Indian Journal of Weed Science (2024) **56**(3): 251–257
http://dx.doi.org/10.5958/0974-8164.2024.00041.8

RESEARCH ARTICLE

Post-emergence herbicide combinations for wet-seeded rice dominated with grass weed flora

Lekshmi Sekhar*[1], M. Ameena[1], Nimmy Jose[2] and P. Shalini Pillai[1]

Received: 20 April 2024 | Revised: 19 September 2024 | Accepted: 22 September 2024

ABSTRACT

The efficacy of herbicide combinations on weed control in wet-seeded rice with grasses as dominant weed flora was evaluated in field experiments conducted at Kerala Agricultural University, India during 2018 and 2019. Experiment comprised of 10 treatments, *viz*. cyhalofop-butyl (CB) 80 g/ha, penoxsulam (PS) + cyhalofop-butyl (6% OD) - commercial formulation 150 g/ha, cyhalofop-butyl 80 g/ha + carfentrazone-ethyl (CE) 200 g/ha, bispyribac-sodium (BS) 25 g/ha, bispyribac-sodium 25 g/ha + cyhalofop-butyl 80 g/ha, bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl (FPE) 60 g/ha, fenoxaprop-p-ethyl 60 g/ha, stale seedbed (SSB) *fb* chemical weeding with glyphosate 800 g/ha + oxyfluorfen 150 g/ha at 15-20 days after land preparation + cyhalofop-butyl 80 g/ha + carfentrazone-ethyl 200 g/ha, hand weeding twice at 20 and 45 DAS and unweeded control (UWC). The population of grass weeds increased over time, occupying 48.9 and 42.3% of the weed spectra during the initial phase and peaking at 87.40 and 75% towards 60 DAS, respectively during 2018 and 2019. Tank mix application of bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl 60 g/ha resulted in the lowest density of grass weeds at all stages and registered 100 and 92.97% reduction in weed count over unweeded control at 15 and 45 days after treatment application, respectively. The tank mix of bispyribac-sodium with cyhalofop-butyl and fenoxaprop-p-ethyl improved weed control compared to their individual application. Post-emergence herbicide combinations of bispyribac-sodium + fenoxaprop-p-ethyl, penoxsulam + cyhalofop-butyl (6% OD) and bispyribac-sodium + cyhalofop-butyl registered superior weed control efficiency than the broad-spectrum herbicide bispyribac-sodium and increased the grain yield by 58.84, 56.78, and 56.51%, respectively over the unweeded control.

Keywords: Bispyribac-sodium, Tank mix application, Weed flora, Weed management practices

INTRODUCTION

Rice stands as a critical staple food for over 3.5 billion individuals globally (CGIAR 2020), with the largest concentration residing in Asia. In India, it is grown on an area of about 41.10 million hectares (m ha) with a total production of 135 million tonnes (mt) during 2022-23 (GOI 2023), and in Kerala, it occupies 1.92 m ha area with a production of 5.96 mt (GOK 2023). Direct-seeding of rice (DSR) has been implemented as a substitute for the conventional practice of transplanting rice in numerous Asian countries. Weeds are the major biotic constraint in DSR as the weeds emerge concurrently with rice. The decrease in rice yield caused by uncontrolled weeds dominated by broad-leaved weeds in rainfed lowland rice was approximately 59.75% (Reddy and Ameena 2021).

Though herbicides are effective and economical in controlling weeds in DSR, continuous use of same herbicide or herbicides with a similar mode of action will lead to the development of herbicide resistance and inter and intraspecific shift in weed flora occurs either slowly or rapidly due to herbicide selection pressure (Duary *et al*. 2015). As application of single herbicide cannot deliver proficient weed control in DSR due to diverse weed community, a combination of graminicides with one of the herbicides for the control of sedges and broad-leaved weeds was found to be better for broad-spectrum weed control in DSR (Karim *et al*. 2004). Hence, there is a need to evaluate the performance of available herbicides and their combinations for the successful management of complex weed flora in DSR especially in the context of differential response of herbicides to weeds belonging to same family. With this background, the present study was carried out to evaluate the efficacy of tank mixtures of different herbicides for the control of a diverse weed flora in DSR.

[1] Department of Agronomy, College of Agriculture, Trivandrum, Kerala 690522, India

[2] Rice Research Station, Moncompu, Alappuzha, Kerala 688502, India

* Corresponding author email: lekshmisekhar1@gmail.com

MATERIALS AND METHODS

The field study was carried out in the paddy fields of Integrated Farming System Research Station, Karamana, Thiruvananthapuram of Kerala Agricultural University, Thrissur, Kerala, India during the *Kharif* seasons (June-September) of 2018 and 2019. The soil of the experimental field was sandy clay loam with a pH of 5.20. The available N, P and K content was 200.7, 30.5 and 414.25 kg/ha, respectively. The experiment was conducted in a randomized block design (RBD) with three replications. Nine weed control treatments, *viz*. cyhalofop-butyl (CB) 80 g/ha, penoxsulam (PS) + cyhalofop-butyl (6% OD) - commercial formulation 150 g/ha, cyhalofop-butyl 80 g/ha + carfentrazone-ethyl (CE) 200 g/ha, bispyribac-sodium (BS) 25 g/ha, bispyribac-sodium 25 g/ha + cyhalofop-butyl 80 g/ha, bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl (FPE) 60 g/ha, fenoxaprop-p-ethyl 60 g/ha, stale seedbed (SSB) *fb* chemical weeding with glyphosate 800 g/ha + oxyfluorfen 150 g/ha at 15-20 days after land preparation + cyhalofop-butyl 80 g/ha + carfentrazone-ethyl 200 g/ha, hand weeding twice at 20 and 45 DAS were tried out and an unweeded control (UWC) was included as control for comparison. The rice variety '*Uma*' (*MO 16*), a medium duration (120-135 days) was used as the experimental variety. The fertilizers were applied at 90: 45: 45 kg/ha N: P: K as per the recommendations of the Kerala Agricultural University (KAU, 2016). The full dose of phosphatic fertilizer was given as basal. One-third dose each of nitrogen was given as top dressing at 15 DAS, active tillering (35 DAS) and panicle initiation stages (60 DAS). Potassium was applied as equal doses at seedling stage (15 DAS) and the panicle initiation stage (60 DAS). All the herbicides were applied as post-emergence at 18 DAS, when weeds reached 3–4 leaf stage.

Weed dry weight were recorded at 15, 30, 45 days after treatment application (DATA). The weed control efficiency was worked out as per standard formula and grain yield was recorded.

RESULTS AND DISCUSSION

Weed flora

Fifteen species of weeds were observed in the wet-seeded rice (WSR). The weed flora in the experimental field was very diverse and composed of grass weeds, broad-leaved weeds, sedges and ferns. The grass weeds comprised of *Leptochloa chinensis*, *Echinochloa colona*, and *Isachne miliacea*. The main broad-leaved weeds were *Sphenoclea zeylanica*, *Bergia capensis*, *Monochoria vaginalis*, *Limnocharis flava*, *Ludwigia perennis*, *Alternanthera philoxeroides* and *Lindernia parviflora*. The sedges present were *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea*. *Marsilea quadrifolia* was the only fern species observed in the experimental field.

The relative proportion of weeds revealed that grass weeds were the most dominant weed flora in WSR in both 2018 and 2019, followed by BLWs and sedges. (**Figure 1**). Among the grass weeds, *L. chinensis* was the most abundant, accounting for more than 40% of the total population in both years, followed by. *E. colona* and *I. miliacea.* At 15 DATA, grass weeds constituted 46% and broad-leaved weeds comprised 12% of the population during 2018, whereas they were 62 and 26%, respectively, during 2019 at UWC (weedy check). Out of this, *L. chinensis* constituted 56% in 2018 and 65% in 2019. Ferns accounted for 32.60% of the UWC at 15 DATA during 2018.

The population of grass weeds was increased by 30 DATA and encompassed 67 and 68% of total population during 2018 and 2019 of which, *L. chinensis* contributed 67 and 61% of total grass populace, respectively. The dominance of grass weeds in WSR could be attributed to its persistent non-dormant weed seed bank and favourable soil conditions in wet seeding. Weed management practices had a significant effect on the absolute density of grass weeds, BLWs, and sedges at 15, 30, and 45 DATA during both years.

Absolute density of weeds

In general, the population of grass weeds increased in all treatments from 15 to 45 DATA in both 2018 and 2019. Grass weed population increased and peaked at 87.40 and 75% towards 60 DAS, occupying 48.9 and 42.3% of the weed spectra during the initial phase.

Tank mix application of BS 25 g/ha + FPE 60 g/ha had the lowest absolute density of grass weeds at all stages and was statistically equivalent to hand weeding twice at 20 and 45 DAS at 45 DATA. (**Table 1**). The combination registered 100 and 92.97% reduction in weed count over UWC at 15 and 45 DATA in WSR. The lower grass weed count in the treatment could be attributed to the combined efficiency of the mix in broad spectrum control of grass weeds. FPE 60 g/ha was also effective against grass weeds, with 97.17 and 91.24% reductions over UWC at 15 and 45 DATA, respectively. BS 25 g/ha + FPE 60 g/ha registered lower count of grass weeds compared to the sole application and could be considered as an additive selection for control of grass weeds.

The treatments consisting of BS 25 g/ha + FPE 60 g/ha and SSB *fb* chemical weeding with glyphosate 800 g/ha + oxyfluorfen 150 g/ha at 15 - 20 days after land preparation *fb* CB 80 g/ha + CE 200 g/ha showed an absolute density of zero for grass weeds at 15 DATA during both years of the study. The success of the SSB followed by chemical weeding treatment may be attributed to the effectiveness of the stale seedbed method in preventing the germination and establishment of dominant grass weeds like *L. chinensis* and *E. colona*, as well as the application of glyphosate, which eradicated established weeds, and oxyfluorfen, which prevented the growth of new weeds. However, the population of grass weeds under the SSB followed by chemical weeding treatment increased from 15 to 45 DATA, which recorded counts of 20 and 24/m^2, during 2018 and 2019, respectively, at 45 DATA.

The application of CB 80 g/ha alone was found to be more effective in controlling grass weeds than its combination with BS 25 g/ha and CE 200 g/ha. The combination treatments resulted in reductions of 50.09 and 24.61% at 15 DATA, and 36.03 and 10.56% at 45 DATA, respectively, as shown in Table 1. This might be due to the antagonistic effect of the herbicides with different modes of action used in the combination, as noted by Matzenbacher *et al.* (2015) who found that mixing acetyl-CoA carboxylase (ACCase) inhibitors with ALS (Aceto Lactate Synthase) inhibitors can result in antagonism. The treatment also performed better than the application of the broad-spectrum herbicide, BS 25 g/ha, and provided very good control of grass weeds in the study area. FPE 60 g/ha, PS + CB (6% OD) 150 g/ha, and CB 80 g/ha + CE 200 g/ha were also found to provide very good control of grass weeds during both seasons at 15 DATA. However, the higher count of grass weeds observed in the PS + CB (6% OD) 150 g/ha treatment during the later stages of the study was attributed to the uncontrolled population of *L. chinensis.*

Throughout both years of the study, UWC exhibited the greatest absolute density of grass weeds at all stages, followed by plots treated with BS 25 g/ha. The increased number of grass weeds in the BS treatment can be attributed to the higher count of *L. chinensis*, indicating that BS is ineffective in controlling this particular weed, despite its effectiveness against all other types of grass weeds. However, when BS was combined with FPE and CB, it resulted in reductions of 35-50% and 11-40%, respectively, in the population of *L. chinensis* compared to its individual application.

In the experimental site, which was mainly dominated by grass weeds, the presence of BLWs was generally low. The application of BS 25 g/ha was found to be effective in managing BLWs in both years of the study, resulting in the lowest count of BLWs under this treatment (**Table 1**). When BS 25 g/ha was combined with FPE 60 g/ha, the density of BLWs was significantly reduced in both years, with a reduction of 73.39% at 15 DATA compared to the sole application of BS 25 g/ha. This improvement might be due to the synergistic effect of FPE and BS in managing BLWs, even though FPE is primarily a grass killer. Although the pre-mix formulation of PS + CB 150 g/ha (6% OD) was effective in controlling a broad range of BLWs, it was found to be ineffective against *L. perennis* in WSR. This result was supported by the findings of Menon *et al.* (2016).

The combination of SSB and chemical weeding exhibited effective control of BLWs at the early stages of the crop by inhibiting the germination and emergence of BLW seeds. The application of pre-emergent herbicide controlled the emerged seeds, and glyphosate application after emergence helped in controlling the germinated ones. Staling stimulated the emergence of BLWs, which are mostly seed propagated, and multiple modes of action maximized the efficiency of chemical weeding. However, this treatment was not effective in controlling BLWs at later stages due to the excessive growth of *M. vaginalis* and *L. flava* under flooding.

The use of CB 80 g/ha and FPE 60 g/ha resulted in the highest count of broad-leaved weeds, which was similar to that of the untreated control, indicating the ineffectiveness of these treatments in controlling broad-leaved weeds.

The absolute density of sedges was significantly affected by the weed management treatments. Similar to the grass weeds, SSB followed by chemical weeding was effective in controlling sedges, with a count of zero at 15 DATA in both years (**Table 1**). However, the treatment was not able to maintain control of sedges in the later stages, resulting in higher absolute density.

Tank mixing BS 25 g/ha with FPE 60 g/ha resulted in consistently lower sedge counts at all stages observed. PS + CB (6% OD) 150 g/ha and BS 25 g/ha showed the best control of sedges with reductions of 91.35 and 100%, respectively at 15 DATA. The sole application of BS 25 g/ha and FPE 60 g/ha resulted in higher sedge counts compared to the tank mix combination of BS 25 g/ha + FPE 60 g/ha, highlighting the importance of applying herbicides in combination for effective weed management.

The sedge population was completely controlled by hand weeding twice at 20 and 45 DAS, with no sedges detected in the UWC at 15 DATA. This is consistent with the findings of Mubeen *et al.* (2014), who reported that HW reduced weed density by 90%, particularly for grass weeds. However, in the study, no sedges were detected in the UWC towards the end of the crop, which may be due to the early completion of their growth and life cycle.

The untreated plots had a higher count of weeds throughout the crop growth, but a decreasing trend was observed towards the later stages. This decrease could be attributed to the completion of the life cycle of some weeds and the competition from other weeds that emerged earlier.

Weed dry matter production

The results of data analysis showed that the treatments significantly affected the total dry matter production (DMP) of weeds at 15, 30, and 45 DATA. The tank mix application of BS 25 g/ha + FPE 60 g/ha had the lowest weed DMP, which was significantly lower than the individual application of each herbicide. When compared to BS 25 g/ha, FPE 60 g/ha, and the UWC at 15, 30, and 45 DATA, the combination reduced weed DMP by 83.09, 83.89, and 96.55%; 86.38, 93.18 and 98.20%; and 73.26, 86.49 and 89.70%, respectively (as shown in **Figure 2**). The lower weed DMP in the combination treatments can be attributed to the synergistic effects of herbicide combinations. Although BS 25 g/ha effectively controlled grass weeds, broad-leaved weeds (BLWs), and sedges, its ineffectiveness on the aerobic grass *L. chinensis* resulted in high weed DMP. Previous studies by Jacob (2014) and Sekhar *et al.* (2020) also reported that BS was ineffective in controlling *L. chinensis*. However, the combination of BS with FPE and CB proved to be efficient in controlling *L. chinensis*, highlighting the importance of using herbicide combinations to manage complex weed flora in the WSR.

Chemical weeding of stale seedbeds at 15 DATA resulted in zero weed DMP up to 35 DAS. However, weed DMP increased at later stages, which might be due to the lower efficiency of CB 80 g/ha + CE 200 g/ha in managing late-emerging *M. vaginalis* and *L. flava*. Among the herbicidal treatments, CB 80 g/ha had the highest weed DMP, followed by sole application of FPE 60 g/ha and BS 25 g/ha. The weed DMP increased by 1.6-6.5 times in plots that received single herbicide applications compared to those that received tank mix or ready mix applications. On the other hand, CB 80 g/ha + CE 200 g/ha resulted in higher weed DMP at later stages and was statistically

Table 1. Effect of treatments on absolute density of grasses, broad-leaved weeds and sedges

Treatment	Absolute density (no./m^2)											
	2018						2019					
	Grasses		Broad-leaved weeds		Sedges		Grasses		Broad-leaved weeds		Sedges	
	15 DATA*	45 DATA	15 DATA	45 DATA	15 DATA	45 DATA	15 DATA	45 DATA	15 DATA	45 DATA	15 DATA	45 DATA
Cyhalofop-butyl	1.64 (2.7)	6.21 (38.7)	9.35 (90.7)	8.24 (68.0)	4.46 (21.3)	5.58 (33.3)	1.77 (2.7)	4.47 (20.0)	8.27 (68.0)	11.13 (129.3)	5.92 (34.7)	5.56 (30.7)
Penoxsulam + cyhalofop-butyl (6% OD) – ready mix formulation	2.38 (6.7)	5.41 (29.3)	1.17 (1.3)	5.02 (25.3)	1.44 (2.7)	0.70 (0.0)	2.41 (5.3)	6.27 (40.0)	3.71 (13.3)	3.50 (12.0)	1.34 (1.3)	0.70 (0.0)
Cyhalofop-butyl + carfentrazone-ethyl	1.91 (4.0)	6.53 (42.7)	4.76 (22.7)	2.92 (10.7)	2.31 (5.3)	5.33 (37.3)	2.41 (5.3)	4.70 (22.7)	5.33 (28.0)	6.15 (42.7)	1.77 (2.7)	1.66 (2.7)
Bispyribac-sodium	6.70 (46.7)	9.66 (93.3)	2.51 (6.7)	2.27 (5.3)	2.12 (4.0)	0.70 (0.0)	6.03 (36.0)	9.46 (90.7)	2.87 (8.0)	0.70 (0.0)	1.64 (2.7)	0.70 (0.0)
Bispyribac-sodium + cyhalofop-butyl	2.12 (5.3)	7.56 (57.3)	2.77 (8.0)	6.32 (40.0)	1.17 (1.3)	4.21 (21.3)	2.41 (5.3)	4.86 (24.0)	0.70 (0.0)	2.29 (6.7)	1.77 (2.7)	0.70 (0.0)
Bispyribac-sodium + fenoxaprop-p-ethyl	0.70 (0.0)	3.24 (10.7)	1.17 (1.3)	3.15 (10.7)	0.70 (0.0)	0.70 (0.0)	0.70 (0.0)	3.21 (10.7)	1.77 (2.7)	0.70 (0.0)	0.70 (0.0)	0.70 (0.0)
Fenoxaprop-p-ethyl	1.64 (2.7)	3.43 (12.0)	7.40 (54.7)	7.23 (53.3)	3.82 (14.7)	2.91 (8.0)	2.12 (4.0)	3.82 (14.7)	10.08 (101.3)	10.82 (120.0)	5.58 (30.7)	3.53 (13.3)
Stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl	0.70 (0.0)	4.46 (20.0)	0.70 (0.0)	6.54 (44.0)	0.70 (0.0)	10.21 (104.0)	0.70 (0.0)	4.88 (24.0)	0.70 (0.0)	6.25 (40.0)	0.70 (0.0)	5.07 (25.3)
Unweeded control	10.60 (113.3)	12.16 (148.0)	5.45 (29.3)	4.16 (17.3)	4.80 (22.7)	0.70 (0.0)	11.03 (121.3)	12.46 (156.0)	6.95 (49.3)	6.76 (52.0)	4.93 (24.0)	0.70 (0.0)
Hand weeding twice at 20 and 45 DAS**	1.64 (2.7)	3.45 (12.0)	1.91 (4.0)	5.65 (32.0)	0.70 (0.0)	0.70 (0.0)	1.34 (1.3)	3.04 (9.3)	2.65 (6.6)	2.12 (5.3)	0.70 (0.0)	1.34 (1.3)
LSD (p=0.05)	2.01	0.56	1.90	1.61	1.48	2.73	0.27	1.28	0.91	2.86	0.54	0.99

*DAS - Days after sowing

comparable to BS due to the combination's inability to control *M. vaginalis* and *F. miliacea*.

Hand weeding performed twice at 20 and 45 DAS resulted in a significant reduction in weed DMP, by 96.80, 98.56, and 92.84%, respectively, when compared to the UWC at 15, 30, and 45 DATA (**Figure 2**). However, there was an increase in weed DMP for most of the herbicidal treatments at 45 DATA, and a fivefold increase was observed in the un-weeded control from 15 to 30 DATA. Although the weed DMP was lower at 45 DATA than at 30 DATA during both years, the reduction in DMP per unit area towards the later stages may have been due to the decreased weed count in the unweeded control.

Weed control efficiency

Among the weed management practices, higher WCE of 96.80, 98.56 and 92.84% were recorded in HW twice at 20 and 45 DAS, respectively at 15, 30 and 45 DATA. In WSR, tank mix application of BS 25 g/ha + FPE 60 g/ha was just as effective as HW treatments applied twice at 20 and 45 DAS, with WCE of 96.55, 98.20, and 89.70% at 15, 30 and 45 DATA (**Figure 3**). This was possibly due to the effective management of a wide range of weeds through the combined action of herbicides with different modes of action. Blouin *et al*. (2010) reported similar results, stating that mixtures of ALS inhibitor herbicides with FPE at optimal doses resulted in better weed control in rice.

The combination of BS 25 g/ha with FPE 60 g/ha or CB 80 g/ha, as well as ready mix combination of PS + CB (6% OD) 150 g/ha, resulted in better weed control compared to the individual application of these herbicides. The WCE for the individual application of herbicides ranged from 79.05 to 81.46%, 67.92 to 85.86%, and 18.92 to 61.39% at 15, 30 and 45 DATA, respectively. However, when the herbicides were combined, the WCE ranged from 83.01 to 100%, 80.85 to 98.20%, and 50.73 to 89.70%, respectively. These findings suggest that tank mixing BS 25 g/ha with FPE 60 g/ha or CB 80 g/ha and applying a ready mix of PS and CB (6% OD) 150 g/ha may have a synergistic effect in controlling a wide range of weeds, resulting in a lower total weed biomass and higher WCE. The most significant impact was observed when BS 25 g/ha was mixed with FPE 60 g/ha, which provided excellent control of a broad spectrum of weeds.

At 15 DATA, the highest WCE of 100% was achieved with SSB *fb* chemical weeding, possibly because there was very little weed dry matter accumulation in the early stages. The use of herbicide combinations resulted in a WCE improvement of 26.79 to 33.87% over the application of BS alone, which only registered a 61.39% WCE at 45 DATA.

FPE 60 g/ha and CB 80 g/ha had the lowest total weed control among the treatments, as they were not effective in controlling BLWs and sedges. On the other hand, tank mix applications of CB 80 g/ha or FPE 60 g/ha with BS 25 g/ha improved the control of *E. colona, M. vaginalis, C. iria*, and *F. miliacea* compared to sole application, resulting in an enhanced WCE in herbicide combinations. These findings suggest that herbicide combinations are necessary for broad-spectrum weed control in WSR.

Grain yield

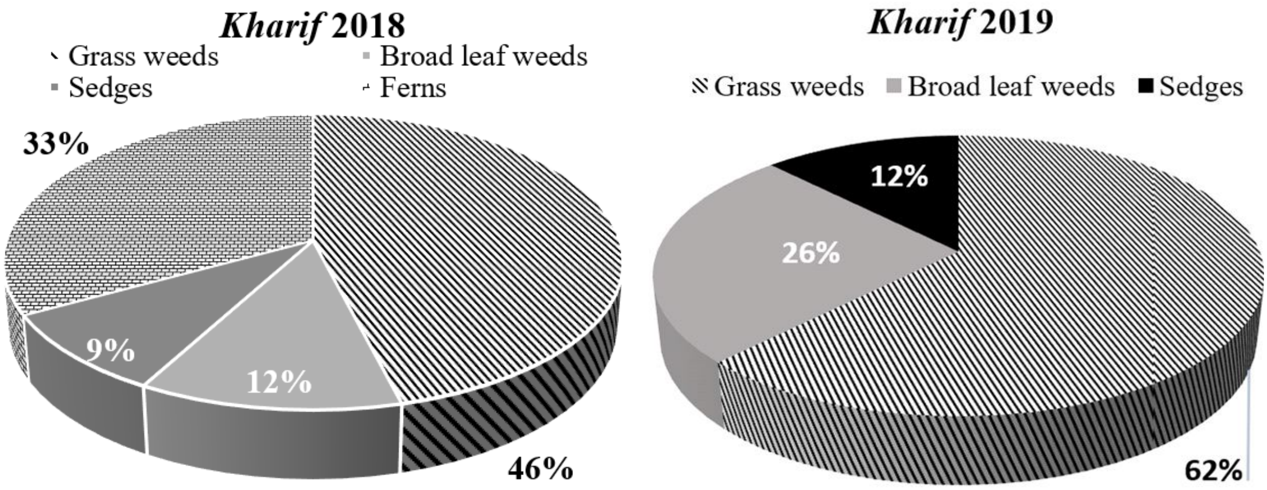
Grain yield was significantly influenced by weed management treatments during both years (**Table 2**). All the tested herbicides and the herbicide combinations were observed to improve the grain and straw yield compared to unweeded control during both the years.

The maximum grain yield (4.93 and 5.47 t/ha) and straw yield (6.84 and 6.79 t/ha) was attained by HW twice at 20 and 45 DAS during both 2018 and 2019, and recorded 60.19% increase in grain yield over unweeded control in WSR. Herbicide

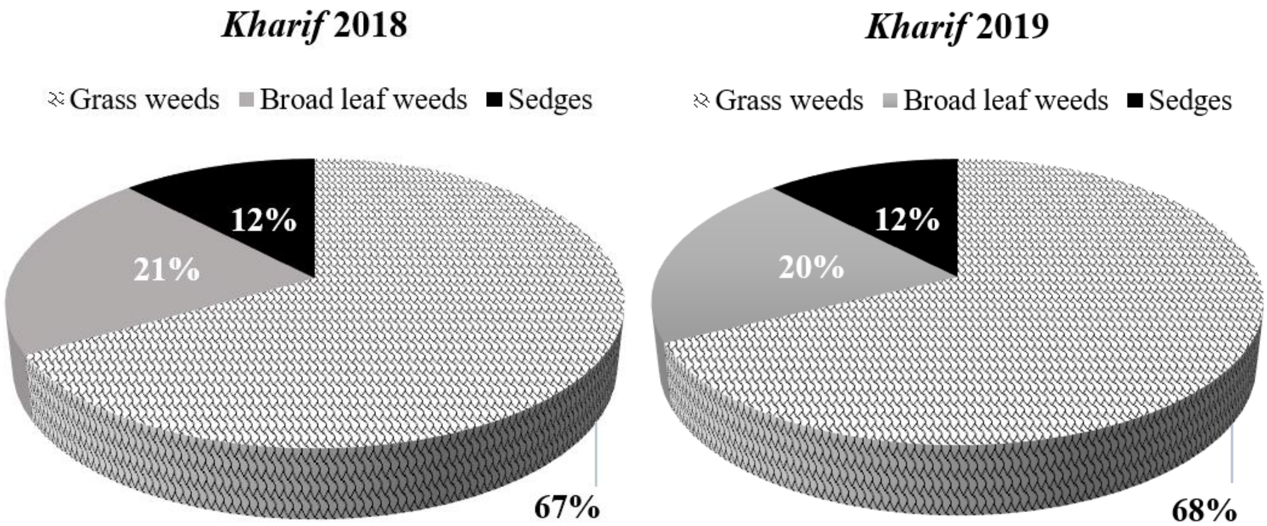
Table 2. Effect of weed management practices on grain yield and straw yield

Treatment	Grain yield (t/ha)		Straw yield (t/ha)	
	2018	2019	2018	2019
Cyhalofop-butyl	3.26	2.17	4.51	3.58
Penoxsulam + cyhalofop-butyl (6% OD) – ready mix formulation	4.55	5.03	6.06	6.27
Cyhalofop-butyl + carfentrazone-ethyl	3.68	4.20	4.99	5.65
Bispyribac-sodium	3.76	4.19	5.64	5.26
Bispyribac-sodium + cyhalofop-butyl	4.37	5.14	5.92	6.09
Bispyribac-sodium + fenoxaprop-p-ethyl	4.76	5.30	6.12	6.37
Fenoxaprop-p-ethyl	3.20	3.12	4.52	4.30
Stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl	4.02	4.74	5.52	5.89
Unweeded control	2.13	2.01	3.88	3.42
Hand weeding twice at 20 and 45 DAS*	4.93	5.47	6.84	6.79
LSD (p=0.05)	0.881	0.911	0.843	0.755

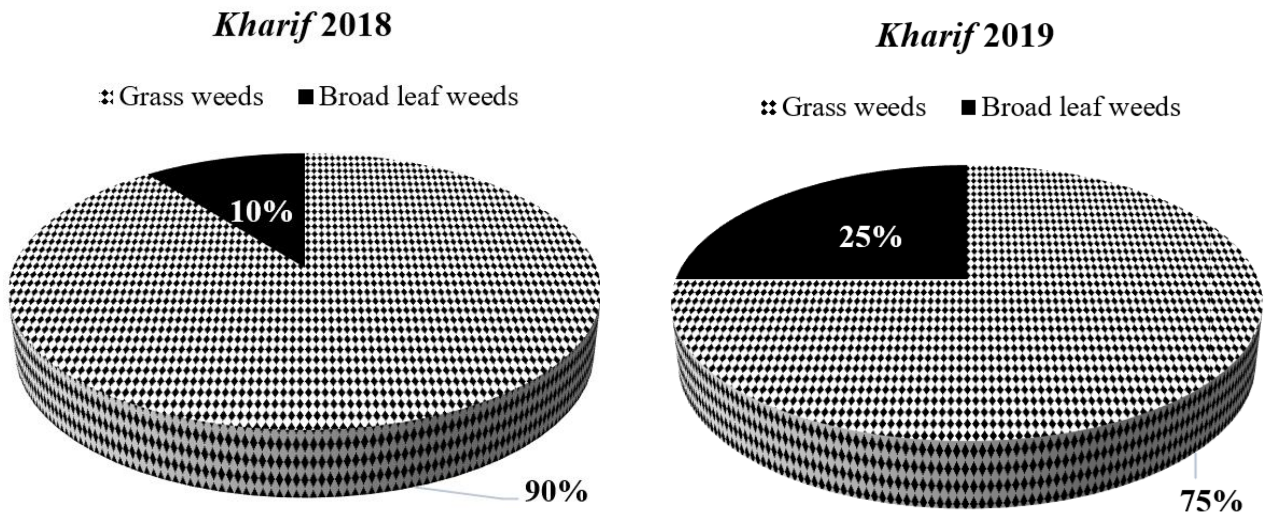
*DAS - Days after sowing



15 days after treatment application



30 days after treatment application



45 days after treatment application

Figure 1. Weed spectrum in un-weeded control

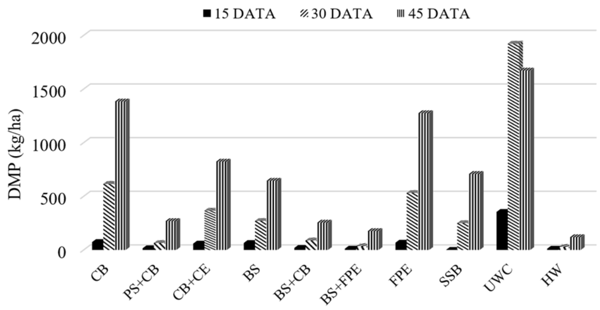


Figure 2. Effect of weed management practices on weed dry matter production (pooled)

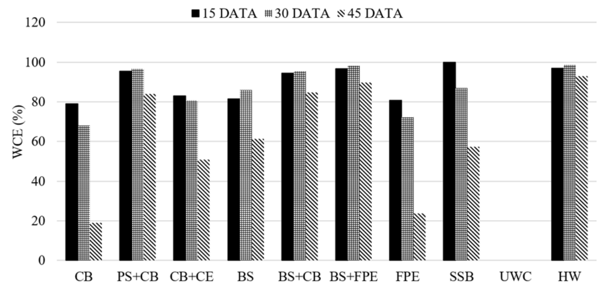


Figure 3. Effect of weed management practices on weed control efficiency (pooled)

combinations of BS 25 g/ha + FPE 60 g/ha, PS + CB (6% OD) 150 g/ha and BS 25 g/ha + CB 80 g/ha produced superior grain yield (5.03, 4.79 and 4.76 t/ha, respectively) and straw yield (6.25, 6.18 and 6.00 t/ha, respectively) which were statistically similar to the hand weeded weed free check.

Un-weeded control recorded the least values in grain yield and straw yield, which reduced grain yield by 56.77 and 63.13%, respectively, in WSR during 2018 and 2019, compared to the treatment with highest grain yield (**Table 2**). The heavy and unhampered infestation of weeds contributed to very severe competition and inopportune exploitation of growth factors, which might have resulted in lower yields and yield attributes in un-weeded control. Reddy (2020) also reported a grain yield reduction of 59.03% in weedy check in WSR. Herbicide combinations produced higher grain yields than single herbicide applications, increasing grain yield by 16-28% compared to sole application of BS and 56-59% compared to un-weeded control (**Table 2)** Higher yield attributes in herbicide combinations compared to sole application during both years due to enhanced control of complex weed flora, could be leading to lower crop-weed competition. Vigorous stands offer rice plants an advantage to outcompete weeds, which ultimately translates into better growth, allometry, yield components and finally increased yield.

It was concluded that post-emergence herbicide combinations of bispyribac-sodium + cyhalofop-butyl, penoxsulam + cyhalofop-butyl and bispyribac-sodium + fenoxaprop-p-ethyl were more effective in controlling complex weed flora in WSR besides higher grain yield.

REFERENCES

Blouin DC, Webster EP and Bond JP. 2010. On a method of analysis for synergistic and antagonistic joint-action effects with fenoxaprop mixtures in rice (*Oryza sativa*). *Weed Technology* 24: 583–589.

CGIAR [Consultative Group for International Agricultural Research]. 2020. Ricepedia [on-line]. Available: http://ricepedia.org/rice-as-food/theglobal-staple-rice-consumers.

Duary B, Mishra MM, Dash R and Teja KC. 2015. Weed management in lowland rice. *Indian Journal of Weed Sci*ence 47: 224–232.

GOI [Government of India]. 2023. Data bank of Crops Unit-I, Crop division, Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare.

GOK [Government of Kerala]. 2023. https://www.ecostat.kerala.gov.in/publication-detail/final-estimates-of-areaproduction-and-yield-of-crops-2022-23

Jacob G. 2014. *Herbicidal management of Chinese sprangletop (Leptochloa chinensis (L.) Nees.) in direct seeded rice*. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 96p.

Karim RSM, Man AB and Sahid IB. 2004. Weed problems and their management in rice fields of Malaysia: an overview. *Weed Biology and Management* 4(4): 177–186.

KAU [Kerala Agricultural University]. 2016. *Package of Practices Recommendations: Crops 2016* (15th Ed.), Kerala Agricultural University, Thrissur, 393p.

Matzenbacher FO, Kalsing A, Dalazen G, Markus C and Merotto A. 2015. Antagonism is the predominant effect of herbicide mixtures used for imidazolinone resistant barnyardgrass (*Echinochloa crusgalli*) control. Planta daninha [e-journal].

Menon MV, Bridgit TK and Girija T. 2016. Efficacy of herbicide combinations for weed management in transplanted rice. *Journal of Tropical Agriculture* 54(2): 204–208.

Mubeen K, Jhala AJ, Hussain M, Siddiqui MH, Zahoor F, Shehzad M and Mehmood K. 2014. Effects of seeding time and competition period on weeds, growth and yield of direct seeded fine rice (*Oryza Sativa* L.). *Academic Journal of Interdisciplinary Studies* 3(5): 55–64.

Reddy MSSK. 2020. *Biology and management of goose weed (Sphenoclea zeylanica Gaertner) in wetland rice.* M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 169p.

Reddy MSSK and Ameena M. 2021. Efficacy of pre- and post-emergence ready-mix herbicides in rainfed lowland wet-seeded rice. *Indian Journal of Weed Science*. 53(1): 88–91.

Sekhar L, Ameena M and Jose N. 2020. Herbicides and herbicide combinations for management of *Leptochloa chinensis* in wet-seeded rice. *Indian Journal of Weed Science.* 52(3): 211–216.