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Effects of pre-mix herbicide combinations on weed management in transplanted rice (*Oryza sativa*)

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Rice (*Oryza sativa* L.) serving as a staple food for almost half of the global population, plays a pivotal role in ensuring food security and economic stability worldwide (Hashim *et al.* 2024). Weeds are a significant threat to rice cultivation as various weed spp., including grasses, sedges, and broad-leaf weeds, compete with the crop for nutrients and resources (Kumari *et al.* 2023). While manual weeding is effective, it is labour-intensive, costly, and often constrained by labour availability and timing. In contrast, herbicides offer an efficient and cost-effective weed control solution for heterogeneous weed populations if applied correctly. However, the continuous use of single herbicides or those with the same mode of action can lead to weed resistance and shifts in weed population (Knezevic *et al.* 2017). Encouraging the application of multiple herbicides with distinct active ingredients can enhance broad-spectrum weed control, while also potentially mitigating herbicide resistance (Mahajan and Chauhan 2015). Identifying low-dose herbicides and herbicide mixtures that are effective against heterogeneous weed flora are important pertaining to the sustainability of rice ecosystem. To address these challenges, it is essential to test high-efficacy herbicides and herbicide combinations to effectively manage mixed weed flora in transplanted rice. Our study was structured around two primary objectives, viz. evaluating post-emergence herbicides efficacy for weed management; and investigating their impact on the growth, yield attributes, and overall yield of transplanted rice.

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The field experiment was conducted during rainy (*kharif*) season of 2021 at the Research Farm of Banaras Hindu University, Varanasi, Uttar Pradesh. The area experiences a semi-arid to semi-humid climate, with weekly temperatures ranging from 28.5–36°C and a total precipitation of 1261.1 mm during the crop-growing season. The soil, classified as sandy clay loam, had a *p*H of 7.4 and contained 0.37% SOC; 205.8 kg/ha N; 19.6 kg/ha P; and 225.7 kg/ha K in top 0–15 cm soil layer. The experiment was laid out in a randomized block design (RBD) comprised of 9 different weed management treatments, viz. T_1, Bispyribac sodium 20% + pyrazosulfuron 15% WDG @43.75 g/ha along with Spreadmax (silicon based non-ionic surfactant) @0.5 ml/litre; T_2, Bispyribac sodium 20% + pyrazosulfuron 15% WDG @52.50 g/h along with Spreadmax (silicon based non-ionic surfactant) @0.5 ml/litre; T_3, Bispyribac sodium 20% + pyrazosulfuron 15% WDG @61.25 g/ha along with Spreadmax (silicon based non-ionic surfactant) @0.5 ml/litre; T_4, Bispyribac sodium 10% SC @25 ml/ha; T_5, Pyrazosulfuron 10% WP @15 g/ha; T_6, Triafamone 20% + ethoxysulfuron 10% WG @66.5 g/ha; T_7, Penoxsulam 1.02% + cyhalofop-butyl 5.1% OD @135 ml/ha; T_8, Hand weeding (20 and 40 DAS); and T_9, Untreated control, replicated thrice. Rice seedlings were hand transplanted with 30 cm × 30 cm spacing. Recommended nutrient doses (120 kg N, 60 kg P_2O_5 and 60 kg K_2O/ha) as urea, single superphosphate (SSP) and muriate of potash (MOP) were applied. Nitrogen was split into three doses (50% as a basal dose, 25% as a top dressing at tillering, and 25% at panicle initiation), and phosphorus and potassium were applied as a basal dose. Herbicides were sprayed 14 days after transplanting (DAT) with a knapsack sprayer (500 litre/ha, flat fan nozzle) for post-emergence weed control. Rice plant biomass was determined by measuring 1 m long stalks in three rows/plot. Weed density and biomass were assessed at 60 DAT and at harvest by placing two 50 cm × 50 cm quadrats in each plot. The weeds were sun-dried and then oven-dried at 70°C until constant weight, and weighed. At harvest, rice tillers and panicles per square meter were recorded, and measurements such as test weight, unfilled grain, total grain, filled grain, panicle weight, and panicle length were taken from ten random panicles. Grain yield was quantified at 14% moisture content in kg/ha. The collected data underwent an analysis of variance following the methodology outlined by Gomez and Gomez (1984). Additionally, the weed biomass and density data were subjected to a square root transformation ($\sqrt{(x+0.5)}$).

Application of triafamone+ethoxysulfuron and bispyribac sodium + pyrazosulfuron (T_2) herbicides resulted in a 58.5% and 61.5% reduction, respectively, in the weed density of *Ceasulia axillaris* and an 82.4% and 83.8% reduction, respectively, in dry matter compared to the control at 60 DAT. Similar trends were observed at harvest. All the herbicides reduced the *Echinochloa colona* density by 43–62% and dry matter by 55–70%. Among the herbicidal treatments, bispyribac sodium + pyrazosulfuron (T_2) and triafamone + ethoxysulfuron were more efficient in reducing the density and dry matter of *Physalis minima*. Compared to the non-treated check plot at 60 DAT and at harvest application of triafamone + ethoxysulfuron and bispyribac sodium + pyrazosulfuron (T_2) reduced *Ammania baccifera* density by 55%, 61% and dry matter by 62%, 68%, respectively. Applying bispyribac sodium + pyrazosulfuron (T_2) and triafamone + ethoxysulfuron reduced the density of *Cyperus difformis* by 76% and 80%, respectively compared to control. A similar trend was recorded for biomass reduction (68% and 74%, respectively). It was interesting to note that the application of penoxsulam + cyhalofop-butyl achieved the highest reduction in *Paspalum distichum* density (61%) and dry matter (67%). Whereas triafamone + ethoxysulfuron was the most effective in reducing *Spilanthes acmella* biomass by 82%. Among herbicides, bispyribac sodium + pyrazosulfuron (T_2) and triafamone + ethoxysulfuron were more effective than other treatments in controlling *C. axillaris, E .colona, P. minima, A. baccifera, C. difformis, F. miliacea* and *S. acmella* (Table 1 and 2). These results are in accordance with the findings of Kaur *et al.* (2016), Hossain and Malik (2017), Menon *et al.* (2017) and Yadav *et al.* (2019). In contrast, penoxsulam + cyhalofop-butyl was the most effective combination for controlling *P. distichum* and *L. chinensis*. These results are in line with Srinithan *et al.* (2021). Among the herbicidal treatments, application of bispyribac sodium + pyrazosulfuron (T_2) leads to 75% and 59% higher biomass production, compared to non-treated treatment at 60 DAT and 100 DAT, respectively as against triafamone + ethoxysulfuron which increased biomass by 78% and 58%. The weedy plots had the lowest tiller production (Table 3). Applying bispyribac sodium + pyrazosulfuron (T_2) also resulted in substantial increases (133%) in tiller production compared to the weedy treatment. Yield attribute parameters namely number of grain/panicle filled grain/panicle, test weight, panicle length, and panicle weight did not differ statistically among the treatments. Hand weeding recorded the highest grain yield, showing a 132% improvement compared to the untreated control. The maximum grain yield was observed in the bispyribac sodium + pyrazosulfuron (T_2) and triafamone + ethoxysulfuron treatments, followed by penoxsulam + cyhalofop-butyl. Conversely, the weedy plot exhibited the lowest grain yield,

Table 1 Effect of weed control treatments on density of weeds at 60 DAT and at harvest of puddle-transplanted rice

Treatment	*C. axillaris*		*P. minima*		*S. acmella*	*A. baciferra*		*C. difformis*	*E. colona*	*P. distichum*
	60 DAT	Harvest	60 DAT	Harvest	Harvest	60 DAT	Harvest	60 DAT	60 DAT	Harvest
T_1	3.3bc (10.7)	2.8bc (7.3)	3.4bc (11)	1.58b (2)	2.6bc (6.6)	3.4bc (11)	2.6bcd (6.3)	3.7cd (13.3)	3.2bc (10)	2.8b (7.3)
T_2	3.1cd (9.0)	2.5bc (6.3)	2.9d (8.3)	0.71d (0)	2.4de (5.6)	3bc (8.6)	2.4cd (5.3)	3.66cd (13)	2.73c (7)	2.6bcd (6.3)
T_3	3.3bc (10.7)	2.8bc (7.6)	3.1cd (9.6)	0.71d (0)	2.5cde (6)	3.3bc (10.6)	2.5bcd (5.6)	3.84cd (14.3)	3bc (8.6)	2.7bc (7)
T_4	3.5b (12)	2.6bc (6.3)	3.4b (11.6)	1.34c (1.3)	2.7b (7)	3.7b (13.3)	2.7bc (6.6)	4.67b (21.3)	3.1bc (9.3)	2.4cde (5.3)
T_5	3.5b (11.7)	3b (8.6)	3.39bc (11.)	0.71d (0)	2.6bcd (6.3)	3.4bc (11.3)	2.7b (7)	4.88b (23.3)	3.5b (12.3)	2.3de (5)
T_6	3.0d (8.3)	2.4cd (5.3)	3d (8.6)	0.71d (0)	2.4ef (5.3)	2.9c (7.6)	2.3d (5)	3.39d (11)	2.6c (6.6)	2.5bcde (5.6)
T_7	3.4b (11)	2.8bc (7.6)	3.1d (9.3)	1.76b (2.6)	2.8de (5.6)	3.3bc (10.3)	2.6bcd (6.3)	4.06c (16)	3bc (8.6)	2.2e (4.3)
T_8	1.9e (3)	2.1d (4)	1.9e (3.3)	0.71d (0)	2.2f (4.6)	2.1d (4)	2e (3.6)	2.27e (4.6)	1.3d (1.3)	1.9f (3)
T_9	4.7a (21.7)	3.6a (13)	3.9a (15.3)	2.2a (4.3)	3.4a (11.3)	4.4a (19.6)	3.6a (12.6)	7.37a (54)	4.2a (17.6)	3.4a (11.3)

Refer to the methodology for Treatment details. DAT, Days after transplanting.

Table 2 Effect of weed control treatments on dry weight of weeds at 60 DAT and at harvest of puddle-transplanted rice

Treatment	*C. axillaris*		*P. minima*		*S. acmella*	*A. baciferra*		*C. difformis*	*E. colona*	*P. distichum*
	60 DAT	Harvest	60 DAT	Harvest	Harvest	60 DAT	Harvest	60 DAT	60 DAT	Harvest
T_1	2.b (3.7)	2.5d (6)	1.5cd (1.7)	1.7c (2.4)	1.7bc (2.4)	1.9b (3.2)	2.2bc (4.4)	4.1d (16.3)	3.3bc (10.3)	3.5ab (11.9)
T_2	1.9b (3.2)	2.6d (6.2)	1.34d (1.4)	0.71d (0)	1.8bc (2.8)	1.87b (3)	2.1bc (4.2)	4d (15.6)	3cd (8.8)	2.6c (6.3)
T_3	2.1b (3.9)	2.6d (6.8)	1.5cd (1.6)	0.71d (0)	1.9b (3)	1.84b (2.9)	1.91c (3.5)	4.2cd (17.2)	3.1c (9.2)	3.4b (11.6)
T_4	2.2b (4.4)	3.3bc (10.7)	1.6bc (2.1)	0.9d (0.4)	1.9b (3.2)	2.5a (6.1)	2.4b (5.3)	4.81bc (22.6)	3.4b (11.1)	2.40c (5.3)
T_5	2.3b (4.7)	3.8b (14.4)	1.7b (2.3)	0.71d (0)	1.9b (3.5)	2.7a (7.2)	2.2bc (4.5)	5.1b (26)	3.4b (11.3)	2.7c (6.9)
T_6	1.9b (2.9)	2.3d (5.1)	1.4d (1.6)	0.71d (0)	1.6bc (2.3)	1.7b (2.5)	1.9c (3)	3.6d (12.8)	2.8d (7.5)	2.8c (7.7)
T_7	2.1b (4.3)	2.9cd (8.4)	1.5bcd (1.8)	2.2b (4.6)	1.6bc (2.3)	2.4a (5.5)	2.6ab (6.2)	4.1d (16.3)	3.1c (9.4)	2.4c (5.1)
T_8	1.9c (3.1)	1.8e (3.1)	1.2e (0.9)	0.71d (0)	1.3c (1.3)	1.1c (0.8)	0.9d (0.4)	2e (3.7)	1.9e (3)	1.7d (2.6)
T_9	4.3a (18.3)	4.9a (24.4)	2.4a (5.2)	2.7a (6.9)	3.6a (12.9)	2.9a (8)	2.9a (8.3)	7a (49.7)	5a (25.5)	4a (15.5)

Refer to the methodology for Treatment details. DAT, Days after transplanting.

Table 3 Effect of weed control treatments on growth attributes and yield attributes of puddle-transplanted rice

Treatment	Dry weight (g)		No. of tiller/m^2	Filled grains/ panicle	Unfilled grains/ panicle	No. of grains/ panicle	Test weight (g)	Panicle length (cm)	Panicle weight (g)	No. of panicle/ m^2	Grain yield (kg/h)	Straw yield (kg/ha)
	60 DAT	100 DAT										
T_1	56.8de	140bc	266c	197	11cde	208	19.5	27	4.32	244c	6650	8460
T_2	62.9bc	152.6ab	313b	209	10de	219	19.46	25.8	4.73	288b	7162	9050
T_3	61.8bcd	145.6bc	268c	181	11.6c	191	18.84	26.1	4.84	226d	6595	8830
T_4	54.7e	144.6bc	264c	192	13b	204	21.18	26.3	4.94	241c	6405	8350
T_5	57.5cde	138.3c	249d	196	14b	206	20.7	26.3	5.07	234cd	6275	8510
T_6	64.1b	151.6abc	307b	202	10cde	217	20.37	26	4.81	279b	6959	9880
T_7	60.4bcd	146bc	271c	173	11d	193	19.73	27	4.82	245c	6658	9000
T_8	70.7a	162.6a	363a	221	9e	234	20.61	26.6	4.58	314a	7542	9500
T_9	35.9f	95.6d	235d	170	20a	181	19.63	24.1	4.27	179e	5708	7500
				NS		NS	NS	NS	NS			

Refer to the methodology for Treatment details. DAT, Days after transplanting.

followed by plots treated solely with bispyribac sodium and pyrazosulfuron. Similar trends were observed for straw yield (Table 3). Notably hand weeding emerged as the most effective approach for reducing weed density and biomass. Herbicides contributed to increased tillers, and panicle length compared to weedy plots. This improvement in crop growth characteristics is due to the effective suppression of weed competition, which allows rice plants to utilise available resources more efficiently. However, bispyribac sodium and pyrazosulfuron alone recorded the least effectiveness against weeds. Previously Saikia *et al.* (2024) have also documented the insufficient control of weeds using a single herbicide. The herbicide treatments did not achieve the same level of weed-free conditions as the hand-weeded treatment. Nevertheless, herbicide application significantly increased grain yield and rice biomass accumulation compared to the weed check treatment. Herbicide applications effectively reduced weed competition, creating a more favourable environment for rice growth. Ultimately resulted in an increase in grain yield compared to the untreated control. Application of pre-mix combination of bispyribac sodium + pyrazosulfuron (T_2) and triafamone + ethoxysulfuron leads to the highest grain and straw yield. While manual weeding has shown effectiveness in weed control at specific time intervals (20 and 40 DAT), its feasibility on a large scale is hindered by technical constraints such as labour availability and productivity (Nagargade *et al.* 2024). As a result, herbicide combinations offer a practical alternative due to their ease of use and effectiveness.

SUMMARY

An experiment was conducted during rainy (*kharif*) season of 2021 at the Agricultural Farm of Banaras Hindu University, Varanasi, Uttar Pradesh for evaluating the efficacy of pre-mix herbicide combinations applied as post emergence in managing weeds in transplanted rice. We assessed 9 different weed management treatments, including sole herbicide and pre-mix combinations and hand weeding in randomized block design. Results showed that herbicide combinations such as triafamone + ethoxysulfuron and bispyribac sodium + pyrazosulfuron effectively reduced weed density and biomass, improving crop growth attributes and ultimately yield. The study highlights the importance of using herbicide combinations for effective weed management in puddle-transplanted rice cultivation.

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