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RESEARCH ARTICLE

Bio-efficacy of herbicide mixtures on weed dynamics in direct wet-seeded rice

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ABSTRACT

Weed infestation is the major yield limiting factor in direct wet-seeded rice (WSR). Herbicides use is gaining acceptance among the farmers as it is easy, economical, time saving, and efficient to manage weeds. The herbicide mixtures with different modes of action are preferable to use in rotation. An experiment was conducted to evaluate and identify a suitable pre-mix herbicide mixture and its dosage rate to get optimum weed management and rice yield in WSR during wet seasons of 2017 and 2018 at research farm of ICAR–National Rice Research Institute, Cuttack, Odisha, India using randomized complete block design with three replications. Nine treatments were tested including: *viz.* post-emergence application (PoE) of florpyrauxifen-benzyl + cyhalofop-butyl at 120, 150, 180 and 360 g/ha; florpyrauxifen-benzyl at 25 and 30 g/ha PoE; bispyribac-sodium 30 g/ha PoE; weed free and weedy check. Among the herbicide treatments, florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE was most effective to control weeds with the lowest weed density, biomass, and weed index, lower weed persistence index and highest weed control index, weed control efficiency, crop resistance index, treatment efficiency index and weed management index at 60 days after sowing in WSR with higher rice grain yield, and was at par with the weed free. In weedy check, 40% rice yield loss was recorded. Thus, florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE may be recommended for effective weed control in direct wet-seeded rice.

Keywords: Direct-seeded rice, Florpyrauxifen-benzyl + cyhalofop-butyl, Herbicide, Weed management, Wet-seeded rice

INTRODUCTION

Rice cultivation is an integral part of Indian agricultural economy being the second largest rice producer in the world. The average rice yield in India was 2.7 t/ha with total rice production of 116.42 Mt from an area of 43 Mha (Shahbandeh 2021). The lower rice productivity in India is due to different biotic and abiotic constraints. Among different biotic stresses, weed infestation is responsible for 40-60% yield loss (Dass *et al*. 2017) which accounts for about $4.42 billion every year in India (Gharde *et al.* 2018).

With the growing water and labour scarcity, farmers are adopting direct-seeded rice (DSR) as the method of crop establishment instead of the conventional puddled transplanted rice (PTR) (Rao *et al.* 2007). DSR is advantageous over transplanting due to faster and easier planting, reduced labour and drudgery, earlier crop maturity by 7-10 days, more efficient water use, higher tolerance of water deficit, lower methane emission and often higher profit in areas with an assured water supply (Balasubramanian and Hill 2002, Rao *et al.* 2007, Chauhan 2012).

Direct wet-seeded rice (WSR) is the method, where pre-germinated rice seeds are sown or broadcasted in puddled soil (Rao *et al.* 2017). The rainfed lowland ecosystem occupies nearly 35% (14.8 Mha) of total rice planted area in India *i.e.* 43 m ha, where, there is a possibility of puddling and sowing of pre-germinated rice seeds (Subbaiah and Balasubramanian 2000). However, WSR is very prone to weed infestation (Saha and Munda 2018) as the weed seeds emerge and grow along with the crop right from the beginning; especially the early emerging grassy weeds only are capable of reducing the grain yield even up to 50-91% (Rao *et al.* 2007 and Saha *et al*. 2021). Among different weed management methods, chemical method is easy, economical, efficient and effective way to suppress weeds (Bhurer *et al*. 2013). But the continuous use of same herbicide with same mode of action leads to weed flora shift and development of herbicide resistance in weeds. Therefore, herbicide mixtures with different spectrum of weed control that are more effective are essential to manage weeds in DSR. This

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study was conducted to evaluate and identify a suitable pre-mix herbicide mixture and its dosage rate to get optimum weed management and rice yield in WSR.

MATERIALS AND METHODS

The experiment was conducted at Institute Research Farm of ICAR-National Rice Research Institute, Cuttack (Odisha) (20°272 102 2 N, 85°562 92 2 E; 24 m above mean sea level) during wet seasons of 2017 and 2018. The experiment soil was sandy clay loam with pH 7.8 with low available N (215.4 kg/ha), medium available P (48 kg/ha), high available P (322.8 kg/ha) and medium organic carbon (0.52%). The experiment was laid out in Randomized Complete Block Design with nine treatments and three replications. The treatments include: post-emergence application (PoE) of florpyrauxifen-benzyl + cyhalofop-butyl 12% EC (w/v) 120 (20+100) g/ha, 150 (25+125) g/ha, 180 (30+150) g/ha and 360 (60+300) g/ha; florpyrauxifen-benzyl 2.5% EC (w/v) 25 g/ha, 30 g/ha; bispyribac-sodium at 30 g/ha; weed free and weedy check.

The field was prepared by mould board plough followed by puddling using a disc harrow. The gross and net plot size were 6.0 m x 5.0 m and 5.1 m x 4.0 m, respectively. The test variety *'Naveen'* (115 days duration, Indica type) was sown manually at 20 cm apart rows with a seed rate of 40 kg/ha on 13th and 11th June during 2017 and 2018 respectively. Light irrigation was given and the field was kept saturated during the first 10 days. Thereafter thin layer of standing water (1-2 cm) was maintained for 21 days after rice emergence. Afterward, 2-3 cm depth of irrigation water was applied after disappearance of water in the field till 15 days before maturity. Bispyribac-sodium was sprayed 10 days after seeding (DAS) at 2-3 leaf stage of weeds and all the other herbicides were sprayed at 15 DAS on saturated soil (after draining out water) using a knapsack sprayer fitted with flat fan nozzle with spray volume 300 l/ha and spray pressure 200 kPa. The field was irrigated 48 hours after spraying. The untreated weedy check (control) was kept undisturbed and the weed free plots were kept weed free during the entire cropping period. Recommended fertilizer application (N:P:K: : 100:60:40 kg/ha) was followed, with full dose of P and K application as basal during final land preparation and the N fertilizer application in four equal splits at 15, 30, 45 and 60 DAS. The crop was harvested on 6th and 3rd October 2017 and 2018, respectively.

The data on associated weeds was recorded at 30 and 60 DAS. Weed count was done randomly from three spots by placing quadrat of 50 cm x 50 cm (0.25 m^2) in each plot. Weeds present in quadrat were uprooted carefully along with roots. The root portion was cleaned thoroughly so that the attached soil would be detached. Then the weeds were oven dried at 60^{o}C for 36 to 48 hours. After complete oven drying, the dry matter of weeds (biomass) were recorded. Similarly, five random rice plants were selected from each plot and their biomass was measured and computed to per meter square values at 30 and 60 DAS. The weed density and biomass data were computed to per meter square values and were subjected to square root of transformation *i.e.* $\sqrt{x+0.5}$ for statistical analysis. Yields from different plots were recorded at harvest. Different weed indices *viz.* weed control index (WCI), weed control efficiency (WCE), weed index (WI), weed persistence index (WPI), crop resistance index (CRI), treatment efficiency index (TEI) and weed management index (WMI) (Sarma 2016); and summed dominance ratio (SDR) (Kim *et al.* 1983) were calculated using the following equations.

$$WCI = \frac{\text{Weed biomass in control (weedy) plot} - \text{Weed biomass in treated plot}}{\text{Weed biomass in control (weedy) plot}} \times 100$$

$$WCE = \frac{\text{Weed density in control plot} - \text{Weed density in treated plot}}{\text{Weed density in control plot}} \times 100$$

$$WI = \frac{\text{Yield from weed free plot} - \text{Yield from treated plot}}{\text{Yield from weed free plot}} \times 100$$

$$WPI = \frac{\text{Weed biomass in treated plot}}{\text{Weed biomass in control plot}} \times \frac{\text{Weed density in control plot}}{\text{Weed density in treated plot}}$$

$$CRI = \frac{\text{Dry weight produced by the crop in treated plot}}{\text{Dry weight produced by the crop in control plot}} \times \frac{\text{Weed biomass in control plot}}{\text{Weed biomass in treated plot}}$$

$$TEI = \frac{(\text{Yield from treated plot} - \text{Yield from control plot})/\text{Yield from control plot}}{\text{Weed biomass in treated plot}/\text{Weed biomass in control plot}}$$

$$WMI = \frac{(\text{Yield from treated plot} - \text{Yield from control plot})/\text{Yield from control plot}}{(\text{Weed biomass in control plot} - \text{Weed biomass in treated plot})/\text{Weed biomass in control plot}}$$

$$SDR = \frac{\left[\frac{\text{Weed density of a given species}}{\text{Total weed density}} \times 100\right] + \left[\frac{\text{Weed dry weight of a given species}}{\text{Total weed dry weight}} \times 100\right]}{2}$$

The data were subjected to the Analysis of Variance using the Statistical Analysis System (SAS) and significant differences among the treatment means tested Fisher's protected Least Significant Difference (LSD) test at $\sqrt{x+0.5}$.

RESULTS AND DISCUSSION

Effect on weeds

The weed flora in the experimental field was dominated by grasses *viz. Echinochloa colona, Leptochloa chinensis*; sedges *viz. Cyperus difformis, Cyperus iria, Fimbristylis mileacea* and broad-leaved weeds (BLWs) *viz. Sphenoclea zeylanica, Marsilia quadrifolia* during both the years. Other weeds observed in lower density were *Panicum repens, Alternanthera sessilis, Eclipta alba,* and *Ludwigia octovalvis.* In the control (weedy) plots, density of sedges was the highest at all stages of the crop, though the biomass of grasses was the highest at 30 DAS. Similar findings were also reported in direct-seeded rice (Saha and Munda 2018). Among the weeds appeared in the weedy plot, the density of sedges was the highest (42 and 37%), followed by grasses (35 and 27%); and BLWs (23 and 36% at 30 and 60 DAS, respectively). The weed biomass of grasses, sedges and BLWs were 58, 23 and 19% at 30 DAS and 34, 46 and 20% at 60 DAS, respectively among the weeds that occurred in the weedy check.

All the treatments significantly influenced the weed density at both 30 and 60 DAS (**Table 1**). Except *E. colona*, the density of all other weeds increased from 30 to 60 DAS. *E. colona* and *C. difformis* were the early competitors under grasses and sedges, respectively and their density decreased gradually due to their shorter (50-60 days) lifespan. Among the grasses, *L. chinensis* continued to compete with the crop during entire crop period. Among the sedges, *C. iria* and *F. miliacea* posed maximum competition during 30-60 DAS and the major broad-leaved weeds *i.e. S. zeylanica* and *Marsilea quadrifolia* competed moderately throughout the crop growing period. The treatment, florpyrauxifen-benzyl + cyhalofop-butyl at 360 g/ha PoE, recorded the lowest total weed density at 30 DAS, but at high dose it caused rice phyto-toxicity that caused emergence and growth of new flushes of weeds that led to higher total weed density at 60 DAS. Significantly the lowest total weed density was observed with florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE which was at par with florpyrauxifen-benzyl at 30g/ha PoE as reported earlier in aerobic rice (Sreedevi *et al.* 2020).

All the weed control treatments affected weed biomass significantly (**Table 2**). Weed biomass followed similar trend as weed density. The density of sedges was the highest among the weed categories, but the grasses weed biomass was higher at 30 DAS. At 60 DAS, biomass of sedges was highest. florpyrauxifen-benzyl + cyhalofop-butyl at 150 g/ha PoE recorded lowest total weed biomass and at 60 DAS it was at par with florpyrauxifen-benzyl 30 g/ha PoE.

The highest WCI was observed under florpyrauxifen-benzyl + cyhalofop-butyl at 150 g/ha PoE followed by florpyrauxifen-benzyl at 30 g/ha PoE (**Table 3**). Florpyrauxifen-benzyl + cyhalofop-butyl at 360 g/ha PoE (85.90%) controlled the weed population at 30 DAS but it could not control weeds at 60 DAS (46.83%) due to phytotoxic effect caused by its higher dose on crop resulting in greater weed emergence at the cleared space which caused increased weed competition (Table 3). At 60 DAS, the highest WCI was observed under florpyrauxifen-benzyl + cyhalofop-butyl at 150 g/ha PoE (54.08%).

Florpyrauxifen-benzyl + cyhalofop-butyl at 360 resulted in higher WPI (1.11 and 0.65 at 30 and 60 DAS, respectively) which was followed by

Table 1. Effect of treatments on weed density (no./m^2) at 30 and 60 DAS in WSR (pooled data of 2 years)

Treatment	Grasses				Sedges						BLWs				Others		Total	
	E. colona		*L. chinensis*		*C. difformis*		*F. miliacea*		*C. iria*		*S. zeylanica*		*M. quadrifolia*					
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
FPB+CFB 120 g/ha	2.77^{b}	1.92^{ab}	3.29^{c}	4.09^{c}	2.63^{c}	1.84^{b}	2.83^{b}	3.65^{b}	2.95^{d}	4.25^{bc}	3.13^{b}	3.87^{c}	2.61^{cd}	3.78^{b}	4.35^{c}	5.31^{b}	8.61^{b}	10.45^{bc}
	(7.20)	(3.20)	(10.30)	(16.20)	(6.40)	(2.90)	(7.50)	(12.80)	(8.20)	(17.60)	(9.30)	(14.50)	(6.30)	(13.80)	(18.40)	(27.70)	(73.60)	(108.70)
FPB+CFB 150 g/ha	2.19^{cd}	1.76^{b}	2.86^{e}	3.44^{d}	1.92^{e}	1.34^{c}	2.47^{c}	2.95^{c}	2.45^{e}	4.05^{c}	2.79^{c}	3.27^{d}	2.28^{d}	2.86^{c}	3.85^{d}	4.32^{c}	7.29^{d}	8.71^{c}
	(4.30)	(2.60)	(7.70)	(11.30)	(3.20)	(1.30)	(5.60)	(8.20)	(5.50)	(15.90)	(7.30)	(10.20)	(4.70)	(7.70)	(14.30)	(18.20)	(52.60)	(75.40)
FPB+CFB 180 g/ha	2.02^{d}	1.79^{b}	2.81^{e}	3.96^{c}	1.73^{f}	2.30^{a}	1.95^{d}	3.49^{bc}	1.70^{f}	3.86^{c}	2.66^{c}	4.38^{bc}	0.71^{e}	3.89^{b}	3.33^{e}	5.27^{b}	6.07^{e}	10.48^{b}
	(3.60)	(2.70)	(7.40)	(15.20)	(2.50)	(4.80)	(3.30)	(11.70)	(2.40)	(14.40)	(6.60)	(18.70)	(0.00)	(14.60)	(10.60)	(27.30)	(36.40)	(109.40)
FPB+CFB 360 g/ha	0.71^{e}	1.55^{b}	2.59^{f}	3.55^{d}	0.71^{g}	1.97^{b}	1.79^{d}	3.13^{c}	0.71^{g}	3.49^{d}	2.28^{d}	4.09^{c}	0.71^{e}	3.55^{b}	2.81^{f}	4.59^{c}	4.64^{f}	9.37^{c}
	(0.00)	(1.90)	(6.20)	(12.10)	(0.00)	(3.40)	(2.70)	(9.30)	(0.00)	(11.70)	(4.70)	(16.20)	(0.00)	(12.10)	(7.40)	(20.60)	(21.00)	(87.30)
FPB 25 g/ha	2.83^{b}	2.02^{a}	3.55^{b}	4.45^{b}	2.97^{b}	2.21^{ab}	2.81^{bc}	3.66^{b}	3.70^{b}	4.56^{b}	3.18^{b}	4.11^{c}	2.77^{c}	3.90^{b}	4.72^{b}	5.46^{b}	9.36^{b}	11.02^{b}
	(7.50)	(3.60)	(12.10)	(19.30)	(8.30)	(4.40)	(7.40)	(12.90)	(13.20)	(20.3)	(9.60)	(16.40)	(7.20)	(14.70)	(21.80)	(29.30)	(87.10)	(120.90)
FPB 30 g/ha	2.37^{c}	1.82^{b}	2.85^{e}	3.65^{d}	2.28^{d}	1.76^{b}	2.61^{c}	3.18^{c}	3.30^{c}	4.09^{c}	2.88^{c}	3.44^{d}	3.00^{bc}	3.56^{b}	4.24^{c}	5.07^{b}	8.27^{c}	9.65^{c}
	(5.10)	(2.80)	(7.60)	(12.80)	(4.70)	(2.60)	(6.30)	(9.60)	(10.40)	(16.20)	(7.80)	(11.30)	(8.50)	(12.20)	(17.50)	(25.20)	(67.90)	(92.70)
BPS 30 g/ha	2.21^{c}	1.48^{b}	3.11^{d}	4.69^{b}	2.77^{c}	2.37^{a}	2.93^{b}	3.70^{b}	3.58^{b}	4.68^{a}	3.11^{b}	4.51^{b}	3.26^{b}	3.96^{b}	4.96^{b}	5.81^{ab}	9.22^{b}	11.48^{b}
	(4.40)	(1.70)	(9.20)	(21.50)	(7.20)	(5.10)	(8.10)	(13.20)	(12.30)	(21.40)	(9.20)	(19.80)	(10.10)	(15.20)	(24.10)	(33.30)	(84.60)	(131.20)
Weed free	0.71^{e}	0.71^{c}	0.71^{g}	0.71^{e}	0.71^{g}	0.71^{d}	0.71^{e}	0.71^{d}	0.71^{g}	0.71^{e}	0.71^{e}	0.71^{e}	0.71^{e}	0.71^{d}	0.71^{g}	0.71^{d}	0.71^{g}	0.71^{d}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Weedy check	5.22^{a}	2.39^{a}	4.00^{a}	5.36^{a}	4.88^{a}	2.17^{a}	3.27^{a}	4.36^{a}	4.07^{a}	5.01^{a}	3.87^{a}	5.10^{a}	3.73^{a}	4.55^{a}	5.45^{a}	6.19^{a}	12.22^{a}	12.83^{a}
	(26.70)	(5.20)	(15.50)	(28.20)	(23.30)	(4.20)	(10.20)	(18.50)	(16.10)	(24.60)	(14.50)	(25.50)	(13.40)	(20.20)	(29.20)	(37.80)	(148.90)	(164.20)
LSD (p=0.05)	0.19	0.47	0.12	0.31	0.14	0.29	0.20	0.45	0.17	0.37	0.18	0.39	0.40	0.45	0.35	0.58	0.87	1.04

BPS: bispyribac-sodium, BLWs: broad-leaved weeds, CFP: cyhalofop-butyl, DAS: days after sowing, FPB: florpyrauxifen-benzyl, LSD: least significant difference; Figures within and without parentheses indicate original and transformed values, respectively.

Table 2. Effect of different weed control treatments on weed biomass (g/m^2) at 30 and 60 DAS in WSR (pooled data of 2 years)

Treatment	Grasses				Sedges						BLWs				Others		Total	
	E. colona		*L. chinensis*		*C. difformis*		*F. miliacea*		*C. iria*		*S. zeylanica*		*M. quadrifolia*					
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
FPB+CFB 120 g/ha	1.83^{b} (2.84)	1.60^{b} (2.05)	2.37^{bc} (5.12)	2.72^{b} (6.89)	1.23^{bc} (1.01)	1.39^{c} (1.44)	1.04^{b} (0.58)	2.26^{bc} (4.63)	1.82^{bc} (2.81)	2.53^{b} (5.90)	1.06^{bc} (0.62)	1.51^{c} (1.77)	1.57^{b} (1.92)	1.71^{cd} (2.41)	1.89^{c} (3.09)	3.17^{b} (9.56)	4.30^{c} (17.99)	5.93^{b} (34.65)
FPB+CFB 150 g/ha	1.48^{cd} (1.69)	1.33^{c} (1.27)	2.22^{c} (4.42)	2.57^{b} (6.09)	1.00^{c} (0.51)	1.07^{d} (0.65)	0.96^{bc} (0.43)	1.76^{d} (2.61)	1.55^{c} (1.89)	2.42^{b} (5.36)	0.99^{bc} (0.49)	1.32^{d} (1.24)	1.41^{b} (1.49)	1.39^{d} (1.43)	1.49^{d} (1.73)	2.92^{b} (8.01)	3.63^{d} (12.65)	5.21^{c} (26.66)
FPB+CFB 180 g/ha	1.39^{d} (1.42)	1.49^{c} (1.73)	2.76^{b} (7.13)	2.89^{b} (7.85)	0.95^{c} (0.40)	1.70^{b} (2.39)	0.87^{c} (0.25)	2.38^{bc} (5.15)	1.15^{d} (0.82)	2.51^{b} (5.82)	0.97^{bc} (0.44)	1.67^{bc} (2.28)	0.71^{c} (0.00)	2.24^{b} (4.50)	2.00^{cd} (3.51)	3.37^{b} (10.85)	3.80^{d} (13.97)	6.41^{b} (40.57)
FPB+CFB 360 g/ha	0.71^{e} (0.00)	1.31^{d} (1.22)	2.54^{bc} (5.97)	2.79^{b} (7.30)	0.71^{d} (0.00)	1.48^{c} (1.69)	0.84^{c} (0.21)	2.14^{c} (4.09)	0.71^{e} (0.00)	2.39^{b} (5.23)	0.90^{c} (0.31)	1.57^{bc} (1.98)	0.71^{c} (0.00)	2.21^{b} (4.38)	1.72^{d} (2.45)	3.33^{b} (10.60)	3.07^{e} (8.94)	6.08^{bc} (36.49)
FPB 25 g/ha	1.86^{b} (2.96)	1.68^{b} (2.31)	2.67^{bc} (6.65)	2.77^{b} (7.18)	1.35^{bc} (1.31)	1.64^{bc} (2.19)	1.03^{b} (0.57)	2.49^{b} (5.68)	1.74^{bc} (2.53)	2.64^{b} (6.49)	1.07^{bc} (0.64)	1.58^{bc} (2.00)	1.57^{b} (1.97)	1.74^{c} (2.54)	2.78^{b} (7.22)	3.29^{b} (10.35)	4.93^{b} (23.85)	6.26^{bc} (38.73)
FPB 30 g/ha	1.58^{c} (2.01)	1.52^{b} (1.80)	2.32^{c} (4.89)	2.54^{b} (5.95)	1.11^{c} (0.74)	1.34^{c} (1.29)	0.99^{bc} (0.49)	2.17^{c} (4.22)	1.75^{bc} (2.57)	2.45^{b} (5.55)	1.01^{bc} (0.52)	1.37^{cd} (1.38)	1.55^{b} (1.89)	1.44^{d} (1.56)	2.32^{c} (4.89)	3.18^{b} (9.63)	4.30^{c} (18.00)	5.65^{c} (31.38)
BPS 30 g/ha	1.49^{cd} (1.73)	1.26^{d} (1.09)	2.52^{bc} (5.86)	2.93^{b} (8.11)	1.39^{b} (1.44)	1.74^{b} (2.54)	1.06^{b} (0.62)	2.51^{b} (5.81)	1.93^{b} (3.22)	2.71^{b} (6.85)	1.15^{b} (0.82)	1.71^{b} (2.42)	1.72^{b} (2.49)	1.81^{c} (2.76)	2.91^{b} (7.98)	3.42^{b} (11.23)	4.96^{b} (24.12)	6.43^{b} (40.81)
Weed free	0.71^{e} (0.00)	0.71^{e} (0.00)	0.71^{d} (0.00)	0.71^{c} (0.00)	0.71^{d} (0.00)	0.71^{e} (0.00)	0.71^{d} (0.00)	0.71^{e} (0.00)	0.71^{e} (0.00)	0.71^{c} (0.00)	0.71^{d} (0.00)	0.71^{e} (0.00)	0.71^{c} (0.00)	0.71^{e} (0.00)	0.71^{e} (0.00)	0.71^{c} (0.00)	0.71^{f} (0.00)	0.71^{d} (0.00)
Weedy check	3.32^{a} (10.52)	1.96^{a} (3.34)	3.93^{a} (14.93)	4.81^{a} (22.64)	2.04^{a} (3.68)	2.14^{a} (4.09)	1.14^{a} (0.79)	2.94^{a} (8.14)	2.45^{a} (5.52)	4.91^{a} (23.62)	2.11^{a} (3.97)	2.57^{a} (6.11)	2.18^{a} (4.26)	3.08^{a} (8.99)	3.76^{a} (13.67)	5.43^{a} (28.95)	7.61^{a} (57.34)	10.31^{a} (105.88)
LSD(p=0.05)	0.18	0.16	0.42	0.49	0.26	0.17	0.12	0.31	0.31	0.59	0.24	0.16	0.33	0.29	0.53	0.57	0.46	0.64

BPS: bispyribac-sodium, BLWs: broad-leaved weeds, CFP: cyhalofop-butyl, DAS: days after sowing, FPB: florpyrauxifen-benzyl, LSD: least significant difference, WSR: wet-seeded rice

Figures within and without parentheses indicate original and transformed values, respectively.

Table 3. Effect of treatments on different crop and weed indices at 30 and 60 DAS in WSR (pooled data of two years)

Treatment	WCI		WCE (%)		WPI		CRI		TEI		WMI	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
FPB+CFB 120 g/ha	68.63	67.27	50.57	33.80	0.63	0.49	4.50	4.23	1.56	1.50	0.71	0.73
FPB+CFB 150 g/ha	77.94	74.82	64.67	54.08	0.62	0.55	7.79	6.86	2.56	2.24	0.72	0.75
FPB+CFB 180 g/ha	75.64	61.68	75.55	33.37	1.00	0.58	4.02	2.75	1.35	0.86	0.43	0.53
FPB+CFB 360 g/ha	84.41	65.54	85.90	46.83	1.11	0.65	5.07	2.81	1.18	0.54	0.22	0.28
FPB 25 g/ha	58.41	63.42	41.50	26.37	0.71	0.50	2.89	3.25	1.01	1.15	0.72	0.66
FPB 30 g/ha	68.61	70.36	54.40	43.54	0.69	0.52	4.84	5.17	1.62	1.72	0.74	0.72
BPS 30 g/ha	57.94	61.46	43.18	20.10	0.74	0.48	2.50	2.94	0.92	1.01	0.67	0.63
Weed free	100.00	100.00	100.00	100.00	-	-	-	-	-	-	0.68	0.68
Weedy check	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	0.00	0.00	-	-

AMI: agronomic management index, BPS: bispyribac-sodium, BLWs: broad-leaved weeds, CRI: crop resistance index, CFP: cyhalofop-butyl, DAS: days after sowing, FPB: florpyrauxifen-benzyl, TEI: treatment efficiency index, WCE: weed control efficiency, WCI: weed control index, WI: weed index, WMI: weed management index, WPI: weed persistence index, WSR: wet-seeded rice

florpyrauxifen-benzyl + g/ha PoE cyhalofop-butyl at 180 g/ha PoE (0.58) and 150 g/ha PoE (0.55) (**Table 3**) indicating resistance of escaped weeds to control measures.

The crop resistance index (CRI) indicates increased vigour of crop plant due to weed control measures. Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE recorded maximum crop resistance to grow (7.79 and 6.86 at 30 and 60 DAS, respectively) followed by florpyrauxifen-benzyl 30 g/ha PoE (5.17) at 60 DAS (**Table 3**) indicating much less harmful effect of herbicides on crop as compared to other treatments.

Treatment efficiency index (TEI) indicates the weed killing potential of a particular herbicide treatment. Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE showed maximum TEI at both 30 (2.56) and 60 (2.24) DAS (**Table 3**) followed by florpyrauxifen-benzyl 30 g/ha PoE (1.62 and 1.72 at 30 and 60 DAS respectively).

Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ ha PoE showed maximum weed management index (WMI) (0.75) closely followed by florpyrauxifen-benzyl + cyhalofop-butyl 120 g/ha PoE (0.73) and florpyrauxifen-benzyl 30 g/ha PoE (0.72) (**Table 3**). The lowest WMI was observed under florpyrauxifen-benzyl + cyhalofop-butyl 360 g/ha PoE due to its phyto-toxicity to rice.

Among the grasses, *L. chinensis* recorded highest SDR than *E. colona* at both 30 and 60 DAS

(**Table 4**). Whereas, among the sedges, *C. iria* and *F. miliacea* dominated over *C. difformis* at 60 DAS and among the BLWs both *S. zeylanica* and *M. quadrifolia* were moderately dominant at 60 DAS as reported in aerobic rice system (Rahman *et al.* 2012).

Effect on rice

The treatments didn't influence the crop biomass significantly at 30 DAS but at 60 DAS (**Table 5**) the highest crop growth was recorded under weed free plots followed by florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE.

The highest grain yield was recorded in the weed free, which was at par with florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE (**Table 5**). Florpyrauxifen-benzyl + cyhalofop-butyl 120 g/ha PoE, florpyrauxifen-benzyl 25 g/ha PoE and bispyribac-sodium 30 g/ha PoE recorded at par yield. The florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE recorded 12.6% yield advantage over the recommended herbicide bispyribac-sodium 30 g/ha PoE supporting the findings of Meher *et al.* (2018) and Sreedevi *et al.* (2020). The uncontrolled weeds in the weedy check caused around 40% rice grain yield loss (**Table 5**). Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE restricted the yield loss at 6.83% showing 12.6% yield advantage over the recommended herbicide bispyribac-sodium due to broad spectrum weed control during the critical crop-weed competition period.

It may be concluded that florpyrauxifen-benzyl + cyhalofop-butyl 150 (25+125) g/ha PoE was the most effective herbicide mixture to control weeds in WSR as it recorded lowest weed density, biomass, weed index, weed persistence index and highest weed control index, weed control efficiency, crop resistance index, treatment efficiency index and weed management index and higher rice grain yield which was at par with the weed free.

Table 4. Effect of treatments on summed dominance ratio of different weed species at 30 and 60 DAS in WSR (pooled data of two years)

Treatment	Grasses				Sedges						BLWs				Others	
	E. colona		*L. chinensis*		*C. difformis*		*F. miliacea*		*C. iria*		*S. zeylanica*		*M. quadrifolia*			
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
FPB+CFB 120 g/ha	12.78	4.43	21.23	17.39	7.15	3.41	6.71	12.57	13.38	16.61	8.04	9.22	9.62	9.83	21.09	26.54
FPB+CFB 150 g/ha	10.77	4.11	24.79	18.91	5.06	2.08	7.02	10.33	12.70	20.60	8.88	9.09	10.36	7.79	20.43	27.09
FPB+CFB 180 g/ha	10.03	3.37	35.68	16.62	4.87	5.14	5.43	11.69	6.23	13.75	10.64	11.36	0.00	12.22	27.12	25.85
FPB+CFB 360 g/ha	0.00	2.76	48.15	16.93	0.00	4.26	7.60	10.93	0.00	13.87	12.92	11.99	0.00	12.93	31.32	26.32
FPB 25 g/ha	10.51	4.47	20.89	17.25	7.51	4.65	5.44	12.67	12.88	16.77	6.85	9.36	8.26	9.36	27.65	25.47
FPB 30 g/ha	9.34	4.38	19.18	16.38	5.52	3.46	6.00	11.90	14.80	17.58	7.19	8.29	11.51	9.07	26.47	28.94
BPS 30 g/ha	6.19	1.98	17.58	18.13	7.24	5.06	6.07	12.15	13.94	16.55	7.14	10.51	11.05	9.17	30.79	26.45
Weed free	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weedy check	18.14	3.16	18.22	19.28	11.03	3.21	4.11	9.48	10.22	18.65	8.33	10.65	8.21	10.40	21.73	25.18

BPS: bispyribac-sodium, BLWs: broad-leaved weeds, CFP: cyhalofop-butyl, DAS: days after sowing, FPB: florpyrauxifen-benzyl, WSR: wet-seeded rice

Table 5. Effect of treatments on crop dry matter (at 30 and 60 DAS) and grain yield (at harvest) in WSR (pooled data of two years)

Treatment	Rice biomass (g/m^2)		Rice grain yield (t/ha)			Weed index
	30 DAS	60 DAS	2017	2018	Pooled	
FPB+CFB 120 g/ha	6.75	17.67^{d}	4.62bc	4.74b	4.68^{bc}	11.20
FPB+CFB 150 g/ha	8.21	22.04^{b}	4.88ab	4.94ab	4.91^{ab}	6.83
FPB+CFB 180 g/ha	4.68	13.45^{f}	4.12c	4.22c	4.17^{c}	20.87
FPB+CFB 360 g/ha	3.78	12.37^{f}	3.65c	3.79c	3.72^{c}	29.41
FPB 25 g/ha	5.74	15.15^{e}	4.42bc	4.50bc	4.46^{bc}	15.28
FPB 30 g/ha	7.27	19.56^{c}	4.70b	4.78b	4.74^{b}	10.06
BPS 30 g/ha	5.02	14.44^{ef}	4.30bc	4.42bc	4.36^{bc}	17.31
Weed free	8.60	26.35^{a}	5.24a	5.33a	5.27^{a}	-
Weedy check	4.78	12.76^{f}	3.08d	3.20d	3.14^{d}	40.42
LSD (p=0.05)	NS	1.10	0.53	0.49	0.52	-

BPS: bispyribac-sodium, CFP: cyhalofop-butyl, DAS: days after sowing, FPB: florpyrauxifen-benzyl, LSD: least significant difference, NS: not significant, WSR: wet-seeded rice

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