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RESEARCH ARTICLE

Effect of herbicides on weeds and direct-seeded rice growth and yield

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ABSTRACT

A study was carried out during 2022 and 2023 in Raipur, Chhattisgarh with an objective to study the effect of sequential pre-emergence application (PE) followed by (*fb*) post-emergence application (PoE) of herbicides on weed management and grain yield of direct-seeded rice (DSR). Weed flora associated with DSR were: *Alternanthera sessilis*, *Cyanotis axillaris*, *Echinochloa colona*, *Cyperus iria*. Pendimethalin 1000 g/ha PE *fb* tank mixed bispyribac-sodium 25 g/ha + metsulfuron-methyl + chlorimuron-ethyl ready mix (RM) 4 g/ha PoE at 25 to 30 days after seeding (DAS) reduced weed density with higher rice plant height, leaf area and maximum rice grain yield, which was comparable with pendimethalin 1.0 kg/ha PE *fb* penoxsulam + cyhalofop-butyl (RM) 135 g/ha PoE 25-30 DAS and hand weeding twice at 30 and 60 DAS. It was concluded that pendimethalin 1.0 kg/ha PE *fb* bispyribac-sodium 25 g/ha + metsulfuron-methyl + chlorimuron-ethyl (RM) 4 g/ha tank mix PoE at 25-30 DAS effectively managed weeds in direct-seeded rice which resulted in maximum rice growth and yield as well as maximum net return and B:C ratio.

Keywords: Direct-seeded rice, Metsulfuron-methyl + chlorimuron-ethyl, Pendimethalin, Penoxsulam + cyhalofop-butyl, Weed management

INTRODUCTION

Rice (*Oryza sativa* L.) is a primary food crop grown widely over 162 million hectares in more than hundred countries of the world (Anonymous 2022) with an annual global production of about 680.7 million tons (Anonymous 2022a). It is the staple food for more than half of the world's population. In India, rice is the major food grain crop and an important part of the national economy, cultivated in an area of 47.83 million hectares, with a production and productivity of 135.7 MT and 2.83 t/ha, respectively (Anon 2023) and accounted for over Rs. 1.8 trillion in the Indian economy (Anonymous 2020b). Chhattisgarh accounts for 3.82 Mha area with a production of 7.82 MT and productivity of 2.04 t/ha in the state (Anonymous 2023).

The direct-seeding of rice (DSR) results in the increased efficiency of time, energy, water, and labor costs (Rao *et al*. 2007). Despite of several advantages, heavy weed infestation is one of the major constraints in direct-seeded rice since weeds cause severe rice yield losses. Herbicide usage for weed management is becoming the popular method of weed control in rice, because of lower costs involved (Rao *et al*. 2017). But, weed shift from grasses to non-grasses and annual sedges is being observed in rice field due to continuous use of high dose of herbicides like pendimethalin, pyrazosulfuron-ethyl *etc*. (Singh *et al*. 2017). These herbicides provide effective control of annual grasses when applied as pre-emergence, rendering an effective control during the first 20 to 25 days. Later emerging weeds at later stages of rice growth becomes uncontrollable causing considerable loss of rice yield, besides adding weed seeds to the seed bank of the soil. Hence, to achieve weed control at the later stages, pre-emergence application of herbicides alone is not sufficient to adequately manage weeds. Thus, sequential application of both pre- and post-emergence herbicides is essential to achieve broad spectrum weed control during critical period so as to realize the yield potential of rice. Pre- and post-emergence herbicides offer selective, timely, effective, and cost-efficient weed control rather than manual weeding (Jayadeva *et al*. 2011). Hence, a study was carried out with an objective to study the effect of sequential pre-emergence application (PE) followed by (*fb*) post-emergence application (PoE) of herbicides on weed management, crop growth, and rice yield in direct-seeded rice.

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MATERIALS AND METHODS

This experiment was conducted during the *Kharif* 2022 and 2023 at Research cum Instructional Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. Raipur is situated in south eastern part of Chhattisgarh at 21o23'N latitude and 81o71'E longitude at the height of 290.20 m above the mean sea level (MSL). The soil of the experimental field was clayey in texture and neutral (pH 7.18) in reaction with medium fertility having 0.39% soil organic carbon, low nitrogen (255 kg/ha), medium phosphorous (17.40 kg/ha) and high potassium (370 kg/ha), respectively.

The experiment was laid out in randomized block design (RBD) with three replications and seven treatments, *viz*. pendimethalin + pyrazosulfuron-ethyl ready mix (RM) 785 g/ha PE followed by (*fb*) one hand weeding (HW) at 30 days after seeding (DAS), penoxsulam + pendimethalin (RM) 625 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE at 25-30 DAS, penoxsulam + pendimethalin (RM) 625 g/ha PE *fb* fenoxaprop-ethyl 67 g/ha + ethoxysulfuron 18 g/ha PoE at 25-30 DAS, pendimethalin 1.0 kg/ha PE *fb* bispyribac-sodium 25 g/ha + metsulfuron-methyl + chlorimuron-ethyl (RM) 4 g/ha tank mix PoE at 25-30 DAS, pendimethalin 1.0 kg/ha PE *fb* penoxsulam + cyhalofop-butyl (RM) 135 g/ha PoE 25-30 DAS, hand weeding (HW) twice at 30 and 60 DAS, partially weedy check with HW once at 60 DAS. The rice variety "Indira Rajeshwari (IGKV R 1)" was sown on 1st July 2022 and 3rd July 2022 and harvested on 3rd November 2022 and 15 November 2023. The crop received 783 and 855 mm rainfall during the crop period in 2022 and 2023, respectively. The rainfall received was more in 2023 and hence the field remained filled with water for a long time with lesser weed infestation and higher rice tillering, plant height and higher yield than 2022 *Kharif* season.

Herbicides were applied as per the treatments mentioned in experimental details. Pendimethalin + pyrazosulfuron-ethyl (RM) 785 g/ha, penoxsulam + pendimethalin (RM) g/ha, pendimethalin 1.0 kg/ha spraying was done 2 days after sowing (DAS). The bispyribac-sodium 25 g/ha, fenoxaprop-ethyl 67 g/ha + ethoxysulfuron 18 g/ha, metsulfuron-methyl + chlorimuron-ethyl (RM) 4 g/ha tank mix, penoxsulam + cyhalofop-butyl (RM) 135 g/ha PoE were applied as sequential post-emergence herbicides at 25-30 DAS, as per the treatment details. For herbicides application, hand operated knapsack sprayer was used which was fitted with flat fan deflector nozzle. For the herbicide application water (500 liters/ha) was used as carrier.

Rice plant height and leaf area data was collected from the experimental plots at 20, 40, 60, 90 DAS and at harvest. The rice grain yield was collected and economic analysis was done using standard procedures. Total and species wise weed density associated with DSR in the experimental plots were recorded at 40 DAS. Weed count was done from three spots using quadrat of 0.5 m x 0.5 m (0.25 m^2) randomly placed in each plot. The number of weeds were counted and the density was expressed as number/m^2. Weed density data was subjected to square root transformation *i.e.*, $\sqrt{x+0.5}$, for statistical analysis.

RESULTS AND DISCUSSION

Weed flora

The weed flora of the experimental field consisted of *Alternanthera sessilis, Cyanotis axillaris, Echinochloa colona, Cyperus iria*. The *Alternanthera sessilis, Cyanotis axillaris* dominated the weed flora during entire vegetative growth stage and were present during later stages of the crop too. The occurrence of other weeds like *Celosia argentea, Phyllanthus niruri*, etc. was uneven with lesser density.

Effect on rice

Rice plant height gradually increased with age of the crop and reached to its maximum at harvest. At 20 DAS, rice plant height was not-significantly amongst tested treatments. At 40, 60 and 90 DAS, significantly taller rice plant, higher leaf area was registered with pendimethalin 1.0 kg/ha PE *fb* bispyribac-sodium 25 g/ha + metsulfuron-methyl + chlorimuron-ethyl (RM) 4 g/ha tank mix PoE as compared to other treatments, but it was at par with pendimethalin 1.0 kg/ha PE *fb* penoxsulam + cyhalofop butyl (RM) 135 g/ha PoE, and HW twice at 30 and 60 DAS (**Table 1**). The minimum plant height was recorded in partially weedy check (HW once at 60 DAS) during both years of study. Similar trend was also observed at harvest.

Weeds compete with rice plants for light. Leaf area determines light interception and is an important parameter in determining plant productivity (Koester *et al.* 2014). The higher rice leaf area in the effective treatments minimized the light availability to weeds and hence caused lower weed biomass. When weed density is low, rice plants receive more sunlight, which is essential for photosynthesis. Adequate light helps rice plants grow taller as they can photosynthesize more efficiently and allocate resources towards vertical growth. Weeds can

deplete soil nutrients and affect their availability to rice plants. With fewer weeds competing for nutrients, rice plants can access a higher amount of essential nutrients like nitrogen, phosphorus, and potassium. This improved nutrient availability supports better overall growth and contributes to increased plant height, same condition for water. Similar findings were reported by Sanodiya and Singh (2018) and Ramachandiran and Balasubramanian (2012).

The highest rice grain yield (6.56 and 6.69 t/ha) was recorded with pendimethalin 1.0 kg/ha as PE *fb* bispyribac-sodium 25 g/ha + metsulfuron-methyl + chlorimuron-ethyl (RM) 4 g/ha tank mix PoE (**Table 2**). It was found at par with pendimethalin 1.0 kg/ha PE *fb* penoxsulam + cyhalofop-butyl (RM) 135 g/ha PoE, HW twice at 30 and 60 DAS and penoxsulam + pendimethalin (RM) 625 g/ha as PE *fb* fenoxaprop-ethyl 67 g/ha + ethoxysulfuron 18 g/ha PoE. The partially weedy check (HW once at 60 DAS) recorded reduction in grain yield of 61% and 56 % in comparison to best treatment during 2022 and 2023, respectively.

Pendimethalin pre-emergent spray inhibited root and shoot growth and controlled the weeds growth by preventing weeds from emerging, particularly during the crucial development phase of the crop. Pendimethalin controlled *Echinochloa colonum, Cyanotis axillaries* and *Cyperus* spp. and penoxsulam moving throughout plant tissue prevented it from producing acetolactate synthase, a necessary enzyme for growth. Cyhalofop-butyl is an inhibitor of acetyl coenzyme -A carboxylase, targeting *Echinochloa colona,*

Table 1. Rice plant height at different periods of crop growth as influenced by different weed management treatments

Treatment	Rice plant height (cm)									
	20 DAS		40 DAS		60 DAS		90 DAS		At harvest	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Pendimethalin + pyrazosulfuron-ethyl (RM) 785 g/ha PE *fb* HW once at 30 DAS	31.3	33.4	58.5	62.4	82.5	84.5	97.4	99.5	104.5	105.5
Penoxsulam + pendimethalin (RM) 625 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	30.5	31.6	57.5	54.5	80.6	81.2	95.5	92.5	103.7	104.5
Penoxsulam + pendimethalin (RM) 625 g/ha as PE *fb* fenoxaprop-ethyl 67 g/ha + ethoxysulfuron 18 g/ha PoE	32.4	34.5	60.2	63.3	85.5	87.6	101.5	104.9	105.7	106.6
Pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha + (metsulfuron-methyl + chlorimuron-ethyl) (RM) 4 g/ha tank mix PoE	33.6	36.4	67.6	71.5	90.4	93.4	104.7	106.7	109.4	111.4
Pendimethalin 1000 g/ha PE *fb* penoxsulam + cyhalofop-butyl (RM) 135 g/ha PoE	33.4	35.3	65.6	69.2	88.5	90.4	103.4	105.1	107.4	109.3
Hand weeding (HW) twice at 30 and 60 DAS	33.1	35.1	62.4	67.6	87.8	89.6	103.5	106.4	107.08	108.1
Partially weedy check (HW once at 60 DAS)	29.8	30.1	54.6	50.5	75.2	78.0	85.4	89.5	101.69	102.6
LSD (p=0.05)	3.61	3.98	7.44	4.89	5.57	4.21	5.58	3.61	2.61	4.14

* PE =pre-emergence application; PoE = post-emergence application; DAS = days after seeding, RM = ready mix

Table 2. Leaf area at different periods of crop growth and rice grain yield as influenced by different weed management treatments

Treatment	Leaf area (cm^2/m^2)						Grain yield (t/ha)	
	20 DAS		40 DAS		60 DAS			
	2022	2023	2022	2023	2022	2023	2022	2023
Pendimethalin + pyrazosulfuron-ethyl (RM) 785 g/ha PE *fb* HW once at 30 DAS	266.9	271	433.3	436	894.4	899	5.82	6.08
Penoxsulam + pendimethalin (RM) 625 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	265.4	267	430.5	433	885.4	890	5.62	5.89
Penoxsulam + pendimethalin (RM) 625 g/ha as PE *fb* fenoxaprop-ethyl 67 g/ha + ethoxysulfuron 18 g/ha PoE	264.1	268	438.3	441	899.3	905	6.02	6.30
Pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha + (metsulfuron-methyl + chlorimuron-ethyl) (RM) 4 g/ha tank mix PoE	266.3	269	450.4	456	912.2	917	6.56	6.69
Pendimethalin 1.0 Kg/ha PE *fb* penoxsulam + cyhalofop- butyl (RM) 135 g/ha PoE	263.8	265	447.3	453	908.5	912	6.25	6.51
HW twice at 30 and 60 DAS	262.2	264	443.5	449	905.5	909	6.12	6.45
Partially weedy check (HW once at 60 DAS)	263.2	267	290.3	295	510.0	465	2.50	2.92
LSD (p=0.05)	3.98	4.30	6.67	7.07	9.81	8.05	0.68	0.49

*HW = Hand weeding; PE =Pre-emergence application; PoE = post-emergence application; DAS = days after seeding, RM = ready mix

Echinochloa crus-galli, Alternanthera sessilis, Cyperus difformis, Cyperus iria, at critical stage of crop weed competition resulting in less weed biomass with better suppression of weeds, which allowed the crop to grow with its potential as compared to other treatments

Effect on weeds

Pendimethalin 1.0 kg/ha PE *fb* bispyribac-sodium 25 g/ha + metsulfuron-methyl + chlorimuron-ethyl (RM) 4 g/ha tank mix PoE at 25-30 DAS has significantly reduced the density of *Alternanthera sessilis* and it was at par with pendimethalin 1.0 kg/ha PE *fb* penoxsulam + cyhalofop-butyl (RM) 135 g/ha PoE and penoxsulam + pendimethalin (RM) 625 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE during both years (**Table 3**). Partially weeded check recorded significantly highest weed density of *Alternanthera sessilis* during both years.

At 40 DAS, HW twice at 30 and 60 DAS recorded significantly lowest *Cyanotis axillaris* density and it was at par with pendimethalin 1.0 kg/ha PE *fb* bispyribac-sodium 25 g/ha + (metsulfuron-methyl + chlorimuron-ethyl) (RM) 4 g/ha tank mix PoE, pendimethalin + pyrazosulfuron-ethyl (RM) 785 g/ha PE (*fb*) HW once and penoxsulam + pendimethalin (RM) 625 g/ha PE *fb* fenoxaprop-ethyl 67 g/ha + ethoxysulfuron 18 g/ha PoE during both the years. *Echinochloa colona* was absent at 40 DAS in these treatments. *Cyperus iria* was absent at 40 DAS with application of penoxsulam + pendimethalin (RM) 625 g/ha PE *fb* fenoxaprop-ethyl 67 g/ha + ethoxysulfuron 18 g/ha PoE, pendimethalin 1.0 kg/ha PE *fb* penoxsulam + cyhalofop-butyl (RM) 135 g/ha PoE and penoxsulam + pendimethalin (RM) 625 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE (**Table 3**).

HW twice at 30 and 60 DAS recorded significantly lower weed density and at 40 DAS it was at par with pendimethalin 1.0 kg/ha PE *fb* bispyribac-sodium 25 g/ha + metsulfuron-methyl + chlorimuron-ethyl (RM) 4 g/ha tank mix PoE, during both years.

Table 3. The density (no./m^2) of dominant weed species at 40 DAS as influenced by different weed management treatments

Treatment	*Alternanthera sessilis*		*Cyanotis axillaris*		*Echinochloa colona*		*Cyperus iria*		Others		Total	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Pendimethalin + pyrazosulfuron-ethyl (RM) 785 g/ha PE *fb* HW once at 30 DAS	2.68 (6.66)	2.39 (5.20)	1.77 (2.62)	1.61 (2.11)	1.18 (0.89)	1.11 (0.73)	1.40 (1.45)	1.34 (1.30)	1.92 (3.19)	2.15 (4.13)	3.91 (14.82)	3.74 (13.46)
Penoxsulam + pendimethalin (RM) 625 g/ha PE *fb* bispyribac-sodium 25 g/ha	1.97 (3.38)	1.92 (3.18)	3.45 (11.42)	3.32 (10.50)	1.54 (1.88)	1.48 (1.70)	0.71 (0.00)	0.71 (0.00)	2.30 (4.81)	2.16 (4.18)	4.69 (21.49)	4.48 (19.57)
Penoxsulam + pendimethalin (RM) 625 g/ha as PE *fb* fenoxaprop-ethyl 67 g/ha + ethoxysulfuron 18 g/ha PoE	3.28 (10.28)	3.06 (8.86)	1.97 (3.36)	1.91 (3.15)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	2.46 (5.55)	2.62 (6.37)	4.44 (19.19)	4.34 (18.37)
Pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha + (metsulfuron-methyl + chlorimuron-ethyl) (RM) 4 g/ha tank mix PoE	1.54 (1.89)	1.48 (1.70)	1.74 (2.53)	1.61 (2.10)	1.02 (0.53)	1.06 (0.62)	1.07 (0.64)	1.00 (0.51)	2.06 (3.73)	1.75 (2.55)	3.13 (9.32)	2.83 (7.49)
Pendimethalin 1000 g/ha PE *fb* penoxsulam + cyhalofop-butyl (RM) 135 g/ha PoE	2.05 (3.72)	2.00 (3.48)	2.21 (4.39)	2.00 (3.52)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	2.86 (7.69)	2.61 (6.30)	4.04 (15.80)	3.72 (13.31)
Hand weeding (HW) twice at 30 and 60 DAS	2.47 (5.59)	2.37 (5.10)	1.72 (2.44)	1.65 (2.23)	1.06 (0.63)	1.03 (0.55)	1.41 (1.50)	1.30 (1.20)	1.63 (2.15)	1.55 (1.91)	3.58 (12.31)	3.39 (10.99)
Partially weedy check (HW once at 60 DAS)	6.07 (36.38)	5.84 (33.56)	4.78 (22.32)	4.58 (20.45)	4.37 (18.62)	4.57 (20.42)	3.70 (13.16)	3.32 (10.55)	3.85 (14.33)	3.36 (10.76)	10.26 (104.81)	9.81 (95.75)
LSD (p=0.05)	0.78	0.33	0.62	0.55	0.35	0.16	0.41	0.21	0.65	0.44	0.94	0.57

* PE =pre-emergence application; PoE = post-emergence application; DAS = days after seeding, RM = ready mix

Table 4. Economics of direct-seeded rice as influenced by different weed management treatments

Treatment	Cost of Cultivation (₹/ha)		Gross return (₹/ha)		Net return (₹/ha)		B:C ratio	
	2022	2023	2022	2023	2022	2023	2022	2023
Pendimethalin + pyrazosulfuron-ethyl (RM) 785 g/ha PE *fb* HW once at 30 DAS	32716	33579	118796	132726	86080	99147	2.63	2.95
Penoxsulam + pendimethalin (RM) 625 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	33079	33123	114580	128579	81501	95456	2.46	2.88
Penoxsulam + pendimethalin (RM) 625 g/ha as PE *fb* fenoxaprop-ethyl 67 g/ha + ethoxysulfuron 18 g/ha PoE	34200	34244	122808	137529	88608	103285	2.59	3.02
Pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha + (metsulfuron-methyl + chlorimuron-ethyl) (RM) 4 g/ha tank mix PoE	33355	33799	133824	146043	100469	112244	3.01	3.32
Pendimethalin 1.0 Kg/ha PE *fb* penoxsulam + cyhalofop-butyl (RM) 135 g/ha PoE	34565	35009	127568	142113	93003	107104	2.69	3.06
Hand weeding (HW) twice at 30 and 60 DAS	38603	40272	124848	139712	86245	99440	2.23	2.47
Partially weedy check (HW once at 60 DAS)	34103	35247	51000	63744	16897	28497	0.50	0.81

* PE =pre-emergence application; PoE = post-emergence application; DAS = days after seeding, RM = ready mix

Partially weeded check (HW once at 60 DAS) recorded maximum weed density of other weeds during both years (**Table 3**).

Economics

The maximum cost of cultivation was recorded in treatment HW twice at 30 and 60 DAS due to high labour cost and lowest cost of cultivation was recorded with penoxsulam + pendimethalin (RM) 625 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE (25-30 DAS) during both years. The highest net return and B:C ratio were recorded with pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha + (metsulfuron-methyl + chlorimuron-ethyl) (RM) 4 g/ha tank mix PoE (25-30 DAS) followed by pendimethalin 1000 g/ha PE *fb* penoxsulam + cyhalofop butyl (RM) 135 g/ha PoE (25-30 DAS) and penoxsulam + pendimethalin (RM) 625 g/ha as PE *fb* fenoxaprop-ethyl 67 g/ha + ethoxysulfuron 18 g/ha PoE (25-30 DAS). Although, herbicides usage increased the cost of cultivation, the increased yield compensated resulting in higher net returns. Similar results were reported by Dewangan *et al.* (2016), Dhakal *et al.* (2019), Chitale and Tiwari (2021), Yogananda *et al.* (2019).

Conclusions

It may be concluded that pendimethalin 1.0 kg/ha PE *fb* bispyribac-sodium 25 g/ha + (metsulfuron-methyl + chlorimuron-ethyl) (RM) 4 g/ha tank mix PoE at 25-30 DAS effectively managed weeds in direct-seeded rice which resulted in maximum rice growth and yield as well as maximum net return and B:C ratio.

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