield parameters and greengram yield, compared to other treatments.

Keywords*:* Doon valley, Greengram, Non-chemical weeding, Mulching, Crop geometry

Greengram (*Vigna radiata* L.) locally known as "mung", a *Kharif* season pulse crop widely grown in arid and semi-arid parts of India, is one of the most significant pulse crops. It contains around 25% protein, 1.3% fat, 3.5% mineral, 4.1% fiber, and 56.7% carbohydrates. When sprouted, it also contains a notable amount of ascorbic acid and riboflavin. Despite being a staple of our daily diet, this crop's average yield is quite poor in India. Tamang *et al*. (2015) noted that because of their short stature, weeds severely reduce greengram's yield. Weeds constitute a severe concern since they compete for resources such as space, light, nutrients, water, and other growth inputs and lower the productivity of *Kharif* greengram by up to 65.4 to 96.5 %, depending on the species of weed and the level of crop weed competition (Verma *et al*. 2015, Dungarwal *et al*. 2003, Tamang *et al*. 2015). In addition to having low crop yields, they also harbor pests and insects that raise agricultural costs. Therefore, managing weeds at critical period is essential to improve productivity of the greengram.

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The low population will also result in a lower yield. Hence, in order to get a higher yield, the ideal plant population of greengram is required (Mansoor *et al*. 2010) and higher plant population was also reported to help in suppressing weed growth**.** Herbicides were evaluated for their efficacy in managing weeds in greengram (Tamang *et al.* 2015, Bajiya *et al.* 2025). But studies on non-chemical weed management are limited. Hence, current study was conducted at SGRR University, Dehradun with an objective to evaluate the efficacy of non-chemical weed management methods viz. crop geometry, hand weeding and mulching in managing weeds and enhancing yield of greengram in the Western Himalayan areas of Dehradun.

A field experiment was conducted at Agriculture Research Block, School of Agricultural Sciences, Shri Guru Ram Rai University, Pathribagh, Dehradun, Uttarakhand in the *Kharif* season of 2022. The sandy loam soil of the experimental field had a pH of 7.26, was rather neutral, had a low amount of available nitrogen (225.3 kg/ha) and organic carbon (0.42%), a medium amount of available phosphorus (16.1 kg/ha) and available potassium (236.3 kg/ha). The study used a factorial randomized complete block design, with two factors at various levels and three replications.

First factor crop geometry comprised of three crop rows to row and plant to plant spacings viz. 20 cm × 15 cm, 25 cm × 12 cm and 30 cm × 10 cm and second factor of different non- chemical weed control treatments comprising: weedy check (control), hand weeding once at 20 days after seeding (DAS) + mulching, and hand weeding twice at 30 and 45 DAS. After the experimental area was ploughed and the optimal soil moisture condition was reached, the plot was leveled with the aid of a tractor-drawn leveller and two cross harrowing operations. The sowing of greengram variety "*Shikha*" was done on June 20, 2022 and was harvested on September 16, 2022. Line sowing method for sowing was adopted while plant geometry varied according on the treatments. N, P and K 20:40:40 kg/ha. The wheat straw 5 t/ha was used as mulch in the experimental plot. Greengram harvesting was done manually, and after threshing, washing, and sun-drying, plot-wise weight measurements were made.

Weed density was recorded in each plot at 25DAS, 40 DAS and at harvest, using quadrat of 50 × 50 cm (0.25 m^2) from the area marked for observations. For recording weed dry matter (weed biomass), all the weed species within the area of quadrat were cut close to the ground surface separately and air dried first (4-5 days) and then dried in the hot air oven maintained at of 70 ±1 ^{0}C temperature. Weed biomass at 25 DAS, 40 DAS and at greengram harvest was recorded and expressed as gram per square meter during crop season. Weed control efficiency was calculated in relation to total weed dry weight by using the recommended formula and expressed in per cent during crop season:

Effect on greengram

Growth characteristics such as crop height, number of branches, number of nodules, and dry matter production per plant were significantly impacted by varying row spacing. It was noted that the 30 ×10 cm recorded the highest greengram plant height (51.46 cm), largest number of branches (21.09 cm), maximum number of nodules (29.39 cm), and maximum dry matter accumulation (54.17 g/plant) at 75 DAS, which was substantially better than the other treatments. The elimination of intra-plant competition and having better access to ground area and sunlight and nutrients may have allowed

Table 1. Effect of crop geometry and non-chemical weed management treatments on growth attributes of greengram

Treatment	Crop height (cm)			No. of branches/plant			No. of nodules/plant		Dry matter production (g/plant)		
	25 DAS*	50 DAS	75 DAS	25 DAS	50 DAS	75 DAS	25 DAS	50 DAS	25 DAS	50 DAS	75 DAS
Crop geometry											
20 cm × 15 cm	17.35	38.12	49.18	4.45	12.15	18.48	20.33	27.88	6.23	25.11	53.04
25 cm × 12 cm	18.07	41.00	50.23	5.33	13.59	19.44	22.44	28.38	7.28	25.99	53.52
30 cm × 10 cm	21.00	46.48	53.46	6.69	16.40	22.09	24.98	31.39	9.61	30.88	57.17
LSD (p=0.05)	1.564	2.312	2.011	1.291	2.664	2.111	2.192	1.987	2.643	3.614	3.381
Non-chemical weed management treatment											
Weedy check	16.78	35.92	47.81	3.84	10.72	17.73	17.02	26.67	5.32	24.42	52.43
Hand weeding once at 20 days after seeding (DAS) + mulching	21.09	46.23	51.15	6.51	16.47	22.79	25.94	31.61	9.13	29.65	56.50
Hand weeding twice at 30 and 45 DAS	18.55	43.44	47.81	5.52	13.95	20.49	24.40	29.38	7.67	26.51	53.80
LSD (p=0.05)	2.161	2.312	2.518	1.134	2.131	1.987	1.869	2.100	1.984	3.100	2.541

Table 2. Effect of crop geometry and non-chemical weed management treatments on yield and yield contributing characters of greengram

Treatment	No. of pods/plant	No. of grains/pod	Thousand grain weight (g)	Grain yield kg/ha	Stover yield kg/ha	Harvest index
Crop geometry						
20 cm × 15 cm	12.52	9.99	35.40	824.11	1874.7	31.79
25 cm × 12 cm	13.54	11.70	35.83	836.45	1890.8	32.07
30 cm × 10 cm	16.60	13.58	36.41	865.44	1924.7	33.32
LSD (p=0.05)	2.171	1.211	0.451	10.51	21.34	1.011
Non-chemical weed management treatment						
Weedy check	11.74	9.32	34.39	801.32	1864.1	31.61
Hand weeding once at 20 days after seeding + Mulching	14.83	12.59	36.88	897.67	1937.1	32.67
Hand weeding twice at 30 and 45 DAS	12.10	10.35	35.36	828.33	1903.1	32.11
LSD (p=0.05)	1.637	1.371	1.192	12.36	20.98	0.511

greengram to thrive well with maximum crop height, no. of pods/plant, grains/pod, thousand grain weight, grain yield (kg/ha) and stover yield (kg/ha) at the spacing of 30 cm × 10 cm as compared to 20 cm × 15 cm and 25 cm × 12 cm. The above finding is in complete agreement with Mansoor *et al*. (2010); Yadav (2004) and Rasul (2012) Foysalkabir *et al*. (2016).

Various weed control strategies significantly impacted every growth and yield-related parameter of the greengram. With hand weeding once at 25 DAS + mulching, the maximum crop height; number of branches; number of nodules; and maximum dry matter were observed. In the weedy check, the lowest values of studied parameters were observed due to intense competition by the uncontrolled weeds, which inhibited growth and development. Chaudhari (2016) and Chhodavadia (2014) also reported similar results.

Different weed control treatments had a substantial impact on grain and stover yield and harvest index. Hand weeding once at 20 DAS + mulching recorded the highest grain yield (905.9 kg/ha), stover yields (1907 kg/ha), and harvest index (32.4). The decrease in weed competitiveness with the crop during the critical crop-weed competition phase that aided in improved growth and development resulting in appreciable yield (Meena et al., 2009; (Chhodavadia *et al*. 2014). In contrast, the weedy check recorded significantly lower values of growth, yield attributes, and yield of greengram. The combined effect of spacing and weed control methods on grain yield of the greengram was also significant (**Table 3**).

Table 3. Interaction effect of crop geometry and non-chemical weed management treatments on grain yield of greengram

Treatment	Weedy check	Hand weeding once at 20 days after seeding (DAS) + Mulching	Hand weeding twice at 30 and 45 DAS
20 cm × 15 cm	795.0	864.3	813.0
25 cm × 12 cm	815.0	892.3	802.0
30 cm × 10 cm	790.0	936.3	870.0
LSD (p=0.05)		18.21	

Effect on weeds

The highest total weed density and biomass was observed in weedy check, at all the dates of observation (**Table 4**). At 25 DAS, 40 DAS and at harvest stage, hand weeding once at 20 DAS + mulching had significantly lesser weeds density and biomass than the other weed control treatments. The results are in line with the findings of Kundra *et al*. (1989) and Nayak *et al*. (2000). However significantly higher weed density and biomass were recorded with the plant geometry of 30 cm × 10 cm as compared to other spacing showed. Significantly higher weed control efficiency was observed with 20 × 15 cm followed by 30 × 10 cm & 25 × 12 cm. Wider plant spacing often leads to higher weed infestation. This is because wider spacing provides more space for weeds to germinate, grow, and compete with the crop for resources like nutrients and sunlight as observed by Mengistu and Mekonnen (2020). While hand weeding once at 20 DAS + mulching has recorded significantly higher WCE due to lesser weed density and biomass, compared to other treatments. Nayak *et al*. (2000) also reported similar results.

Table 4. Effect of crop geometry and non-chemical weed management treatments on weed density and biomass in greengram

Treatment	Total weed density (no./m^2)			Total weed biomass (g/m^2)			Weed control efficiency (%)
	25 DAS	40 DAS	At harvest	25 DAS	40 DAS	At harvest	
Crop geometry							
20 cm × 15 cm	24.1	17.0	9.3	3.65	1.43	0.51	85.8
25 cm × 12 cm	26.3	20.1	11.1	3.76	2.10	0.94	81.2
30 cm × 10 cm	32.0	24.2	14.0	4.11	2.78	1.09	78.3
LSD (p=0.05)	3.24	2.19	2.94	0.61	0.50	0.12	2.36
Non-chemical weed management treatment							
Weedy check	52.0	48.2	32.2	6.67	5.10	4.18	46.2
Hand weeding once at 20 days after seeding (DAS) + mulching	14.1	9.4	7.4	2.14	1.04	0.85	89.5
Hand weeding twice at 30 and 45 DAS	21.5	19.3	13.1	4.08	3.11	0.50	85.7
LSD (p=0.05)	2.31	4.57	4.01	0.53	0.41	0.11	3.01

It may be concluded that hand weeding once at 20 DAS + mulching with greengram sown at the spacing of 30 cm × 10 cm results in significantly higher greengram productivity due to effective weed management in greengram grown in Uttarakhand Doon Valley areas.

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RESEARCH NOTE

Weed management in sesame using herbicides with and without soil mulch in lateritic soil of West Bengal

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ABSTRACT

A field experiment was conducted during the pre-*Kharif* season of 2020 at the Agricultural Farm of the Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal with sesame variety '*Rama*' to study the weed growth and productivity of summer sesame as influenced by herbicides under two soil mulch practices. A split plot design with three replications was used for experimentation. Two soil mulch practices comprising of sowing after pre-sowing irrigation (soil mulch) and sowing followed by (*fb*) irrigation (no mulch) were allocated in the main plots and six weed managements treatments in sub-plots, *viz.* pre-emergence application (PE) of pendimethalin 1.0 kg/ha; early post-emergence application (EPoE) of fenoxaprop-p-ethyl at 60 g/ha 18 days after seeding (DAS); pretilachlor 450 g/ha PE; propaquizafop 60 g/ha EPoE at 18 DAS; untreated control and weed free check. Sesame was infested with ten weed species with predominance of grassy weeds (60.23%).Total weed density and total weed biomass at 45 DAS were reduced by 24.70% and 25.18%, respectively, under soil mulch compared to no mulch. Soil mulch recorded 12.99% higher sesame seed yield, over no mulch. Similarly, fenoxaprop-ethyl 60 g/ha EPoE, pendimethalin1.0 kg/ha PE and propaquizafop 60 g/ha EPoE produced higher sesame seed yield than other tested herbicidal treatments. Soil mulch sowing of sesame along with fenoxaprop-p-ethyl 60 g/ha EPoE or propaquizafop 60 g/ha EPoE gave effective weed management and higher sesame seed yield, specially in the fields having predominance of grassy weeds in lateritic soil of West Bengal.

Keywords: Fenoxaprop-p-ethyl, Grassy weeds, Pendimethalin, Propaquizafop, Quizalofop-p-ethyl, Sesame, Soil mulching, Weed management

Sesame, often referred to as *til*, is mainly cultivated in pre-*Kharif* season in India during warm and humid months of the year, primarily for its oil and used as a flavoring agent (Andargie *et al.* 2021). As part of the global trend towards healthier plant-based food sources, there has been a recent increase in demand for sesame grains and their byproducts. Worldwide, 7.17 million ton of sesame is produced in an area of 13.10 million ha with an average yield of 864.6 kg/ha (FAO 2022). Whereas, in India, the production is about 0.78 million ton with an area of 1.62 million ha (FAO 2022).

Weed infestation is regarded as one of the most important biotic factors responsible for low productivity of sesame. Slow early crop growth, high temperature, frequent rainfall and adequate soil moisture provide conducive environment to weeds to emerge and exploit the sesame habitat. In most of the areas sesame crop is heavily infested by weeds and thereby resulting in heavy yield loss ranging from 16-68% (Duary and Hazra 2013, Hazra and Duary 2015). Continuous application of the same herbicides year after year in the same crop in the same field may lead to shifting of weed flora and development of herbicides resistance in weed (Duary 2008). Proper and timely management of weeds, by manual weeding, in the crop field to reduce the crop-weed competition is difficult due to a sharp increase in the wages and unavailability of labor. Integrated weed management may help to keep the weed population below threshold level (Rao and Nagamani 2010). Use of stale seedbed technique, tillage practices, making the crop more competitive with the use of competitive varieties, use of crop residue as mulch are nowadays the major components of integrated weed management. Mulching is also one of the important components of integrated weed management in sesame (Fatima and Duary 2020, Fatima *et al.* 2021). Soil mulching is a simple management that uses pre-sowing irrigation followed

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by (*fb*) shallow tillage (which breaks soil capillaries and creates soil mulch) before sesame sowing to attain better weed control, limit evaporation losses and reduce the early irrigation requirement. In contrast, seeding in dry soil *fb* irrigation would require frequent irrigation because of high evaporation losses through soil capillaries in late April-May when the soil temperature is very high (~40° C). Although irrigation immediately after sowing facilitates good crop emergence, it also favors establishment of weeds along with the sesame. In contrast, when soil mulching is used, it is hypothesized that the top 2 cm of the soil layer in which most of the weeds establish dries quickly, and weed establishment is reduced; moisture below 2 cm is conserved, enabling good sesame establishment and reducing the need for early irrigation. There is also a scope of integrating herbicides with cultural practices to improve the sustainable use of herbicides. With this perspective the present experiment was conducted to study the effect of soil mulch sowing and weed management on weed growth and productivity of summer sesame.

A field experiment was conducted during pre-*Kharif* season, 2020 in the Agricultural Farm of the Institute of Agriculture, Visva-Bharati, Sriniketan, Birbhum, West Bengal. The field is situated at about $23^0$39.8232 N latitude and $87^0$37.9722 E longitude with an average altitude of 60 m above the mean sea level. The soil of the experimental site was sandy loam (Ultisol) in texture, medium to low fertility (available N-150.60 kg/ha, available P-29.13 kg/ha, available K-122.47 kg/ha with acidic reaction (pH 5.88). The field experiment was laid out in split-plot design (SPD) assigning two soil mulch practices in main plots and six weed management practices in sub-plots, replicated thrice. All the treatment plots were demarcated by ridges (bunds) on all sides (15 cm high). Two soil mulch practices comprising of sowing after pre-sowing irrigation (soil mulch) and sowing followed by irrigation (no soil mulch) were allocated in the main plot and six weed management treatments, *viz*. pre-emergence application (PE) of pendimethalin 1.0 kg/ha, early post-emergence application (EPoE) of fenoxaprop-p-ethyl 60 g/ha at 18 DAS , pretilachlor 450 g/ha PE, propaquizafop 60 g/ha EPoE at 18 days after seeding (DAS), untreated control and weed free check in sub-plots. The sesame variety '*Rama*' ('Improved Selection-5') was used in the experiment. This variety was developed from the Pulses and Oilseeds Research Station, Berhampur, West Bengal. Sesame was sown in lines manually on 2^{nd} fortnight of March, 2020 with a row spacing of 30 cm. The plant-to-plant distance was later maintained about 10 cm by thinning additional plant. The recommended doses of fertilizers (80:40:40 N:P:K kg/ha) were applied through urea, single super phosphate (SSP) and muriate of potash (MOP). Half quantity of nitrogen and full amount of phosphorus and potassium were applied in each plot as basal during final land preparation. Rest half quantity of N was applied at 21 DAS. Growth parameters and yield attributes were recorded at different growth stages of the crop. All the herbicides were applied using 500 liters of water/ha by spraying uniformly in the experimental plots as per treatments with the help of power operated knapsack sprayer. The population of grasses, sedges and broad-leaved weeds was counted by placing quadrat (0.25/m^2 area) randomly at four places and the density (no./m^2) was estimated. Weed species within the area of quadrat were counted, collected and air dried in hot air oven maintained at 70 to 75ºC temperature for recording weed biomass. The data were subjected to a square root transformation to normalize their distribution. The experimental data were analyzed statistically by the technique of "Analysis of variance" and significance was tested by variance ratio *i.e*. value at 5% level of significance as described by Gomez and Gomez (1984).

Effect on weeds

Sesame was infested with ten weed species out of which *Cynodon dactylon, Digitaria sanguinalis, Echinochloa colona* and *Dactyloctenium aegyptium* were grasses; *Cyperus iria* was the sedges; *Indigofera hirsuta, Hedyotis corymbosa, Ludwigia parviflora, Mollugo stricta* and *Malvastrum coromandelianum* were the broad-leaved weeds predominant throughout the cropping period. There was predominance of grassy weeds in the experimental field. Irrespective of herbicidal treatments, total weed density was significantly the lowest under sowing after pre-sowing irrigation (soil mulch) method. At 45 DAS, total weed density was 24.70% lower (**Table 1**) under the sowing with soil mulch method than in no soil mulch sowing. Weedy check plots registered the highest total weed density at 45 DAS and there was preponderance of grasses (60.23%), followed by broad-leaved weeds (26.82%) and sedges (12.81%) (**Table1**). Among different weed management practices, propaquizafop 60 g/ha EPoE was found to be significantly superior over the others in reducing the density of grasses at 45 DAS.

With regard to lowering down the broad-leaved weed density at 45 DAS, pretilachlor at 450 g/ha PE was most effective. Total weed density at 45 DAS was lowest with propaquizafop 60 g/ha early PoE which was statistically at par with pendimethalin 1.0 kg/ha PE and fenoxaprop ethyl at 60 g/ha EPoE.

At 45 DAS, the grass, broad-leaved, sedge and total weed biomass was lower by 27.63, 21.79, 23.61 and 25.18%, respectively under the soil mulch method than no soil mulch method (**Table 1**). Propaquizafop 60 g/ha EPoE significantly reduced the grassy and total weed biomass at 45 DAS and was on par with fenoxaprop-ethyl 60 g/ha EPoE (**Table 1**). Among herbicide treatments, broad-leaved weeds biomass at 45 DAS was significantly reduced with pretilachlor 450 g/ha PE. Sedges were numerically and significantly lower at 45 DAS with pendimethalin 1.0 kg/ha PE (**Table 1**). Grasses, broad-leaved and sedges together accumulated the highest total biomass at 45 DAS under weedy check, and their contributions to total weed biomass was 55.98, 29.12 and 14.69%, respectively (**Table 1**).

Interaction effect between sowing method and weed management practices on weed density and biomass was found significant at 45 DAS. Density of total weeds was 23.44% lower with propaquizafop under soil mulch sowing than in no soil mulch sowing. Similarly, 19.45% lower density of total weeds was observed with fenoxaprop-p-ethyl under soil mulch sowing than in no soil mulching sowing (**Figure 1**). Biomass of total weed was 21.80% lower

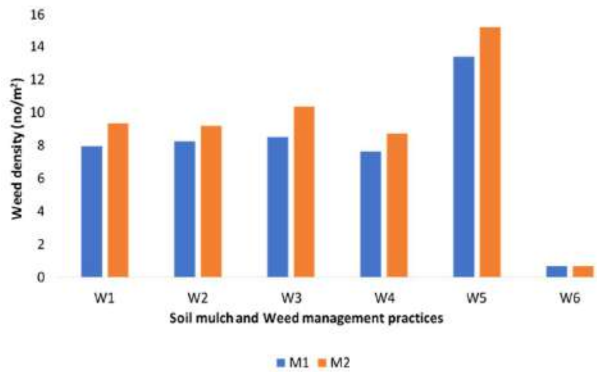

Figure 1. Interaction effect of soil mulch sowing and weed management practices on total weed density at 45 DAS

W1= Pendimethalin1.0 kg/ha PE; W2=Fenoxaprop-ethyl 60g/ha EPoE; W3 =Pretilachlor 450 g/ha PE; W4 =Propaquizafop 60 g/ha EPoE; W5 = Untreated control; W6 = Weed free check; M1 =Soil mulch sowing; M2 =No soil mulch sowing

with fenoxaprop-p-ethyl under soil mulch sowing than in no soil mulching sowing. Propaquizafop under soil mulch sowing method registered 22.01 % lower total weed biomass than in no soil mulching sowing (**Figure 2**). The results are in conformity with Fatima and Duary (2020) and Fatima *et al.* (2021).

Effect on sesame

The plant height at harvest stage of sesame was 6.25% higher (**Table 2**) under soil mulch sowing method in comparison to sowing followed by irrigation method. This might be probably due to suppression of weed seed germination by soil

Table 1. Effect of soil mulch and weed management treatments on weed density and biomass at 45 DAS

Treatment	Weed density (no./m^2) at 45 DAS**				Weed biomass (g/m^2)** at 45 DAS			
	Grass	Broad-leaved	Sedges	Total	Grass	Broad-leaved	Sedges	Total
Soil mulch								
Sowing after pre-sowing irrigation (soil mulch sowing)	5.82 (33.32)	4.59 (20.58)	2.10 (3.92)	7.75 (59.56)	6.00 (35.47)	5.04 (24.88)	2.45 (5.50)	8.28 (68.12)
Sowing followed by (*fb*) irrigation (no soil mulch)	6.68 (44.07)	5.32 (27.76)	2.32 (4.89)	8.92 (79.10)	7.04 (49.01)	5.68 (31.81)	2.77 (7.20)	9.57 (91.05)
LSD (p=0.05)	0.80	0.62	0.41	0.41	0.69	0.49	0.31	0.66
Weed management treatment								
Pendimethalin 1.0 kg/ha PE	7.11 (50.05)	4.98 (24.35)	0.71 (0.00)	8.66 (74.48)	7.60 (57.29)	5.61 (30.98)	0.71 (0.00)	9.43 (8839)
Fenoxaprop-p-ethyl 60 g/ha EPoE	5.74 (32.39)	5.98 (35.28)	2.90 (7.90)	8.73 (75.71)	5.52 (29.95)	6.42 (40.78)	4.00 (15.54)	9.32 (86.42)
Pretilachlor 450 g/ha PE	8.34 (68.99)	4.48 (19.53)	0.71 (0.00)	9.45 (88.71)	8.79 (76.81)	4.94 (23.88)	0.71 (0.00)	10.07 (100.82)
Propaquizafop 60 g/ha EPoE	4.48 (19.61)	6.15 (37.30)	3.09 (9.04)	8.18 (66.48)	5.29 (27.45)	6.40 (40.44)	3.78 (13.76)	9.08 (81.98)
Untreated control	11.10 (122.79)	7.42 (54.63)	5.16 (26.10)	14.29 (203.72)	11.19 (124.82)	8.09 (64.94)	5.77 (32.75)	14.95 (222.98)
Weed free check	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
LSD (p=0.05)	0.56	0.48	0.39	0.57	0.54	0.49	0.54	0.64

*PE = pre-emergence application; EPoE = early post-emergence application; **Figures in parentheses are the original values and the data were transformed to SQRT ($\sqrt{x+0.5}$) before analysis; DAS = days after seeding; PE = pre-emergence; EPoE = early post-emergence.

mulching resulting in less weed competition and higher nutrient uptake and greater light interception by sesame. Propaquizafop 60 g/ha EPoE recorded the highest (**Table 2**) plant height and it was comparable with pendimethalin 1.0 kg/ha PE and fenoxaprop ethyl 60 g/ha EPoE. The untreated control recorded the lowest plant height, which might be due to severe competition exerted by grassy, broad-leaved and sedge weeds throughout the growth period of sesame by shading of weeds or overcrowding in crop-weed ecosystem and competing with the crop for space, light and nutrients. Propaquizafop or fenoxaprop-p-ethyl EPoE and pendimethalin PE were able to check the weed growth, mainly grassy weeds, which were predominant, from initial stage of crop growth and for a quite long period of time reducing weed competition and creating a favorable condition of crop growth. Similar results were also reported by Fatima and Duary (2020) and Fatima *et al.* (2021) in summer sesame in lateritic belt of West Bengal.

Soil mulch sowing method registered higher seeds/capsule, number of capsules/plants than sowing followed by no soil mulch sowing method. The plant height at harvest stage of sesame was 6.25% higher and number of capsules/plants was 17.97% higher (**Table 2**) under soil mulch sowing method than under no soil mulch sowing. There was no significant difference between sowing methods in test weight of sesame. However, test weight differed significantly due to weed management practices (**Table 2**). The highest test weight of sesame was observed under weed free treatment which was significantly superior over untreated control. All other weed management practices were on par with weed free treatment with respect to test weight. Fenoxaprop-ethyl 60 g/ha EPoE registered the highest

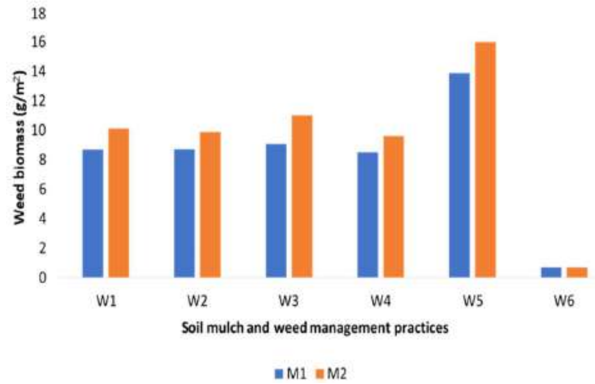

Figure 2. Interaction effect of soil mulch sowing and weed management treatments on total weed biomass at 45 DAS

W1= Pendimethalin1.0 kg/ha PE; W2= Fenoxaprop-ethyl 60 g/ha EPoE; W3 = Pretilachlor at 450 g/ha PE; W4 = Propaquizafop at 60 g/ha EPoE; W5 = Untreated control; W6 = Weed free check; M1 =Soil mulch sowing; M2 =No soil mulch sowing

number of seeds per capsule, number of capsules/plants and it was at par with that of pendimethalin 1.0 kg/ha PE and propaquizafop 60 g/ha EPoE (**Table 2**). This indicates that efficient and timely weed management practices by application of either pre-emergence or early post emergence herbicide effectively controlled dominant weeds appearing in early stage of crop growth which promoted branches and capsule formation of sesame, growth attributes and partitioning dry matter towards seed formation.

Seed and stick yield of sesame under soil mulch sowing method was about 12.99 and 12.85% higher (**Table 2**) than under the no soil mulch sowing, probably due to better weed control with soil mulching. Among weed management treatments, irrespective of the sowing method, seed and stick yield were the highest with fenoxaprop-p-ethyl 60 g/

Table 2. Effect of soil mulch and weed management treatments on plant height, yield attributes and yield of sesame

Treatment	Plant height at harvest (cm)	Capsules / plant	Seeds/ capsule	Test weight (g)	Seed yield (kg/ha)	Stick yield (kg/ha)
Soil mulch						
Sowing after pre-sowing irrigation (soil mulch sowing)	118.3	77.9	53.3	2.95	1239	2233
Sowing followed by (*fb*) irrigation (no soil mulch)	110.9	63.9	46.7	2.85	1078	1946
LSD(p=0.05)	6.95	11.9	4.5	0.49	136.5	208.2
Weed management treatments						
Pendimethalin 1.0 kg/ha PE	119.2	82.4	51.3	2.89	1225	2172
Fenoxaprop-ethyl 60 g/ha EPoE	117.3	79.5	52.7	2.87	1275	2241
Pretilachlor 450 g/ha PE	109.0	61.7	43.5	2.86	1017	1863
Propaquizafop 60 g/ha EPoE	122.0	66.7	50.3	2.87	1158	2099
Untreated control	91.7	44.8	35.8	2.40	768	1567
Weed free check	128.1	90.3	66.3	2.97	1508	2595
LSD (p=0.05)	6.22	7.89	3.11	0.44	125.8	215.6

*PE = pre-emergence application; EPoE = early post-emergence application ha EPoE which was statistically on par with pendimethalin 1.0 kg/ha PE and propaquizafop 60 g/ha EPoE. The sesame seed and stick yield increased considerably with weed management confirming the findings of Fatima and Duary (2020) in sesame.

Conclusion

Based on one season experiment, it can be concluded that sowing of sesame after pre-sowing irrigation (soil mulch sowing), as a cultural practice, has promising effect of reducing weed growth. Sowing of sesame after pre-sowing irrigation (soil mulch) along with either fenoxaprop-p-ethyl 60 g/ha EPoE or propaquizafop-p-ethyl 60 g/ha EPoE at 18 days after sowing were found effective in managing weeds and increasing yield of sesame in lateritic soil of West Bengal specially in the fields having predominance of grassy weeds.

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RESEARCH NOTE

Evaluation of the efficacy of pre- and post-emergence herbicides in *Rabi* sesame

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ABSTRACT

A field experiment was conducted at ICAR-Indian Institute of Oilseeds Research, Hyderabad during *Rabi* season of 2023-24 in a red sandy soil. The objective was to evaluate the effect of sequential application of pre-emergence (PE) and post-emergence (PoE) herbicides on weed management, sesame yield and to identify effective herbicides for weed management, yield preservation, and crop safety. Sesame (*Sesamum indicum* L.) cv "*CUMS 17*" was line-sown. Among the herbicides tested, pre-emergence application (PE) of pendimethalin 30% + imazethapyr 2% EC (pre-mix) (pendimethalin + imazethapyr) 750+50 g/ha achieved significantly highest weed control efficiency (WCE) at 60 DAS and sesame yield. The sequential application of pendimethalin 750 g/ha PE followed by (*fb*) post-emergence application (PoE) of haloxyfop-R-methyl 10.5% w/w EC (haloxyfop-R-methyl) 54 g/ha recorded the next highest yield. Pyroxasulfone 85% w/w WG (pyroxasulfone) 127.5 g/ha PE was statistically at par with above sequential application treatment. Bentazone, metribuzin, fluazifop-p-butyl + fomesafen, and propaquizafop + imazethapyr showed phytotoxicity and resulted in lower sesame yield. The uncontrolled weeds in weedy check limited sesame yield to just 33% of the weed free check. It could be concluded that pendimethalin + imazethapyr 750+50 g/ha PE was superior in terms of attaining higher yield of sesame and effective weed management, while pyroxasulfone PE, haloxyfop-R-methyl, and clethodim PoE demonstrated their potential to use for weed management in sesame.

Keywords: Clethodim, Haloxyfop-R-methyl, Pyroxasulfone, Pendimethalin + imazethapyr, Sesame, Weed management

Sesame (*Sesamum indicum* L.) is a highly valued oilseed crop, known for its adaptability to diverse agro-climatic conditions and its rich oil content (50-60%). The low productivity of sesame has zeroed-in on weed competition as the cause for the low productivity. The slow early growth of sesame led to significant decline in yield up to 50-80%, despite sesame yield potential (Karnas *et al.* 2019). Critical period for crop weed competition in sesame is 15-45 days. The poor competitive ability of sesame makes effective weed management crucial to ensuring optimal sesame productivity. In spite of new technological developments to improve sesame yield, the current crop management systems for sesame need to be further improvised to effectively manage the ever-adopting weeds that are competing with the crop. Currently, herbicide-based weed management strategies are widely used to control weeds in sesame. herbicides applied post-emergence (PoE) such as pendimethalin are commonly used to manage weeds early in the season, while post-emergence herbicides to manage weeds emerging later in the crop cycle. Many herbicides applied post-emergence (PoE), though effective at controlling weeds, can cause crop injury, resulting in stunted growth and yield losses (Grichar *et al.* 2009). This sensitivity has limited the development and adoption of integrated weed management strategies that include both PE and PoE herbicides.

The sensitivity of sesame to herbicides and the complexity of weed control during the crop's critical growth stages, emphasises the pressing need to identify PE and PoE weed management strategies that balance weed suppression with crop safety. Thus, screening herbicides for their efficacy and safety is essential for developing sustainable weed management strategies. This study aims to evaluate the effect of sequential application of pre-emergence and post-emergence herbicides on weed management, and sesame yield and to identify effective herbicides for optimal weed management without compromising the growth and productivity

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of the sesame crop.

A field experiment was conducted at Narkhoda Farm, ICAR-Indian Institute of Oilseeds Research, Hyderabad. The experiment was laid in a Randomized Block Design (RBD), replicated thrice and comprised of 22 treatments (**Table 1**). Sesame variety *"CUMS-17"* was sown on 02/01/2024 in rows spacing of 45 cm and harvested on 10/04/2024. The plot size was 5.0 × 4.0 m. The recommended fertiliser dosage rate of 40:20:20 kg NPK/ha was applied in the form of urea, di-ammonium phosphate (DAP) and muriate of potash. Need based irrigation and plant protection measures were carried out. The pre-emergence application (PE) of herbicides was done on second day after sowing (DAS) following irrigation and post-emergence application (PoE) was done at two leaf stage of weeds using a flat fan type nozzle fitted knapsack sprayer and using 500 liter of water/ha at 18-20 DAS. The treatments include: pendimethalin 30% EC (pendimethalin) 750 g/ha as PE, pendimethalin 750 g/ha PE followed by (*fb*) bentazone 480 g/L SL (bentazone) PoE 960, 760 and 480 g/ha PoE, pendimethalin750 g/ha PE *fb* clethodim 25% EC (pendimethalin + clethodim) 120, 90 and 60 g/ha PoE, pendimethalin *fb* haloxyfop-R-methyl 10.5% w/w EC (haloxyfop-R-methyl) 108, 81 and 54 g/ha PoE, pendimethalin *fb* metribuzin 70% WP (metribuzin) 525, 400 and 300 g/ha PoE, pendimethalin *fb* fluazifop-p- butyl 11.1% w/w + fomesafen 11% w/w SL (fluazifop-p-butyl + fomesafen) 187.5 and 125 g/ha, pendimethalin *fb* propaquizafop 2.5% + imazethapyr 3.75% (propaquizafop + imazethapyr) 37.5+56.25 PoE and 25+37.5 g/ha, pyroxasulfone 85% w/w WG (pyroxasulfone) 127.5 g/ha PE, pendimethalin 30% + imazethapyr 2% EC as PE (pre-mix) (pendimethalin + imazethapyr) 750+50 g/ha PE, pendimethalin *fb* pyrithiobac-sodium 6% w/w +quizalofop ethyl 4% w/w EC (pyrithiobac-sodium + quizalofop-ethyl) 60+40 g/ha PoE at 2-3 leaf stage of weed, weed free and weedy check. The data related to weed density and weed dry weight (weed biomass) was recorded at 60 DAS. Prior to statistical analysis, the weed density and biomass data were subjected to a square root transformation ($\sqrt{x+0.5}$). Phytotoxicity rating (0-100) of herbicides on crop in terms of yellowing, stunting and necrosis was recorded at 15 days after PoE spray as per earlier reported methodology (Vanhala *et al.* 2004). Weed indices were calculated according to the methodologies described by Poddar *et al.* (2017). Statistical procedures followed the guidelines of Gomez *et al.* (1984).

Weed flora

The experimental field was infested with a diverse weed flora dominated by sedges and broad-leaved weed species. Notably, no grassy weeds were observed. *Cyperus rotundus* was the predominant sedge species. Among the broad-leaved weeds, dominant species were: *Amaranthus viridis*, *Argemone mexicana*, *Alternanthera paronychioides*, *Boerhavia diffusa*, *Euphorbia hirta*, *Trianthema portulacastrum*, *Parthenium hysterophorus*, *Phyllanthus maderaspatensis* and *Phyllanthus niruri*.

Phytotoxicity on sesame

The pre-emergence application of pendimethalin, pyroxasulfone and pendimethalin + imazethapyr (pre-mix) did not exhibit any phytotoxicity symptoms on sesame. On the other hand, post-emergence over-the-top herbicides, *viz.* bentazone, metribuzin, fluazifop-p-butyl + fomesafen (pre-mix), propaquizafop + imazethapyr (pre-mix) have shown slight to moderate injury on sesame which includes leaf necrosis to reduction in crop stand. However, the crop has recovered from the damage.

Pendimethalin 750 g/ha PE *fb* pyrithiobac-sodium + quizalofop-ethyl (pre-mix) 60+40 g/ha PoE at 2-3 leaf stage of weed had detrimental effect of complete loss of crop stand. Thus, as this treatment has no potential in sesame weed management, it will not be discussed further.

Weed control

The tested treatments exhibited significant variation in their effectiveness in terms of weed density and biomass (**Table 1**). However, there was no statistically significant difference among the treatments in controlling the density of broad-leaved weeds specifically.

Pendimethalin 750 kg/ha PE followed by propaquizafop + imazethapyr 37.5 + 56.25 g/ha PoE significantly reduced the density of sedges and total weeds, achieving the highest weed control efficiency (WCE) of 78.32%. The use of same treatment at lower rates resulted in a reduced WCE of 62.09%. The treatments using sole PE herbicides, such as pendimethalin at 750 g/ha and pyroxasulfone at 127 g/ha were less effective, in reducing the density of both sedges and broad-leaved weeds, with WCE of 53.8% and 51.37%, respectively. The bentazone 960 g/ha and 760 g/ha recorded WCEs of 75.43%, effectively

Table 1. Effect of herbicides on sesame seed yield and on associated weed density, biomass and weed indicators at 60 DAS

Treatment	Weed density (no./m^2)			WCE (%)	Weed biomass (g/ m^2)	WCI	Phyto-toxicity score	Sesamum seed yield (t/ha)
	Sedges	BLW	Total					
Pendimethalin 750 g/ha PE	5.33 (3.11)	17.33(4)	22.67 (6.18)	53.79	9.33 (2.18)	53.99	0	0.30
Pendimethalin 750 g/ha PE *fb* bentazone 960 g/ha PoE	6.67(2.2)	5.33(2.39)	12 (5.04)	75.43	4.4(2.65)	79.74	20	0.15
Pendimethalin PE *fb* bentazone 760 g/ha PoE	2.67(2.61)	9.33(3.13)	12(4.78)	75.43	6.67(1.65)	67.76	20	0.20
Pendimethalin PE *fb* bentazone 480 g/ha PoE	16(2.87)	10.67(3.24)	26.67(7.5)	43.36	7.87(4.26)	62.84	20	0.22
Pendimethalin 750 g/ha PE *fb* clethodim 120 g/ha PoE	5.33(2.46)	9.33(2.77)	14.67(4.95)	70.42	5.87(2.18)	70.87	0	0.26
Pendimethalin 750 g/ha PE *fb* clethodim 90 g/ha PoE	17.33(3.1)	5.33(2.39)	22.67(6.49)	54.44	9.47(4.11)	53.43	0	0.30
Pendimethalin 750 g/ha PE *fb* clethodim 60 g/ha PoE	13.33(3.68)	16(3.87)	29.33(7.85)	40.80	13.07(3.71)	38.97	0	0.33
Pendimethalin 750 g/ha PE *fb* haloxyfop-R-methyl 108 g/ha PoE	9.33(2.74)	5.33(2.39)	14.67(5.42)	69.48	7.47(3.03)	66.38	0	0.30
Pendimethalin 750 g/ha PE *fb* haloxyfop-R-methyl 81 g/ha PoE	18.67(2.86)	4(1.92)	22.67(6.41)	53.79	8(4.5)	59.89	0	0.38
Pendimethalin 750 g/ha PE *fb* haloxyfop-R-methyl 54 g/ha PoE	10.67(2.85)	2.67(1.65)	13.33(4.95)	73.70	8.13(3.3)	63.79	0	0.42
Pendimethalin 750 g/ha PE *fb* metribuzin 525 g/ha PoE	12 (15)	6.67(15)	18.67(15)	60.13	4.93(15)	75.93	20	0.14
Pendimethalin 750 g/ha PE *fb* metribuzin 400 g/ha PoE	12 (2.56)	6.67(2.39)	18.67(6.52)	60.93	6.27(3.96)	68.70	20	0.18
Pendimethalin 750 g/ha PE *fb* metribuzin 300 g/ha PoE	12 (2.97)	10.67(2.86)	22.67(6.37)	54.69	8.4(3.51)	59.47	20	0.17
Pendimethalin 750 g/ha PE *fb* fluazifop-p-butyl + fomesafen 187.5 g/ha PoE	1.33(2.11)	17.33(3.96)	18.67(5.14)	59.88	4.27(1.18)	78.26	20	0.16
Pendimethalin 750 g/ha PE *fb* fluazifop-p-butyl + fomesafen 125 g/ha PoE	9.33(2.94)	9.33(2.92)	18.67(5.64)	62.23	8.4(2.72)	58.26	20	0.15
Pendimethalin 750 g/ha PE *fb* propaquizafop 2.5% + imazethapyr 37.5+56.25 g/ha PoE	5.33(2.29)	5.33(2.12)	10.67(4.51)	78.32	5.47(2.39)	76.94	20	0.12
Pendimethalin 750 g/ha PE *fb* propaquizafop + imazethapyr 25+37.5 g/ha PoE	12(2.52)	9.33(2.77)	25.33(6.67)	62.09	7.73(3.41)	65.26	20	0.07
Pyroxasulfone 127.5 g/ha PE	17.33(3.17)	6.67(2.65)	24(7.38)	51.37	6.27(4.73)	55.71	0	0.41
Pendimethalin + imazethapyr 750+50 g/ha PE	6.67(2.58)	10.67(3.33)	17.33(6.66)	65.12	21.6(3.33)	71.17	0	0.56
Pendimethalin 750 g/ha PE *fb* pyrithiobac-sodium +quizalofop-ethyl 60+40 PoE	-	-	-	-	-	-	100	-
Weed free	-	-	-	100	-	100	-	0.63
Weedy check	30.67(4.69)	18.67(4.37)	49.33(8.77)	0	21.6(1.82)	0	-	0.21
LSD (p=0.05)	1.14	2.03	2.49	27.21	1.82	19.29	-	0.07

*Figures in parentheses are transformed values; PE = pre-emergence application; PoE = post-emergence application, *fb* = followed by, DAS = days after seeding

controlling both types of weeds. Clethodim 120 g/ha also showed a reasonably good WCE (70.42%). Among the PoE treatments, metribuzin and fluazifop-p-butyl + fomesafen included treatments recorded higher weed densities.

Sesame yield attributes and yield

Among the tested herbicide treatments, pendimethalin 750 g/ha + imazethapyr 50 g/ha (pre-mix) PE and pyroxasulfone 127.5 g/ha PE produced sesame yield statistically comparable to the weed-free check. Variation was observed in grain yield across the treatments.

Among the pre-emergence herbicides, pendimethalin at 750 g/ha, pyroxasulfone 127.5 g/ha, pendimethalin 750 g/ha + imazethapyr 50 g/ha (pre-mix) showed no phytotoxicity symptoms on the sesame crop with fairly higher control of total weeds, demonstrating their potential as safe pre-emergence herbicides for managing weeds in sesame fields as observed earlier by Singh *et al.* (2018).

PoE herbicides at higher dosages were effective in reducing weed biomass. However, PoE herbicides, *viz*. bentazone (Grichar *et al*. 2002), metribuzin (Grichar *et al.* 2009), fluazifop-p-butyl + fomesafen (pre-mix), and propaquizafop + imazethapyr (pre-mix) (Ghadiya *et al.* 2024), caused slight to moderate crop injury and reductions in crop stand. Although, the crop recovered, there was a yield penalty.

Among the post-emergence herbicide treatments, clethodim 120 g/ha and haloxyfop-R-methyl 108 g/ha recorded WCE of 71% and 64%, respectively with sesame yield higher than pendimethalin PE. Ismail *et al.* (2024) demonstrated earlier the effective use of PoE application of clethodim and haloxyfop-R-methyl in sesame.

The results of this study highlight an interesting disparity between weed control efficiency and crop yield in case of PoE herbicide treatments which might be due to their detrimental effects on the crop despite their effectiveness against weeds. Phytotoxicity can lead to reduced crop growth, which offsets the benefits of improved weed control (Grichar *et al.* 2011). Some herbicides for instance, bentazone and fluazifop-p-butyl + fomesafen, while effective in controlling weeds, caused some degree of crop injury, affecting overall yield. The variation in yield and its relationship with WCE in the case of PoE herbicides can be better understood through a more in-depth study of phytotoxicity and the factors influencing the efficacy of herbicide.

The use of pendimethalin at 750 g/ha PE and pyroxasulfone at 127.5 g/ha PE, alone, was effective during initial phase of crop growth. These results highlight the need for integration of weed management practices including the use of post-emergence herbicides and hand weeding or hoeing which could be more effective in reducing overall weed populations.

Pendimethalin at 750 g/ha + imazethapyr at 50 g/ha (pre-mix) PE was the only treatment which exhibited the least yield reduction due to effective weed control. This can be explained by complementary action of pendimethalin, which is effective during germination and establishment whereas imazethapyr particularly effective after emergence of crop due to its soil action. However, results of this study show that premix PE herbicide could not suffice the entire critical period of crop weed competition necessitating the integration of weed management practises.

This research serves as a basis for future research on sesame weed management, focusing on optimizing herbicide use to minimize crop injury and maximize yield. Future studies should examine herbicide toxicity, soil residue, and sustainable strategies such as integrated weed management (IWM).

Conclusion

Based on weed control, crop safety and yield parameters, the combination of pendimethalin + imazethapyr 750+50 g/ha PE is most promising recording effective weed control and higher sesame yield with minimal yield losses due to weeds followed by pyroxasulfone 127.5 g/ha PE.

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