

Effect of acetolactate synthase inhibitor herbicides with 2, 4-D ethyl ester on complex weed flora in transplanted rice (*Oryza sativa*)

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ABSTRACT

A field experiment was conducted during the rainy (*khari*) seasons of 2015 and 2016 at Chiplima, Odisha, to evaluate acetolactate synthase herbicides with 2,4-D ethyl ester for control of complex weed flora in transplanted rice (*Oryza sativa* L.). Post-emergence application of bispyribac sodium @ 20 g/ha, penoxsulam @ 22.5 g/ha, chlorimuron + metsulfuron @ 4 g/ha in sole as well as in combination with 2, 4-D ethyl ester @ 200 g/ha, effectively controlled *Marsilea quadrifolia* L., *Ludwigia perennis* L. and *Ammania baccifera* L. Weeds reduced the grain yield of rice by 37.6%. Application of 2, 4-D ethyl ester alone was not effective against grassy weeds and aquatic fern (*Marsilea quadrifolia* L.) and bispyribac, penoxsulam and chlorimuron + metsulfuron were not much effective against *Ammania baccifera* and *Cyperus difformis* L. However, 2, 4-D ethyl ester in combination with bispyribac or penoxsulam was comparable to weed-free treatment in reducing the weed density. Tank-mix application of bispyribac sodium with 2, 4-D ethyl ester (20 + 200 g/ha) proved the most effective in minimizing *Cyperus* spp. and *Ammania baccifera* along with total control of *Echinochloa* spp., *Marsilea quadrifolia* and *Ludwigia perennis*. This treatment also resulted in the minimum total weed density (8.1/m²), biomass (11.1 g/m²) comparable to weed-free condition and the highest grain yield (5.97 t/ha), net returns (51.8 × 10³ ₹/ha) and benefit: cost ratio (1.4).

Key words : Bispyribac sodium, Chlorimuron ethyl + metsulfuron methyl, Penoxsulam, Rice, 2, 4-D ethyl ester, Weed management

Rice–rice cropping system is very popular in Hirakud command area of Odisha because of its higher yield potential as well as assured procurement price. Among different production factors, weed competition is one of the prime limiting biotic constraints resulting in a reduction of 28–45% in the yield of transplanted rice (Singh *et al.*, 2003). 2, 4-D ethyl ester is commonly used herbicide for control of weeds in rice due to its low cost (₹350/L). But this is not effective against aquatic fern such as *Marsilea quadrifolia* and grassy weeds. Acetolactate synthase (ALS) inhibitor herbicides have become popular because of their excellent control of wide-spectrum weed flora which includes aquatic ferns also. Besides this, it worked well in flooded soil of low-land situation resembling that of rice–rice eco-system (Jabusch and Tjeerdema, 2006).

Herbicides with different mode of action when mixed together, bind with different target sites of the weeds and prevent the probability of resistance in susceptible weed species (Paswan *et al.*, 2012). Thus, herbicide combina-

tion has become one of the options for control of complex weed flora.

In the light of these facts, the present investigation was proposed to examine the possibility of suitable acetolactate synthase herbicides to be tank mixed with 2, 4-D ethyl ester to widen the weed-control spectrum in transplanted rice.

MATERIALS AND METHODS

A field experiment was undertaken at Regional Research and Technology Transfer Station, Orissa University of Agriculture and Technology, Chiplima, Sambalpur, Odisha, during the rainy (*khari*) seasons of 2015 and 2016. The soil of the experimental field was sandy clay loam with acidic in reaction (pH 5.8), having organic carbon 0.38% and available N (KMnO₄ method), P (Olsen) and K (NH₄OHC method) content of 187, 15.4 and 172 kg/ha respectively. The total rainfall received during crop season was 865 and 925 mm during 2015 and 2016 respectively. Nine treatments consisting of T₁, 2, 4-D ethyl ester 38% EC @ 200 g/ha; T₂, penoxsulam 24% SC @ 22.5 g/ha; T₃, bispyribac sodium 10 EC @ 20 g/ha; T₄,

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chlorimuron ethyl + metsulfuron methyl 20 WP @ 4 g/ha); T₅, 2, 4-D ethyl ester + penoxsulam (200 + 22.5 g/ha); T₆, 2, 4-D ethyl ester + bispyribac sodium (200 + 20 g/ha); T₇, 2, 4-D ethyl ester + chlorimuron ethyl + metsulfuron methyl (200 + 4 g/ha); T₈, weed-free; and T₉, weedy check were tried in a randomized block design with 3 replications. All the herbicides were applied 20 days after transplanting. The combined applications of herbicides are tank-mixed. The rice cultivar MTU 1001 of 135 days was transplanted at a spacing of 20 cm × 10 cm. A common fertilizer dose of 80, 40 and 40 kg N, P₂O₅ and K₂O/ha, in the form of urea, diammonium phosphate and muriate of potash, respectively was applied to each experimental unit. Full dose of phosphorus and half dose of potassium and nitrogen were applied basal and the remaining N and P were top-dressed in 2 equal splits, at the maximum tillering and panicle-initiation stages of the crop. The required quantity of herbicides were applied with manually operated knapsack sprayer fitted with flat-fan nozzle using a spray volume of 500 litres of water/ha. Water in the field was drained before application of herbicides to expose the weed and irrigated 1 day after application. Weed counts (numbers/m²) and biomass (g/m²) were taken as random samples from 2 places in the field with the help of (0.5 × 0.5 m) quadrant at 45 days after transplanting (DAT).

The weed samples were air dried in shade initially followed by oven drying at 65°C for 48 h or till they attain constant weight. Data on weed density and biomass were subjected to square-root transformation before statistical analysis to normalize their distribution (Gomez and Gomez, 2010). The crop was harvested at full physiological maturity, sun-dried for a week and threshed manually. All the biometrical observation on crop and weeds were observed as per the standard practices. Weed-control efficiency (WCE) and weed index (WI) were calculated based on the weed biomass and rice grain yield respectively. Economics of different treatments was computed taking into prevailing minimum market prices for inputs used and output obtained from each treatment.

RESULTS AND DISCUSSION

Effect on weeds

Rice field was infested with grasses, sedges and broad-leaf weeds. However, the weed flora was dominated by sedges like *Cyperus difformis* L. and *Cyperus iria* L., constituting 27.8 and 16% of total weed flora respectively. Among grasses, *Echinochloa crus-galli* (L.) P. Beauv and *Echinochloa colonum* (L.) Link. constitute 9.6 and 16% of total weed flora respectively. Among the broad-leaf weeds, *Ammania baccifera* (L.) Roxb., *Marsilea quadrifolia* L. and *Ludwigia perennis* L. constitute 12.8, 9.9 and 7.8% of total weed flora respectively (Table 1).

All treatments were significantly superior to weedy check in reducing the count of *E. crus-galli* and *E. colonum* except 2, 4-D ethyl ester which was not effective against grasses, meant for controlling broad-leaf weeds. Acetolactate synthase (ALS) herbicides (penoxsulam, bispyribac and chlorimuron + metsulfuron) alone and with 2, 4-D provided excellent control of *Echinochloa* spp. and was comparable with weed-free check. The activity of acetolactate synthase herbicides against grassy weeds has been well established (Yadav et al., 2008; Walia et al., 2008). 2, 4-D ethyl ester alone or in combination with acetolactate synthase herbicides effectively controlled *Cyperus iria* as good as weed-free treatment. It was not effective against broad-leaf weed *Marsilea quadrifolia*, as the weed count under the treatment (4.7/m²) was at par with that under weedy check (5.7/m²). Acetolactate synthase herbicides alone were less effective in controlling *Cyperus difformis*. Application of bispyribac sodium and penoxsulam alone or in combination with 2, 4-D ethyl ester gave effective control of *Marsilea quadrifolia* and other broad-leaf weeds. Rawat et al. (2012) reported effectiveness of bispyribac in combination with 2, 4-D ethyl ester in controlling broad-leaf weeds of rice. The same combination or sole application was also effective against *Ludwigia perennis*. Total weed density was less (19.1/m²) with sole application of bispyribac sodium followed by penoxsulam (21.6/m²) in comparison to 2, 4-D ethyl ester (31/m²). The lower weed density under these treatments might be due to broad-spectrum control of all grasses, sedges and broad-leaf weeds by these ALS herbicides. However, tank-mix application of bispyribac sodium with 2, 4-D ethyl ester was the best (8.1/m²) in control of all the weeds. The weed density under this treatment was statistically at par with weed-free treatment (Table 1).

Among sole application of herbicide, the lowest biomass of *Echinochloa* spp. was found with bispyribac sodium (3.4 to 5.2 g/m²) followed by penoxsulam (4 to 7 g/m²), whereas the lowest *Cyperus* spp. biomass was found with sole application of 2, 4-D ethyl ester (4.9 to 11 g/m²). The tank-mix application of penoxsulam, bispyribac sodium and chlorimuron + metsulfuron with 2, 4-D ethyl ester resulted in lower weed biomass than that of their sole application. Total control of *Echinochloa* spp., *M. quadrifolia* and *L. perennis* was recorded by 2, 4-D ethyl ester + bispyribac sodium. All the herbicide combinations were equally effective for control of sedges (*C. difformis* and *C. iria*). Sole application of 2, 4-D ethyl ester was less effective than their tank-mixture application due to the fact that field was infected with complex weed flora and this being basically herbicides of only broad-leaf weeds, failed to control grassy weeds (*Echinochloa* spp.). However, all the

Table 1. Effect of weed management practices on weed density and biomass at 45 days after transplanting in rice (mean data of 2 years)

Treatment	Weed density (Nos./m ²)							Weed biomass (g/m ²)								
	EC	ECr	CD	CI	AB	MQ	LP	Total density	EC	ECr	CD	CI	AB	MQ	LP	Total biomass
2,4-D	5.0 (2.4)	8.9 (3.0)	7.3 (2.9)	3.1 (2.0)	2.0 (1.7)	4.7 (2.4)	0.0 (1.0)	31 (5.6)	15.5 (4.1)	25.8 (5.2)	11.0 (3.5)	4.9 (2.4)	0.7 (1.3)	1.8 (1.7)	0 (1.0)	59.7 (7.8)
Penoxsulam	1.3 (1.5)	2.4 (1.5)	10.0 (3.3)	2.9 (1.9)	3.8 (2.2)	1.2 (1.5)	0.0 (1.0)	21.6 (4.8)	4.0 (2.2)	7.0 (2.8)	15.0 (4.0)	4.6 (2.4)	1.4 (1.5)	0.5 (1.2)	0 (1.0)	32.5 (5.8)
Bispyribac	1.1 (1.4)	1.8 (1.3)	9.6 (3.3)	2.8 (1.9)	3.8 (2.2)	0.0 (1.0)	0.0 (1.0)	19.1 (4.5)	3.4 (2.1)	5.2 (2.5)	14.4 (3.9)	4.5 (2.3)	1.4 (1.5)	0.0 (1.0)	0 (1.0)	28.9 (5.5)
Chlorimuron +metsulfuron	1.4 (1.5)	3.1 (1.8)	11.0 (3.5)	4.3 (2.3)	4.6 (2.4)	2.1 (1.8)	1.3 (1.5)	27.8 (5.4)	4.3 (2.3)	9.0 (3.2)	16.5 (4.2)	6.8 (2.8)	1.7 (1.6)	0.8 (1.3)	0.5 (1.2)	39.6 (6.4)
Penoxsulam + 2,4-D	1.2 (1.5)	1.3 (1.1)	5.0 (2.4)	2.1 (1.8)	1.6 (1.6)	1.2 (1.5)	0.0 (1.0)	12.4 (3.6)	3.7 (2.2)	3.8 (2.2)	7.5 (2.9)	3.4 (2.1)	0.6 (1.3)	0.5 (1.2)	0 (1.0)	19.5 (4.5)
Bispyribac + 2,4-D	0.0 (1.0)	0.0 (0.0)	4.5 (2.3)	2.4 (1.8)	1.2 (1.5)	0.0 (1.0)	0.0 (1.0)	8.1 (3.0)	0.0 (1.0)	0.0 (1.0)	6.8 (2.8)	3.8 (2.2)	0.5 (1.2)	0.0 (1.0)	0 (1.0)	11.1 (3.5)
Chlorimuron + metsulfuron + 2, 4-D	1.4 (1.5)	1.8 (1.3)	5.5 (2.5)	2.5 (1.9)	1.3 (1.5)	1.6 (1.6)	0.0 (1.0)	14.1 (3.8)	4.3 (2.3)	5.2 (2.5)	8.3 (3.0)	4.0 (2.2)	0.5 (1.2)	0.6 (1.3)	0 (1.0)	22.9 (4.9)
Weed-free	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0.0 (1.0)	0 (1.0)	0.0 (1.0)
Weedy check	5.5 (2.5)	9.2 (3.0)	16.0 (4.1)	9.2 (3.2)	7.4 (2.9)	5.7 (2.6)	4.5 (2.3)	57.5 (7.6)	17.1 (4.2)	26.7 (5.3)	24.0 (5.0)	14.7 (4.0)	2.8 (1.9)	2.2 (1.8)	1.8 (1.7)	89.3 (9.5)
SEm±	0.2	0.1	0.3	0.1	0.2	0.1	0.1	0.9	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.6
CD (P=0.05)	0.6	0.4	0.9	0.3	0.5	0.4	0.3	2.7	0.4	0.5	0.4	0.3	0.3	0.4	0.3	1.8

EC, *Echinochloa colonum*; ECr, *Echinochloa crus-galli*; CD, *Cyperus difformis*; CI, *Cyperus iria*; AB, *Ammania baccifera*; MQ, *Marsilea quadrifolia*; LP, *Ludwigia perennis*. Data subjected to square root transformation ($\sqrt{x+1}$); values in the parentheses are transformed values

herbicides were effective over weedy check in this respect.

Weed-control efficiency of herbicide tank mixture were superior to their sole applications (Table 2). The highest weed-control efficiency (89.7%) was achieved by bispyribac sodium + 2, 4-D ethyl ester as post-emergence. The efficacy of this treatment was 71.8 to 73.8% for *Cyperus* spp, 82.1% for *Ammania baccifera* and 100% *Echinochloa* spp., *Marsilea quadrifolia* and *Ludwigia perennis*. In their sole application, bispyribac was effective against most of the weeds only except *A. baccifera* (50%) which was better controlled by 2, 4-D ethyl ester (75%) and both were equally effective against *L. perennis* (100%)

Data on weed index showed the least yield reduction (2.4%) with tank-mix of bispyribac sodium + 2,4-D ethyl ester followed by penoxsulam + 2,4-D ethyl ester (4.7%) and chlorimuron + metsulfuron + 2,4-D ethyl ester (5.7%), whereas yield reduction varied from 10.6 to 22.1% in the sole herbicide applied plots as compared to weed-free treatment. The weed index was lower in all the treatment as compared to weedy check.

Yield attributes and yield

The herbicide treatments affected the number of effective tillers and number of grains/panicle. Effective tillers/m² and grains/panicle which were the highest with 2, 4-D ethyl ester + bispyribac sodium, were at par with that of weed-free treatment (Table 3). Data on effective tillers and grains/panicle showed that all the tank mixtures of herbicides penoxsulam, bispyribac sodium, chlorimuron + metsulfuron with 2, 4-D ethyl ester were at par, whereas their effect was significantly superior to sole application of all the herbicides. The complex weed flora comprising grasses, sedges and broad-leaf weeds caused reduction of 37.6% in grain yield in weedy check as compared to weed-free treatment (6.12 t/ha). Among the tank-mix application, the highest grain yield (5.97 t/ha) was recorded with bispyribac sodium + 2, 4-D ethyl ester which was at par with weed-free check. Bispyribac sodium + 2,4-D ethyl ester, penoxsulam + 2,4-D ethyl ester and chlorimuron + metsulfuron + 2,4-D ethyl ester resulted in an average increase of 36.0, 34.4 and 33.7% in grain yield as compared to the weedy check. Sole application of bispyribac sodium, chlorimuron + metsulfuron and penoxsulam recorded lower grain yield than their tank-mix application with 2,4-D ethyl ester which was possibly due to their ineffectiveness to control *A. baccifera* and *C. difformis*, resulting in lower weed-control efficiency (Tables 1, 2). There was significant reduction of 8.4 and 14.3% of grain yield in bispyribac and penoxsulam treated plots as compared to their tank-mix with 2, 4-D ethyl ester. Rawat *et al.* (2012) also reported that, 2, 4-D ethyl ester did not provide any

control of grassy weeds. Bispyribac sodium, penoxsulam and chlorimuron + metsulfuron were compatible with 2, 4-D ethyl ester, as their site of action is different in the plant. The 2, 4-D ethyl ester affects cell-wall plasticity and nucleic acid metabolism in plant, whereas bispyribac sodium, chlorimuron + metsulfuron and penoxsulam inhibit the synthesis of amino acids. Better performance of these treatments in terms of yield could be owing to better control of complex weed flora tilting the crop-weed proportion in favour of the crop. Rawat *et al.* (2012) observed that, post-emergence application of bispyribac sodium + 2, 4-D ethyl ester was as effective as the hand-weeding.

Economics

All the herbicides alone or in tank-mix application re-

corded higher monetary returns than their sole application and weedy check (Table 3). Among the chemical weed-control treatments, bispyribac sodium + 2, 4-D ethyl ester gave the maximum net returns (₹51.8×10³/ha) and benefit: cost ratio (1.4) followed by penoxsulam + 2, 4-D ethyl ester owing to low cost and high grain yield as compared to the other post-emergence herbicides. Dewangan *et al.* (2013) and Tripathy *et al.* (2016) also reported similar findings with tank-mix application of herbicides. Weed-free treatment though registered higher grain yield (6.12 t/ha), recorded lower monetary returns than tank-mix application of herbicide mixture, due to high cost incurred on manual weeding to keep the crop weed free.

It can be concluded that penoxsulam, bispyribac sodium and chlorimuron + metsulfuron were compatible

Table 2. Effect of weed-management practices on weed-control efficiency and weed index at 45 days after transplanting in rice (mean data of 2 years)

Treatment	WCE (%)								Weed index (%)
	EC	ECr	CD	CI	AB	MQ	LP	Average	
2,4-D	9.3	3.4	54.2	66.6	75.0	17.5	100	46.6	22.1
Penoxsulam	76.4	73.9	37.5	68.7	50.0	78.8	0	55.0	19.3
Bispyribac	80.1	80.4	40	69.3	50.0	100	100	74.3	10.6
Chlorimuron + metsulfuron	74.6	66.3	31.2	53.7	39.2	63.1	70.9	57.0	20.4
Penoxsulam + 2,4-D	78.2	85.8	68.7	77.1	78.6	78.8	100	81.0	4.7
Bispyribac + 2,4-D	100	100	71.8	73.8	82.1	100	100	89.7	2.4
Chlorimuron + metsulfuron + 2, 4-D	74.6	80.4	65.6	72.8	82.1	71.8	100	78.2	5.7
Weed-free	100	100	100	100	100	100	100	100.0	0
Weedy check	0	0	0	0	0	0	0	0.0	37.6

EC, *Echinochloa colonum*; ECr, *Echinochloa crus-galli*; CD, *Cyperus difformis*; CI, *Cyperus iria*; AB, *Ammania baccifera*; MQ, *Marsilea quadrifolia*; LP, *Ludwigia peremis*; WCE, Weed-control efficiency. Data subjected to square root transformation ($\sqrt{x+1}$); values in the parentheses are transformed values.

Table 3. Effect of weed-management practices on yield attributes, yield and economics of rice (mean data of 2 years)

Treatment	Effective tillers/m ²	Grains/panicle	1,000-grain Weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Gross returns (× 10 ³ ₹/ha)	Net returns (× 10 ³ ₹/ha)	Benefit: cost ratio
2,4-D	331	117	22.0	4.77	5.67	71.8	35.4	1.0
Penoxsulam	336	115	22.2	4.94	5.87	74.4	36.5	1.0
Bispyribac	377	119	22.8	5.47	6.50	82.3	44.8	1.2
Chlorimuron + metsulfuron	333	113	23.4	4.87	5.79	73.2	36.9	1.0
Penoxsulam + 2, 4-D	413	122	23.4	5.83	6.93	87.7	49.4	1.3
Bispyribac + 2, 4-D	419	124	24.3	5.97	7.09	89.9	51.8	1.4
Chlorimuron + metsulfuron + 2, 4-D	397	123	23.5	5.77	6.86	86.8	49.9	1.4
Weed-free	421	125	24.1	6.12	7.27	92.1	48.4	1.1
Weedy check	263	112	22	3.82	4.18	53.9	21.7	0.6
SEm±	7.7	0.8	1.2	0.1	0.6	—	—	—
CD (P=0.05)	23.3	2.5	NS	0.3	1.7	—	—	—

Input price (₹/kg) rice seed, 22; urea, 5.52; dimmonium phosphate, 24.45; muriate of potash, 17.44; bispyribac sodium, ₹664/100 ml; chlorimuron +metsulfuron, ₹220/8 g, penoxsulam ₹740/35 ml, 2, 4-D ethyl ester, ₹174/500 ml. Sale rate of rice grain (₹14,100/t), rice straw (₹800/t) and manual labour (₹200/day).

with 2, 4-D ethyl ester and there was no adverse effect on crop growth. It successfully controlled the complex weed flora in rice. Application of bispyribac sodium @ 20 g/ha with 2, 4-D ethyl ester @ 200 g/ha 20 DAT was the most remunerative and effective herbicide mixtures for broad spectrum weed control in transplanted rice.

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