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Weed Control by Single Post-emergence Combination Herbicide Florpyrauxifen-Benzyl Plus Cyhalofop Butyl in Aerobic Rice

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Authors' contributions

This work was carried out in collaboration among all authors. Author BS designed the study, wrote the protocol and wrote the first draft of the manuscript. Author AS performed the statistical analysis and wrote the final draft of the manuscript. Author CT managed the weed data recording and analyses of the weed data. Authors MPK and VM provided the test herbicide material and financial assistance for conduct of the study. Authors RM and GKS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Florpyrauxifen benzyl + cyhalofop butyl is a new combination herbicide product which has proven to control wide range of weed flora. A two year study was planned in the wet and dry seasons of 2015-16 and 2016-17 to evaluate effective dosage of early post-emergence combination herbicide product florpyrauxifen benzyl + cyhalofop butyl (120; 150 and 180 g ha^{-1}) to manage weeds in aerobic rice and study the residual effect on succeeding maize crop. The results revealed that Barnyard grass *(Echinochloa crusgalli*) followed by *Dinebra retroflexa* (viper grass) dominated among the weed flora. The combination product florpyrauxifen benzyl + cyhalofop Butyl 180 g ha^{-1} contributed to significantly lower density and dry biomass accumulation by grass and broadleaf

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weeds as compared to weedy check; however its efficacy was poor on sedges at 60 days after sowing (DAS). Highest weed control efficiency was recorded by florpyrauxifen benzyl + cyhalofop butyl 180 g ha^{-1}. The highest yield (4100 and 3420 kg ha^{-1}) was in plots treated with florpyrauxifen benzyl + cyhalofop butyl at 180 g ha^{-1} and the lowest yield was in florpyrauxifen benzyl 31.25 g ha^{-1} (3280 and 2870 kg ha^{-1}) followed by bispyribac sodium 25 g ha^{-1} (3320 and 2940 kg ha^{-1}) in 2015 and 2016, respectively. Weed infestation decreased the rice yield by nearly about 69% in 2015 and 72% in 2016. A strong negative relationship between rice yield and weed biomass was seen which explained 87 and 91% variation in grain yield at 30 and 60 DAS. Combination product florpyrauxifen benzyl + cyhalofop butyl at all rates did not have any residual toxic effect on succeeding maize. Based on the findings, it can be concluded that aerobic rice weeds can be controlled by applying early post-emergence application of combination product florpyrauxifen benzyl + cyhalofop butyl 150 to 180 g ha^{-1} without any residual toxicity.

Keywords: Aerobic rice; weed management; correlation; cyhalofop butyl; florpyrauxifen benzyl.

NOMENCLATURES

Florpyrauxifen benzyl
Cyhalofop butyl
Bispyribac sodium
Oryza sativa L., Zea mays L.

1. INTRODUCTION

Rice is the major food for more than half of the world's population and about 90% of the world's rice is produced and consumed in Asia [1]. India has the largest area under rice which is 43.5 m ha [2] and ranks second position in production. Rice based cropping systems form an important component of Indian cropping systems. Per capita availability of water is forecasted to decline from current available 1600 to 1000 m^3 $capita^{-1}$ $year^{-1}$ by 2050 [3]. Traditional puddled method of rice cultivation consumes large amount of scarce resources like labour and water [4]. Due to these issues, farmers are shifting from conventional puddled system of establishment to aerobic system where rice is sown on non-puddled and non-saturated seed beds. This saves water, labour and energy compared to transplanting system [5]. Examples suggest that direct seeding of rice by aerobic method also helps in improving the physical and chemical properties of the soil, and promote the growth and yield of other non-rice crops grown in rotation [6].

But, weeds pose a major threat to the success of this system [7]. Aerobic rice fields are severely infested with a diverse range of weeds. The simultaneous emergence of weeds with rice seedlings [8] makes weed control difficult. Also, the hot and humid climate of tropical Asia is conducive to year-round luxuriant growth of almost all weed species [9], with numerous flushes of weeds during the entire growing season. [10] reported that weeds in rice can cause yield losses to the tune of 50 to 90%. Earlier studies confirm that rice yield can be enhanced by 27-300% by adopting suitable weed management [11,12]. Chemical weed control in direct seeded rice is the most suitable method [12].

Several pre-emergence herbicides applied either alone or supplemented with hand weeding have been reported to provide fairly adequate weed suppression in direct seeded rice. However, limited application time window (0-5 days after sowing; DAS), a critical water regime and toxicity to main crop are the associated challenges [13,14]. In this situation, postemergence herbicides appear to offer alternate solution. The popular postemergence herbicides in rice are bispyribac sodium, pyrazosulfuron ethyl, cyhalofop butyl, penoxsulam, benzosulfuron, propanil and fenoxaprop-p-ethyl [15]. As reported in various studies, post emergence herbicides like bispyribac sodium and cyhalofop butyl have the potential to control grasses in aerobic rice systems [16,17] but is not effective on other weed types. Cyhalofop butyl has activity on controlling grasses like *Echinochloa* spp. and sprangletop (*Leptochloa chinensis)* due to differential metabolism of molecule by inhibition of ACCase(Acetyl CoA carboxylase). But, it fails to control grasses emerging late in the season like crowfoot grass (*Dactyloctenium aegyptium)*, goose grass (*Eleusine indica)* and *Sagitaria arvensis* [18] as well as broadleaf weeds. One of the most common herbicides in rice, bispyribac sodium, has been found to be effective on barnyard grass (*Echinochloa colonum)* but ineffective on other weeds like sprangletop (*Leptochloa spp.)* and crowfoot grass (*Dactyloctenium aegypticum)* [19].

Earlier research confirms that a sudden change in rice planting also causes weed flora to shift towards difficult-to-control and competitive grasses, sedges and appearance of weedy rice in various rice growing regions of the world [20]. The mono herbicides currently in use for rice have a narrow spectrum of weed control and are ineffective for season long weed control [10]. A single herbicide with single mode of action is not sufficient to control weeds in aerobic rice system [16]. The weed flora (aquatic and terrestrial) in aerobic rice require two or more herbicides for satisfactory control of a variety of weed species [21]. Application of combination herbicide products with different modes of action, offers the effective solution for broad spectrum weed control in early or mid-season [10]. There is a need to identify early postemergence herbicide products suitable for controlling wide spectrum weed flora, to optimise the rate necessary for efficient weed control for minimising the divergent weed flora menace in aerobic rice.

Florpyrauxifen is a newly developed herbicide that mimicks the action of the plant growth hormone auxin and belongs to arylpicolinate family of herbicides [22]. It also provides control of a wide range of weeds, particularly difficult-to-control weeds and can be used as a potential source of early postemergence weed control in rice. Compatibility of florpyrauxifen benzyl with cyhalofop butyl has been studied earlier in direct seeded rice under puddled condition. The combination product has herbicides with two different modes of action which ensures that weeds resistant to one herbicide are controlled by the other herbicide. Combination product provides the advantage of control of grassy weeds which are major component causing economic losses in aerobic rice. Also, limited information is available on the performance of above combination product in aerobic rice cultivation in India.

Therefore, the present investigation was undertaken with an objective to optimize the effective rate of combination product florpyrauixfen benzyl + cyhalofop butyl and determine if acceptable control for a complex of weed species occurs, and study the residual effect on succeeding crops.

2. MATERIALS AND METHODS

2.1 Experimental Site

Field studies were carried out during the wet (June-Nov) and dry (December-April) seasons of 2015-16 and 2016-17 at ICAR-Indian Institute of Rice Research, Hyderabad, Telangana, India. The site is situated at an altitude of 542.3 m above mean sea level, latitude and longitude of 17°19' N and 78°23' E. A total rainfall of 533 and 644 mm, respectively was received during the rice season of 2015 and 2016. Second season was better with respect to the maximum (33 to 28°C) and the minimum temperature (from 13 to 23°C) as well as higher rainfall (Table 1). The soil was clay loam in texture with available nitrogen 188 kg ha^{-1}, phosphorus 17 kg ha^{-1}, potassium 375 kg ha^{-1} and pH 8.07. The field was under rice-sunflower cropping system for five years preceding the study.

2.2 Experimental Design and Treatments

Eight weed control treatments which included three rates of combination product florpyrauxifen benzyl + cyhalofop butyl mixture at 120, 150 and 180 g ha^{-1} were laid out in randomized complete block design with four replicate. The herbicide treatments used in the study are presented in Table 2.

2.3 Field and Crop Management

Prior to sowing, the field was ploughed twice with a disc harrow and cultivated twice with a cultivator followed by planking which level the seed bed so that the field attained fine tilth. The plot size was kept 4.8 X 4.5 m^2. The chosen rice variety was DRR Dhan 44 (short-duration, high yield yielding, drought-tolerant and suitable for aerobic cultivation) and Maize variety was DHM 121 (High yielding hybrid of medium duration hybrid suitable for kharif and rabi season under zero tillage). Sowing of rice was done on 14th July, 2015 and 26th June, 2016. Maize was sown on 16th December, 2015 and 20th December, 2016. Rice seeds (60 kg ha^{-1}) and Maize (18 kg ha^{-1}) were treated with bavistin 2.5 g kg^{-1} seed and sown. The seeds were sown at a spacing of 20 cm x 10 cm for rice and 60 cm X 40 cm for maize. Immediately after planting, light irrigation was applied and subsequent irrigations were given at 7 to 8 day intervals at vegetative stages and at 5 day intervals at reproductive stages depending upon the rainfall. The herbicides were applied using knapsack sprayer with a flat fan nozzle at 400-500 l ha^{-1} in aqueous medium at 20 DAS to rice crop. The required quantity of herbicides were applied as per the treatments on 3 July 2015 and 15 July 2016 to the rice plots. Weed free condition was maintained by repeated manual weedings whenever weeds were noticed.

A fertilizer rate of 120:60:40 (N: P_2O_5: K_2O) kg ha^{-1} for rice and 120: 60: 50 (N: P_2O_5: K_2O) kg ha^{-1} for maize was applied. In rice crop, at the time of sowing 100% recommended dose of phosphorus and 75% potassium were applied. Nitrogen was applied in three equal splits at 12 days after rice seedling emergence, at tillering stage and at panicle initiation stage. Remaining 25% of potassium was applied at panicle initiation stage. In maize crop, at the time of sowing 50% basal dose of nitrogen and 100% recommended dose of phosphorus and potassium were applied and the remaining half dose of nitrogen was applied in two split doses at 30 and 60 days after sowing (DAS), respectively. Soil moisture was maintained to field capacity and irrigation was given at weekly intervals for rice and for maize irrigation was given as and when needed. Irrigation was skipped whenever rainfall occurred during wet season.

2.4 Sampling and Observations

Weeds were identified visually and were counted species wise. Weed density and dry matter accumulation was recorded at 30 and 60 DAS. Species-wise weed count was done with the help of quadrate of size 50 cm x 50 cm placed at four locations in each plot. Weeds present in quadrate were uprooted carefully along with roots. The root portion was detached and shoot portion of the weed plants were oven dried at 75ºC for 48 h. After complete oven drying, weight was recorded on electronic balance and converted into gm^{-2}.

Harvesting was done on second fortnight of November for rice during both the years and on third fortnight of April for Maize. For rice, the panicles were removed and hand threshed from each experimental plots. For Maize at physiological maturity, the cobs were dehusked and harvested from each plot. Data on grain yield/seed yield of rice/maize was recorded at harvest after proper sun-drying. The grain/seed and straw of the net plot was tied in bundles and weighed to determine the dry matter produced. The clean grain/seed obtained after threshing and winnowing from each net plot were arranged in separate cloth bags and weighed. The results were expressed on 14% moisture basis for rice. The straw/stover yield was obtained by subtracting weight of the grain yield from the total weight of the bundle. Net area of plot was harvested manually by using sickle and the crop was left in the field for sun drying for two days and then bundled. After bundling, the produce was weighed plot-wise.

Weed control efficiency at 60 DAS was estimated as per the formula:

$$\text{WCE (\%)} = \frac{\text{DMC - DMT}}{\text{DMC}} x\ 100$$

Where, DMC is the dry biomass of weeds in control/weed free plots, whereas DMT is the dry biomass of weeds in the herbicide treated plots.

2.5 Statistical Analysis

The data were subjected to Analysis of variance (ANOVA) in SAS 9.3 (SAS 2011, Cary, NC). Weed density data was subjected to square root of transformation (√X + 0.5) to normalize the distribution before statistical analysis. Treatment means were separated by Tukey's Honest Significant Difference test at 5% level of significance. The interaction between year and treatments for weed density, weed biomass and yield was found to be significant, therefore, the data for each year is presented separately.

Table 1. Monthly meteorological data during the rice crop period in 2015 and 2016

	2015					2016				
Months	**Temperature (^{0}C)**		**Relative humidity (%)**		**Rainfall (mm)**	**Temperature (^{0}C)**		**Relative humidity (%)**		**Rainfall (mm)**
	Max.	**Min.**	**Max.**	**Min**		**Max.**	**Min.**	**Max.**	**Min.**	
Jun-15	34	25	78	54	160	33	23	84	60	90
Jul-15	34	24	78	50	25	30	23	89	67	145
Aug-15	31	23	88	64	127	31	23	87	66	181
Sep-15	31	22	90	65	168	28	22	94	76	196
Oct-15	32	20	91	46	36	30	19	91	48	32
Nov-15	31	18	88	55	17	30	13	88	33	0

Table 2. Herbicide treatments, dosage, trade name and time of application

	Rice			Maize
Treatments	**Rate (g ha^{-1})**	**Trade name**	**Time of application**	
Florpyrauxifen benzyl + cyhalofop butyl	120	Rinskor, Dow AgroSciences ltd. https://www.dowagrosciences.com	20DAS	Residual
Florpyrauxifen benzyl + cyhalofop butyl	150	Rinskor, Dow AgroSciences ltd https://www.dowagrosciences.com	20DAS	,,
Florpyrauxifen benzyl + cyhalofop butyl	180	Rinskor, Dow AgroSciences ltd https://www.dowagrosciences.com	20 DAS	,,
Florpyrauxifen benzyl	31.25	Rinskor, Dow AgroSciences ltd https://www.dowagrosciences.com	20DAS	,,
Cyhalofop butyl	80	Clincher, Dow AgroSciences ltd https://www.dowagrosciences.com	20 DAS	,,
Bispyribac sodium	25	Nominee Gold, PI Industries https://www.piindustries.com	20 DAS	,,
Weedy check(WC)	-	-	-	WC
Weed free(WF)	-	-	-	WF

**Days after sowing = DAS*

3. RESULTS AND DISCUSSION

3.1 Weed Flora Dynamics

The experimental field was infested with diverse types of grasses, sedges and broadleaf weeds (Table 3). The dominant weed species present in the plot were *Echinochloa colona* (jungle rice) and *Dinebra retroflexa* (viper grass). The dominance of grasses was due to their simultaneous germination along with rice seedlings after getting favourable soil moisture and temperature. The results are in conformity with the findings of [23] where dominance of grasses in non-saturated rice fields was observed.

3.2 Weed Density

At 30 DAS, all the herbicide treatments significantly reduced weed density over weedy check in both the years. Among the herbicides, lowest density of grass weeds (21 and 7 plants m^{-2}, in 2015 and 2016 respectively) was noted in florpyrauxifen benzyl + cyhalofop butyl at 180 g ha^{-1} but did not differ significantly from its lower rate 150 g ha^{-1} in 2015 (Table 4). In 2015, all the herbicides had comparable density of sedges. But in 2016, florpyrauxifen benzyl + cyhalofop butyl 120, 150 and 180 g ha^{-1} was superior than bispyribac sodium 25 g ha^{-1}, cyhalofop butyl 150 g ha^{-1} and florpyrauxifen benzyl 31.25 g ha^{-1} for reducing the density of sedges. Floryrauxifen benzyl + cyhalofop butyl 180 g ha^{-1} had lowest broadleaf weed population and was similar to its lower rate (150 and 120 g ha^{-1}) and single rate (31.25 g ha^{-1}) in both the years. Total weed count was similar in all rates (120, 150 and 180 g ha^{-1}) of flopyrauxifen benzyl + cyhalofop butyl in 2015 and was superior to other herbicides, whereas florpyrauxifen benzyl + cyhalofop butyl 180 g ha^{-1} had lowest total weed density (18 plants m^{-2}) in 2016. Among herbicides, florpyrauxifen benzyl 31.25 g ha^{-1} had highest total weed density in 2015 (95 plants m^{-2}), whereas Cyhalofop butyl 150 g ha^{-1} recorded the highest total weed density (132 plants m^{-2}) in 2016.

At 60 DAS, the experimental plot had higher weed density in 2016 compared to the previous year. At this stage, lowest grass density (28 and 53 plants m^{-2} in 2015 and 2016, respectively) was seen in plots treated with florpyrauxifen benzyl + cyhalofop butyl 180 g ha^{-1}, and it did not differ from its subsequent lower rates (150 and 120 g ha^{-1}) in either of the years (Table 5). In 2015, flopyrauxifen benzyl + cyhalofop butyl 180 g ha^{-1} recorded the lowest population of sedges (3 plants m^{-2}) whereas in 2016 all the herbicides had similar density of sedges and broadleaf weeds. In 2016, florpyrauxifen benzyl + cyhalofop butyl all the rates (120, 150 and 180 g ha^{-1}) and cyhalofop butyl 150 g ha^{-1} were comparable but superior to other herbicides for reducing broadleaf weeds. The highest total weed count (201 and 276 plants m^{-2} in 2015 and 2016, respectively) was present in weedy check. Total weed density was similar in all rates of flopyrauxifen benzyl + cyhalofop butyl (120; 150 and 180 g ha^{-1}) in 2015.

Although florprauxifen benzyl is an auxin herbicide, it exhibited significant activity on grasses and it was supported from the findings of this experiment. Previous study also supports the findings of this experiment where florpyrauxifen benzyl provided significant grass weed control [24]. Earlier research also reported that cyhalofop butyl has good compatibility with other herbicides and can improve weed control in rice [17]. More weed population in the second growing season, can be explained due to the favourable environmental conditions and higher rainfall. More weeds can also be supported by the lack of competitiveness and increase in weeds population due to each passing year of aerobic rice [25].

3.3 Weed Biomass

All herbicide control methods significantly reduced grass, broadleaf and total weed biomass compared to weedy check in both the years. Dry biomass of grass, broadleaf and sedges increased from 30 DAS to 60 DAS. At 30 DAS, the lowest grass weed biomass (4.0 and 1.0 g m^{-2} in 2015 and 2016, respectively) was accumulated in the plots treated with florpyrauxifen benzyl + cyhalofop butyl 180 g ha^{-1} and was smiliar to its lower rate 150 and 120 g ha^{-1} in 2015. All herbicide control methods had similar population of grass and sedge weeds in 2016 (Table 6). Sedge biomass tended to be comparable in all the herbicide treatments except cyhalofop butyl 150 g ha^{-1} (14 g m^{-2}) in 2015. No population of broadleaf weeds was seen in florpyrauxifen benzyl + cyhalofop butyl 180 g ha^{-1} and lower rates (150 and 120 g ha^{-1}) treated plots in 2015, whereas less population (1 g m^{-2}) was noted in 2016. Biomass accumulation by broadleaf weeds was more in cyhalofop butyl 150 g ha^{-1} treated plots (10 and 11 g m^{-2}, in 2015 and 2016). Higher total weed biomass was accumulated in cyhalofop butyl 150 g ha^{-1} (35 g m^{-2}) in 2015; whereas in 2016, florpyrauxifen benzyl 31.25 accumulated higher total weed biomass (24 g m^{-2}) and was comparable to cyhalofop butyl 150 g ha^{-1} (21 g m^{-2}) and bispyribac sodium 25 g ha^{-1} (19 g m^{-2}).

At 60 DAS, florpyrauxifen benzyl + cyhalofop butyl 180 g ha^{-1} had the lowest grass weed biomass (30 and 45 g m^{-2} in 2015 and 2016, respectively) and was at par to its lower rate of 150 and 120 g ha^{-1} in 2015. Florpyrauxifen benzyl + cyhalofop butyl at all the rates (180, 150 and 120 g ha^{-1}) provided similar control of sedges and broadleaf weeds in both the years. Florpyrauxifen benzyl + cyhalofop butyl 180 g ha^{-1} had the lowest total biomass (31 and 46 g m^{-2} in 2015 and 2016, respectively) than all other herbicide control methods; and was at par to its lower rate of 150 g ha^{-1} and significantly superior to cyhalofop butyl 150 g ha^{-1}, bispyribac sodium 25 g ha^{-1} and weedy check, respectively in 2015 and 2016 (Table 7). The highest total weed biomass (165 and 407 g m^{-2} in 2015 and 2016, respectively) was in weedy check. Telo et al. 2018 also reported that florpyrauxifen benzyl was effective in controlling grass and broadleaf weed biomass to a significant extent.

Florpyrauxifen benzyl + cyhalofop butyl all rates (180; 150 and 120 g ha^{-1}) had higher weed control efficiency than other herbicides (Table 7). Weed control efficiency with all herbicides ranged from 44 to 81% in 2015 and from 49% to 85% in 2016. Higher weed control was attained due to efficient control of grasses and broadleaf weeds. The activity of florpyrauxifen benzyl mixture for control of grasses has also been reported earlier [24]. Higher weed control efficiency due to herbicide was mainly due to restriction in emergence and growth of weeds, which resulted in lower weed dry matter production, leading to higher weed control efficiency and is in line with the findings of [26].

3.4 Yield Attributes and Yield

Rice plants under all herbicide control methods had higher number of grains $panicle^{-1}$ and higher grain and straw yield than control. Weed free treatment recorded highest number of panicles m^{-2}, grain and straw yields than all herbicide control methods in both the years (Table 8). Rice grain yield in the plots receiving herbicide control methods ranged from 3280 to 4100 kg ha^{-1} and 2870 to 3420 kg ha^{-1}, while the weedy check plots yielded 1600 and 1280 kg ha^{-1} in 2015 and 2016, respectively. The highest grain yield was in the plots treated with florpyrauxifen + cyhalofop butyl 180 g ha^{-1} (4100 kg ha^{-1} in 2015 and 3420 kg ha^{-1} in 2016) and was similar to its lower rate 150 g ha^{-1} (4010 and 3330 kg ha^{-1}, in 2015 and 2016 respectively). Compared to weed free, competition by weeds reduced grain yield by 69% in 2015 and 72% in 2016 in weedy check. Higher grain yield was noted in the first season compared to the second can be explained due to lack of competitive weeds at the critical period of plant emergence in the first year and also due to the effectiveness of herbicide in reducing the weed density and biomass.

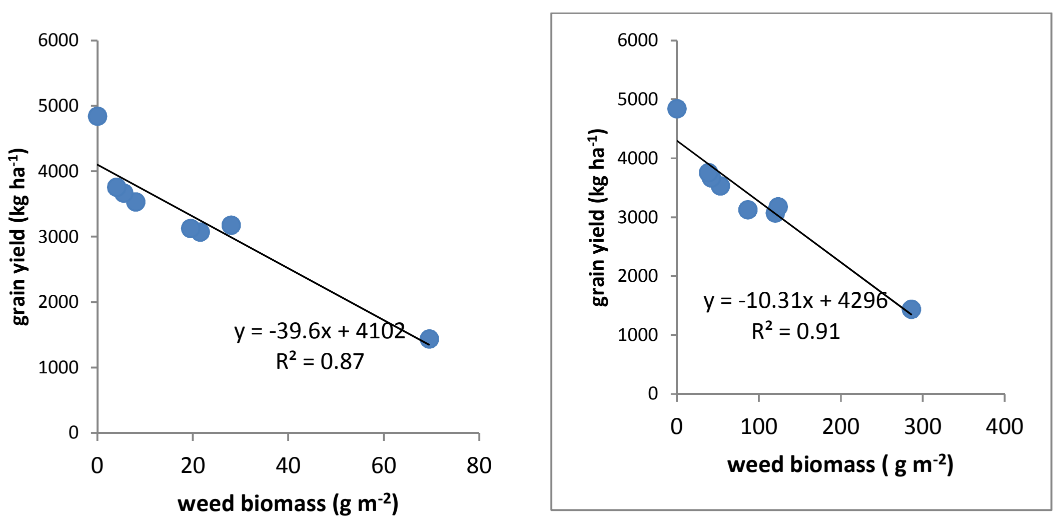
A significant linear negative relationship was observed between grain yield and weed biomass at 60 DAS in 2015 and 2016 growing season (Fig. 1a and 1b). The regression model fitted was y= -39.6x+4102 at 30 DAS (Fig. 1a) and y= -10.31x+4296 (Fig. 1b) at 60 DAS, where y is the grain yield and x is the biomass accumulation by the weeds. The regression model was able to explain about 87% and 91% variation in grain yield due to weed biomass at 30 and 60 DAS. The regression relationship was observed to be slightly stronger at 60 DAS (r^2=0.91) than at 30 DAS (r^2=0.87). The results clearly explain poor competitive ability of rice with weeds and the need to manage the weeds effectively during the critical stages of crop growth. Negative relationship between grain yield and weed biomass has also been reported by many researchers [27].

The highest rate of the herbicide did not pose any phyto-toxic effect on growth parameters and yield of the succeeding maize crop (Table 9). Earlier studies have also reported little to no residual toxicity of florpyrauxifen benzyl on succeeding crop [28,29,30].

Table 3. Weed flora of the experimental plot of rice in 2015 and 2016

Grass weeds	Sedges	Broadleaf weeds
Echinochloa colona (jungle rice)	*Cyperus rotundus* (Yellow nutsedge)	*Alternanthra triandra* (Joyweed)
Echinochloa crusgalli (barnyard grass)	*Cyperus iria* (Rice flatsedge)	*Corchorus olitorious*
Dinebra retroflexa (Viper grass)		*Digeria arvensis*
Dactyloctenium aegypticum (Crowfootgrass)		
Chloris barbata (Swollen finger grass)		

**Common names of weeds presented in parenthesis according to WSSA (Weed Science Society of America) classification*



a b

Fig. 1. Relationship between and rice grain yield (kg ha^{-1}) weed biomass (g m^{-2}) at (a) 30 DAS (b) 60 DAS

Table 4. Effect of weed control treatments on weed density in rice at 30 Days after Sowing (DAS) in 2015 and 2016

Treatments	Rate(g ha^{-1})	Weed density[c]							
		Grass weeds		Sedge		Broadleaf weeds		Total weeds (Grass+sedge+broadleaf weeds)	
		2015	2016	2015	2016	2015	2016	2015	2016
		plants m^{-2}							
Florpyrauxifen benzyl +cyhalofop butyl	120.0	5.8(34)d	5.6 (33)b	2.2(5)b	2.8(8)c	1.7(3)c	3.2(14)cd	41cd	55c
Florpyrauxifen benzyl +cyhalofop butyl	150.0	5.4(29)ed	5.3(32)b	1.9 (4)b	2.2(7)c	1.5(2)c	3.0(10)cd	35d	48c
Florpyrauxifen benzyl + cyhalofop butyl	180.0	4.6(21)e	2.4(7)c	1.8 (3)b	2.2(5)c	1.5(2)c	2.3(6)d	25d	18d
Florpyrauxifen benzyl	31.25	9(81)b	6.4(42)b	2.8(8)b	3.3(12)b	2.5(7)c	4.3(18)cd	95b	72c
Cyhalofop butyl	150.0	6.1(38)d	8.8(83)b	3.9(15)b	3.6(15)b	4.8(24)a	5.7(34)b	76cb	132b
Bispyribac sodium	25.0	7.9(63)c	8.2(71)b	2.8(9)b	3.0(16)b	2.9(9)c	4.6(24)cb	80b	111b
Weedy check	-	10.6(114)a	11.2(142)a	6.8(53)a	4.9(26)a	6.5(44)a	10.2(104)a	211a	272a
Weed free[b]		0	0	0	0	0	0	0	0

[a]*All the herbicide treatments received pendimethalin 1000 g ha^{-1} before sowing as pre-emergence and one hand weeding at 60 DAS except weedy check*
[b]*Data was not included in the analysis;* [c] *Means present within each column with no common letter(s)are significantly different (P=0.05)*
[d] *Total weed density consisted of jungle rice, barnyard grass, viper grass, crow foot grass, yellownut sedge and joyweed*
[e] *Original values of weed density are presented in parenthesis*

Table 5. Effect of weed control treatments on weed density in rice at 60 DAS in 2015 and 2016

Treatments	Rate (gha^{-1})	Weed density[c]							
		Grass weeds		Sedge		Broadleaf weeds		Total weed density[d] (Grass+sedge+broadleaf weeds)	
		2015	2016	2015	2016	2015	2016	2015	2016
		----plants m^{-2}----							
Florpyrauxifen benzyl +cyhalofop butyl	120.0	5.9(35)d	9.1(84)d	3.2(10)c	1.7(3)b	1.5(2)d	3.0(11)b	47c	99c
Florpyrauxifen benzyl +cyhalofop butyl	150.0	5.5(30)d	8.4(73)e	3.1(10)c	1.7(3)b	1.4(2)d	3.1(11)b	41c	87d
Florpyrauxifen benzyl + cyhalofop butyl	180.0	5.3(28)d	7.0(53)f	1.8(3)d	1.5(2)b	1.2(1)d	2.4(7)b	32c	62e
Florpyrauxifen benzyl	31.25	6.7(45)c	9.5(92)cd	5.8(34)b	2.3(5)b	3.5(13)c	3.4(12)b	91b	108c
Cyhalofop butyl	150.0	7.3(53)cb	11.1(131)b	5.7(33)b	1.9(4)b	2.2(5)d	3.9(20)b	91b	155b
Bispyribac sodium	25.0	7.4(55)b	9.9(102)c	6.1(37)b	1.7(3)b	5(25)b	4.5(26)b	117b	130b
Weedy check	-	10.6(112)a	12.8(164)a	6.2(56)a	24.3(21)a	5.7(33)a	9.2(91)a	201a	276a
Weed free[b]	0	0	0	0	0	0	0	0	0

[a]*All the herbicide treatments received pendimethalin 1000 g ha^{-1} before sowing as pre-emergence and one hand weeding at 60 DAS except weedy check*
[b]*Data was not included in the analysis*
[c] *Means present within each column with no common letter(s)are significantly different (P=0.05)*
[d] *Total weed density consisted of jungle rice, barnyard grass, viper grass, crow foot grass, yellownut sedge, and joyweed*
[e] *Original values of weed density are presented in parenthesis*

Table 6. Effect of weed control treatments on weed biomass in rice at 30 DAS in 2015 and 2016

Weed control method	Rate (g ha^{-1})	Weed biomass[c]							
		Grass weeds		Sedge		Broadleaf weeds		Total weed [d] biomass (Grass + sedge + broadleaf weeds)	
		2015	2016	2015	2016	2015	2016	2015	2016
		g m^{-2}							
Florpyrauxifen benzyl + cyhalofop butyl	120.0	12cb	1b	1b	2b	0b	1c	12d	4c
Florpyrauxifen benzyl + cyhalofop butyl	150.0	6c	1b	1b	2b	0b	1c	7e	4c
Florpyrauxifen benzyl + cyhalofop butyl	180.0	4c	1b	1b	1b	0b	1c	5e	3c
Florpyrauxifen benzyl	31.25	16b	7b	2b	7b	1b	10b	19c	24cb
Cyhalofop butyl	150.0	11cb	4b	14a	6b	10b	11b	35b	21cb
Bispyribac sodium	25.0	13b	4b	4b	2b	3b	13b	20c	19cb
Weedy check	-	23a	28a	15a	18a	32a	24a	69a	70a
Weed free[b]		0	0	0	0	0	0	0	0

[a]All the herbicide treatments received pendimethalin 1000 g ha^{-1} before sowing as pre-emergence and one hand weeding at 60 DAS except weedy check
[b]Data was not included in the analysis
[c] Means present within each column with no common letter(s)are significantly different (P=0.05)
[d] Total weed biomass consisted of jungle rice, barnyard grass, viper grass, crow foot grass, yellownut sedge and joyweed

Table 7. Effect of weed control methods on weed biomass and weed control efficiency in rice at 60 DAS in 2015 and 2016

Weed control method	Rate (g ha^{-1})	Weed biomass[c]								Weed control efficiency	
		Grasses		Sedges		Broadleaf weeds		Total weed biomass (grass+sedge+broadleaf weeds			
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
		---g m^{-2}---								-----------%-----------	
Florpyrauxifen benzyl +cyhalofop butyl	120.0	42d	57c	2cb	1b	2d	2d	46d	60d	72	81
Florpyrauxifen benzyl +cyhalofop butyl	150.0	35d	43b	2cb	1b	1d	2d	37e	47e	78	85
Florpyrauxifen benzyl + cyhalofop butyl	180.0	30d	45d	1c	1b	0d	2d	31e	46e	81	85
Florpyrauxifen benzyl	31.25	90b	112b	2cb	3ba	1d	32c	93b	147b	44	52
Cyhalofop butyl	150.0	59c	94b	4b	2ba	28b	60b	91b	156b	45	49
Bispyribac sodium	25.0	61c	65c	4b	2ba	13c	29c	78c	95c	53	69
Weedy check[b]	-	107a	234a	16a	9a	42a	264a	165a	407a	-	-
Weed free		0	0	0	0	0	0	0	0	100	100

[a]All the treatments received pendimethalin 1000 g ha^{-1} before sowing as pre-emergence and one hand weeding at 60 DAS except weedy check

[b]Data was not included in the analysis

[c] Means present within each column with no common letter(s)are significantly different (P=0.05)

[d] Total weed biomass consisted of jungle rice, barnyard grass, viper grass, crow foot grass, yellownut sedge and joyweed

Table 8. Effect of weed control treatments on yield attributes and rice grain yield in 2015 and 2016

Weed control method	Rate (g ha^{-1})	Panicles[b]		Grain yield[b]		Straw yield[b]	
		2015	2016	2015	2016	2015	2016
		----------No m^{-2}--		----------------------kg ha^{-1}--------------			
Florpyrauxifen benzyl + cyhalofop butyl	120.0	294de	332c	3970b	3100c	5540b	4520b
Florpyrauxifen benzyl+ cyhalofop butyl	150.0	316dc	352c	4010b	3330b	5550b	4750b
Florpyrauxifen benzyl+ cyhalofop butyl	180.0	411b	412b	4100b	3420b	5650b	4750b
Florpyrauxifen benzyl	31.25	351c	294de	3280c	2870c	4660c	4340c
Cyhalofop butyl	150.0	332c	316dc	3330c	3030c	4650c	4430c
Bispyribac sodium	25.0	275e	275e	3320c	2940c	4640c	4400c
Weedy check	-	167f	168f	1600e	1280e	3740d	2520d
Weed free	-	601a	602a	5190a	4500a	6500a	5100a

[a]All the treatments received pendimethalin 1000 g ha^{-1} before sowing as pre-emergence and one hand weeding at 60 DAS except weedy check
[b] Means present within each column with no common letter(s)are significantly different (P=0.05)

Table 9. Effect of residual weed control treatments on growth and yield attributes of succeeding maize in 2015-16 and 2016-17

Weed control method	Rate (g ha^{-1})	Plant height[a] (90 DAS)		Grains[a]		Seed yield[a]	
		2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
		-----------cm---------		-----No cob^{-1}-----		------kg ha^{-1}----	
Florpyrauxifen benzyl+ cyhalofop butyl	120.0	203a	197a	1155b	1128b	3300b	3200b
Florpyrauxifen benzyl+ cyhalofop butyl	150.0	205a	202a	1215a	1189b	3300b	3200b
Florpyrauxifen benzyl+ cyhalofop butyl	180.0	204a	202a	1235a	1220a	3400b	3300b
Florpyrauxifen benzyl	31.25	199a	201a	1125b	1135b	3100c	3000c
Cyhalofop butyl	150	200a	199a	1210a	1125b	3100c	3000c
Bispyribac sodium	25	202a	198a	1120b	1107b	3100c	3000c
Weedy check	-	198a	198a	1198a	1112b	3000c	2900c
Weed free	-	205a	205a	1225a	1280a	3700a	3600a

[a] Means present within each column with no common letter(s)are significantly different (P=0.05)

4. CONCLUSION

The combination product of florpyrauxifen benzyl + cyhalofop butyl 150 to 180 g ha^{-1} provided effective control of grasses in addition to the prevailing sedges and broadleaf weeds and was the best herbicide. This can be substituted as a possible alternative option to manage grasses and broad leaf weeds in aerobic rice with minimal residual effect/toxicity on succeeding crops.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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