



Dynamic Weed Control through Targeted Herbicide in Transplanted Black Rice (*Oryza sativa* L.) under Eastern Uttar Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Weed management remains a major challenge, especially under intensive cropping systems in rice cultivation. There is a need to adopt advanced weed control strategies that enable selective suppression of weed flora while minimizing crop injury. However, the indiscriminate and continuous use of single herbicide molecules has led to the emergence of herbicide-resistant weed biotypes, necessitating integrated and rotational approaches. The present field investigation was conducted during the *Kharif* season (June–November 2024) at the Agricultural Research Farm, Institute of Agriculture and Natural Sciences, Deen Dayal Upadhyaya Gorakhpur University, Uttar Pradesh,

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India, to evaluate the efficacy of various herbicide combinations on weed dynamics in transplanted black rice (*Oryza sativa* L.). The experiment consisted of seven treatments: T₁ (100% RDF + Weedy Check), T₂ (100% RDF + Butachlor @750 g a.i./ha + Triafamone @40 g a.i./ha), T₃ (100% RDF + Butachlor @750 g a.i./ha + Bispyribac Sodium @150 g a.i./ha), T₄ (100% RDF + Butachlor @1500 g a.i./ha), T₅ (100% RDF + Triafamone @40 g a.i./ha), T₆ (100% RDF + Bispyribac Sodium @300 g a.i./ha), and T₇ (100% RDF + Hand Weeding). Results indicated that T₇ (Hand Weeding) was the most effective in reducing total weed density and provided complete suppression of dominant weed species while cost intensive. Among the herbicide-based treatments, T₃ showed superior performance, significantly reducing weed density and achieving the highest weed control efficiency due to its broad-spectrum activity. These findings suggest that the strategic use of herbicide combinations can effectively manage weed populations and prevent resistance buildup, thereby supporting sustainable black rice production in Eastern Uttar Pradesh.

Keywords: Weed dynamics; efficacy; herbicide; rice cultivation.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important crop plants globally, serving as the main nutritional staple for approximately 40% of the world's population (Singh et al., 2023). It is a staple cereal crop for over half the global population, with Asia accounting for 90% of its production and consumption (FAO, 2014). Among its various types, black rice has gained significant popularity due to its exceptional nutritional profile and health benefits. Also known as purple rice, forbidden rice, heaven rice, imperial rice, king's rice, and prized rice, black rice is recognized for its rich anthocyanin content, which gives it a distinct purplish-black color and potent antioxidant properties. The general populace was prohibited from cultivating, storing, or consuming black rice without official authorization (Kushwaha, 2016). Due to its rarity and exceptional nutritional properties, black rice was believed to promote longevity and overall health. India, one of the largest rice-growing countries, cultivates rice over an area of 42.5 million hectares, contributing to 29% of the country's calorie intake with an annual production of 85.59 million tons and an average yield of 2.2 tons per hectare. It is one of the most important cereal crop grown under different aquatic condition and mostly under submergence or variable ponding conditions. It belongs to family Poaceae (Gramineae). It accounts 43% of total food grain production and 55% of cereal production in the country. It is a high caloric food, which contain 75% starch, 6-7% protein, 2- 2.5% fat, 0.8% cellulose and 5-9% ash.

Weed infestation remains a persistent challenge in crop production, significantly influenced by

agricultural practices such as crop rotation, tillage, fertilization, row spacing, and herbicide use, as well as by soil properties and environmental conditions (Das, 2008). Effective weed control has been shown to enhance grain yield by up to 85.5% (Mukherjee and Singh, 2005). While a single herbicide application can initially suppress weed populations effectively, the repeated and continuous use of the same herbicide often leads to the development of herbicide-resistant weed biotypes. Moreover, the residual activity of many herbicides is generally limited, with persistence in the soil typically not extending beyond 30 days after transplanting (DAT) (Chauhan et al., 2012). The Clearfield rice system, for instance, involves the cultivation of imidazolinone-resistant rice, allowing targeted weed control with specific herbicides (Jabran & Chauhan, 2015). Despite advancements in herbicide technology, challenges such as the rapid evolution of herbicide-resistant weed biotypes, regulatory restrictions on herbicide use, and environmental concerns persist. Future research should focus on developing novel herbicides with unique mechanisms of action, enhancing precision agriculture techniques, and promoting sustainable weed management practices. Integrated herbicide management in rice integrates multiple strategies to enhance weed control efficiency while mitigating environmental risks. A holistic approach involving herbicide rotation, precision application, and integrated weed management is essential to ensure sustainable rice production and food security. The major weed flora like *Echinochloa colona* and *E. crusgalli*, *Ammannia baccifera*, *Cyperus iria*, *Cyperus difformis*, *Eclipta alba*, *Fimbristylis miliacea*, *Ischaemum rugosum*, *Leptochloa chinensis*, *Monochoria vaginalis* and *Paspalum distichum* were found the most abundant in rice crop (Singh et al. 2016). Yield

losses due to weed infestation typically range between 15% and 20%, but under severe conditions, they may exceed 50%, depending on weed species composition and density (Das et al., 2015). Rice yield loss due to competition with *Echinochloa colona* (L.) Link, *Leersia hexandra* Sw., *Cyperus iria* L., *Ludwigia parviflora* L., and *Monochoria vaginalis* (Burm f.) C. Presl. Ex Kunth was 64% compared with weed-free control (Biswas et al., 2023). Sequential application of herbicides, strategically timed to target weed emergence at various crop growth stages, can effectively manage diverse weed populations. Recent advancements in weed management emphasize the use of low-dose, high-efficacy herbicides. Such approaches not only reduce the overall herbicide load on the environment but also enhance cost-efficiency and simplify application practices (Mishra et al., 2023). At present no single practices either use of herbicide or manual weeding method is effective in eliminating weeds (Parthipan et al., 2013). Sequential pre- and post-emergence herbicide application significantly improved yield and yield attributes of aromatic rice compared to single applications (Raj et al., 2016). This may lead to considerably improved rice yields by minimizing nutrient losses to the environment and managing the nutrient supply. Studies on the bioefficacy of Triafamone and Bispyribac Sodium for weed control in transplanted rice are limited. Therefore, the present study was conducted to evaluate its effectiveness and safety, and to determine the optimal application dose for recommendation to rice growers.

2. MATERIALS AND METHODS

The present investigation was conducted at the Agricultural Research Farm, Institute of Agriculture and Natural Sciences, Deen Dayal Upadhyaya Gorakhpur University, UP India during June 2024 - November 2024 *Kharif* season. It is situated in between 26.45' north latitude and 83.23' east longitude. The elevation of Gorakhpur above sea level is 75 meters. The annual rainfall is 1500 mm obtained mostly during the monsoon *i.e.* July to September, with a few occasional showers during the winter season. The soil was sandy loam to clay loam in texture, with low organic carbon content and medium levels of available nitrogen and phosphorus, while potassium was found to be low. Data were subjected to statistical analysis for level of significance among various treatments as suggested by Gomez & Gomez (1984).

2.1 Weed Density

Data on weed population were collected from each plot at 60 and 120 DAT of the rice plants. Weeds grown in the quadrat (1 m × 1 m) were identified and the quadrat was placed randomly at three places in each plot. The weeds within the quadrat were counted species-wise. Observations on weed density were recorded using quadrat method. Frequencies of different weeds were determined and density of each species was calculated according to Odum (1971).

$$\text{Weed density (Number per sq. m)} = \frac{\text{Total number of weeds}}{\text{Total surveyed unit area}}$$

2.2 Weed Control Efficacy (%)

Weed control efficiency of different weed control treatments was calculated using the following formula developed by Sawant and Jadhav (1985):

$$\text{Weed control efficiency (\%)} = \frac{DWC - DWT}{DWC} \times 100$$

Where,
DWC = Dry weight of weeds in the weedy check
DWT = Dry weight of weeds in the weed management treatment

3. RESULTS AND DISCUSSION

3.1 Diversity of Infested Weed Species

The general conditions for the cultivation of Kala Namak aromatic rice also facilitate the growth of various weed species. These weeds compete with crop plants for essential resources such as light, water, and nutrients, leading to substantial yield reductions. Weed competition intensifies as the weed population increases and their growth rate surpasses that of the crop plants. In the experimental plots where neither herbicides nor hand weeding were employed, a diverse weed flora was observed. A total of nine weed species, representing six botanical families, were identified in the field (Table 1). The majority of these species exhibited an annual life cycle, while a few were classified as perennials. The dominance of weed species from the Cyperaceae and Poaceae families suggests their strong adaptability to the agroecological conditions of the study area. Previous studies have also documented similar weed flora in rice-

growing ecosystems viz. *Echinochloa crusgalli*, *Scirpus maritimus*, *Monochoria vaginalis*, *Cyperus difformis*, *Cynodon dactylon*, *Marsilea minuta*, *Ludwigia octovalvis*, *Nymphaea nouchali*, and *Desmodium trifolium*. The slight variations observed in the present study compared to previous reports may be attributed to differences in seasonal conditions, soil properties, and geographic location.

The study presented in table 2 revealed significant variations in the effectiveness of different weed management treatments in controlling weed infestation in Kala Namak aromatic rice fields at 60 days after transplanting (DAT). As presented in Table 3, the untreated control (T1), which received 100% RDF but no herbicide application or hand weeding, exhibited the highest total weed density (26.23 plants/m²). Among the dominant weed species, *Cyperus iria* (6.67 plants/m²) and *Cyperus rotundus* (3.34 plants/m²) were most prevalent, underscoring the intense weed competition in unmanaged conditions, which can severely impact crop growth and yield. Conversely, herbicide-treated plots demonstrated a significant reduction in weed density. The most effective treatment was T7 (100% RDF + Hand Weeding), which recorded the lowest total weed density (2.52 plants/m²), successfully suppressing all weed species. Among the herbicide-based treatments, T3 (100% RDF + Butachlor @750 g a.i./ha + Bispyribac Sodium @150 g a.i./ha) proved to be the most effective, reducing weed density to 9.84 plants/m² and demonstrating broad-spectrum efficacy against both grassy and broadleaf weeds. Similarly, T4 (100% RDF + Butachlor @1500 g a.i./ha) and T2 (100% RDF + Butachlor @750 g a.i./ha + Triafamone @40 g a.i./ha) recorded lower weed densities of 13.72 and 14.84 plants/m², respectively, indicating their suitability for integrated weed management strategies. Other treatments, such as T5 (100% RDF + Triafamone @40 g a.i./ha) and T6 (100% RDF + Bispyribac Sodium @300 g a.i./ha), resulted in moderately higher weed densities of 15.24 and 15.49 plants/m², respectively. This suggests that a combination of pre-emergence and post-emergence herbicides provides better weed control than standalone applications. The results clearly indicate that T3, T4, and T2 were among the most effective herbicide treatments, significantly reducing weed infestation compared to the untreated control (T1). However, while

manual hand weeding (T7) achieved the highest level of weed suppression, it remains labor-intensive and less practical for large-scale cultivation. These findings highlight the importance of an integrated weed management approach, where herbicide combinations such as Butachlor, Bispyribac Sodium, and Triafamone can effectively suppress weeds and reduce competition, ultimately improving crop productivity in Kala Namak rice cultivation.

The effectiveness of various herbicide treatments in controlling weed infestation at 60 days after treatment (DAT) varied significantly, as shown in Table 3. The untreated control (T1) exhibited the highest total weed density (26.23 plants/m²), with *Cyperus iria* (6.67 plants/m²) and *Cyperus rotundus* (3.34 plants/m²) emerging as the dominant species. This indicates the intense competition posed by weeds in the absence of proper management, which can negatively affect crop growth and yield. In contrast, herbicide-treated plots exhibited a notable decline in weed density. The most effective weed management strategy was T7 (Hand Weeding), which recorded the lowest weed density (2.52 plants/m²) and effectively suppressed all weed species. Among the herbicide-based treatments, T3 (Butachlor @750 g a.i./ha + Bispyribac Sodium @150 g a.i./ha) demonstrated the highest weed suppression, reducing total weed density to 9.84 plants/m². This highlights its broad-spectrum efficacy in controlling both broadleaf and grassy weeds. Similarly, T4 (Butachlor @1500 g a.i./ha) and T2 (Butachlor @750 g a.i./ha + Triafamone @40 g a.i./ha) achieved weed densities of 13.72 and 14.84 plants/m², respectively, reinforcing their effectiveness in integrated weed management. Other treatments, such as T5 (Triafamone @40 g a.i./ha) and T6 (Bispyribac Sodium @300 g a.i./ha), recorded slightly higher weed densities of 15.24 and 15.49 plants/m², respectively. These results suggest that a combination of pre-emergence and post-emergence herbicides is more effective than individual applications. The findings clearly indicate that T3, T4, and T2 were the most effective herbicide treatments, significantly reducing weed pressure compared to the untreated control (T1). However, while manual hand weeding (T7) provided the best weed control, it remains labor-intensive and may not be feasible for large-scale farming.

Table 1. Diversity of infested weed species in the experimental plot

S.N	English name	Scientific name	Family name	Life cycle
	Barnyard grass	<i>Echinochloa crusgalli</i> L.	Poaceae	Annual
	Shusni Shak	<i>Marsilea crenata</i>	Marsileaceae	Annual
	White eclipta	<i>Eclipta alba</i>	Asteraceae	Annual
	Khetpapri	<i>Lindemia procumbens</i>	Scrophulariaceae	Annual
	Duck weed	<i>Sagittaria guyanensis</i>	Alismataceae	Annual
	Nutsedge	<i>Cyperus michelianus</i>	Cyperaceae	Annual
	Nutgrass	<i>Cyperus rotundus</i>	Cyperaceae	Perennial
	Paddy Motha	<i>Cyperus iria</i>	Cyperaceae	Perennial
	Jungle rice	<i>Echinochloa colonum</i>	Poaceae	Perennial

Table 2. Effect of herbicide on Weed density (Number m⁻²) AT 30 DAT

Treatment	<i>E.crusgalli</i>	<i>M. crenata</i>	<i>E. alba</i>	<i>L. procumbens</i>	<i>S. guyanensis</i>	<i>C. michelianus</i>	<i>C. rotundus</i>	<i>C. iria</i>	<i>E.colonum</i>	Total
T1	3.63	2.54	2.18	1.46	3.27	3.27	3.64	7.27	1.33	28.59
T2	2.43	1.70	1.33	1.21	1.53	2.83	1.43	2.63	1.09	16.18
T3	1.42	0.25	1.42	1.09	1.42	1.53	1.09	1.09	1.43	10.73
T4	1.42	1.85	1.82	1.09	1.98	1.09	2.18	2.43	1.09	14.95
T5	1.46	1.33	1.09	1.09	1.42	1.85	2.43	3.64	2.30	16.61
T6	2.32	1.35	2.10	1.53	1.41	1.33	1.74	2.55	2.55	16.88
T7	0.37	0.25	0.36	0.36	0.33	0.24	0.36	0.34	0.14	2.75

Table 3. Effect of herbicide on Weed density (Number m⁻²) AT 60 DAT

Treatment	<i>E.crusgalli</i>	<i>M. crenata</i>	<i>E. alba</i>	<i>L. procumbens</i>	<i>S. guyanensis</i>	<i>C. michelianus</i>	<i>C. rotundus</i>	<i>C. iria</i>	<i>E.colonum</i>	Total
T1	3.33	2.33	2.00	1.34	3.00	3.00	3.34	6.67	1.22	26.23
T2	2.23	1.56	1.22	1.11	1.40	2.60	1.31	2.41	1.00	14.84
T3	1.30	0.23	1.30	1.00	1.30	1.40	1.00	1.00	1.31	9.84
T4	1.30	1.70	1.67	1.00	1.82	1.00	2.00	2.23	1.00	13.72
T5	1.34	1.22	1.00	1.00	1.30	1.70	2.23	3.34	2.11	15.24
T6	2.13	1.24	1.93	1.40	1.29	1.22	1.60	2.34	2.34	15.49
T7	0.34	0.23	0.33	0.33	0.30	0.22	0.33	0.31	0.13	2.52

Table 4. Effect of herbicide on Weed density (Number m⁻²) AT 90 DAT

Treatment	<i>E.crusgalli</i>	<i>M. crenata</i>	<i>E. alba</i>	<i>L. procumbens</i>	<i>S. guyanensis</i>	<i>C. michelianus</i>	<i>C. rotundus</i>	<i>C. iria</i>	<i>E.colonum</i>	Total
T1	2.36	1.65	1.42	0.95	2.13	2.13	2.37	4.74	0.87	18.62
T2	1.58	1.11	0.87	0.79	0.99	1.85	0.93	1.71	0.71	10.54
T3	0.92	0.16	0.92	0.71	0.92	0.99	0.71	0.71	0.93	6.99
T4	0.92	1.21	1.19	0.71	1.29	0.71	1.42	1.58	0.71	9.74
T5	0.95	0.87	0.71	0.71	0.92	1.21	1.58	2.37	1.50	10.82
T6	1.51	0.88	1.37	0.99	0.92	0.87	1.14	1.66	1.66	11.00
T7	0.24	0.16	0.23	0.23	0.21	0.16	0.23	0.22	0.09	1.79

Table 5. Effect of herbicide on Weed density (Number m⁻²) AT 120 DAT

Treatment	<i>E.crusgalli</i>	<i>M. crenata</i>	<i>E. alba</i>	<i>L. procumbens</i>	<i>S. guyanensis</i>	<i>C. michelianus</i>	<i>C. rotundus</i>	<i>C. iria</i>	<i>E.colonum</i>	Total
T1	0.97	0.68	0.58	0.39	0.87	0.87	0.97	1.94	0.36	7.64
T2	0.65	0.45	0.36	0.32	0.41	0.76	0.38	0.70	0.29	4.32
T3	0.38	0.07	0.38	0.29	0.38	0.41	0.29	0.29	0.38	2.86
T4	0.38	0.49	0.49	0.29	0.53	0.29	0.58	0.65	0.29	3.99
T5	0.39	0.36	0.29	0.29	0.38	0.49	0.65	0.97	0.61	4.44
T6	0.62	0.36	0.56	0.41	0.38	0.36	0.47	0.68	0.68	4.51
T7	0.10	0.07	0.10	0.10	0.09	0.06	0.10	0.09	0.04	0.73

Table 6. Weed control efficacy of different herbicide on weed control at different interval

S.N	Treatments	30 DAT	60 DAT	90 DAT	120 DAT
T1	100% RDF + Weedy Check	2.50	2.90	2.93	2.97
T2	100% RDF + Butachlor @750 g a.i/ha + Triafamone 40 g a.i/ha	64.40	74.83	75.57	76.33
T3	100% RDF + Butachlor@750 g a.i/ha + Bispribac Sodium @150 g a.i/ha	74.43	86.50	87.37	88.20
T4	100% RDF + Butachlor @1500 g a.i/ha	47.13	54.77	55.30	55.87
T5	100% RDF + Triafamone @ 40 g a.i/ha	59.40	69.03	69.73	70.43
T6	100% RDF + Bispribac sodium @300 g a.i/ha	64.17	74.53	75.30	76.03
T7	100% RDF + Weed (by Hand Weeding)	96.93	100.00	89.93	87.27
	C.D.	5.819	6.558	6.795	6.835
	SE(m)	1.868	2.105	2.181	2.194
	SE(d)	2.642	2.977	3.084	3.103
	C.V.	5.538	5.517	5.797	5.819
	F test	S	S	S	S

The effectiveness of different herbicide treatments in controlling weed infestation at 90 days after treatment (DAT) varied significantly, as shown in Table 4. The untreated control (T1) exhibited the highest total weed density (18.62 plants/m²), with *Cyperus iria* (4.74 plants/m²) and *Cyperus rotundus* (2.37 plants/m²) being the most dominant weed species. This indicates the persistent weed competition in the absence of any weed management, which can negatively impact crop productivity. Herbicide-treated plots demonstrated a significant reduction in weed density. The most effective treatment was T7 (Hand Weeding), which recorded the lowest weed density (1.79 plants/m²), effectively suppressing all weed species. Among the herbicide-based treatments, T3 (Butachlor @750 g a.i./ha + Bispyribac Sodium @150 g a.i./ha) showed the highest weed suppression, reducing total weed density to 6.99 plants/m², highlighting its broad-spectrum efficacy against both grassy and broadleaf weeds. Similarly, T4 (Butachlor @1500 g a.i./ha) and T2 (Butachlor @750 g a.i./ha + Triafamone @40 g a.i./ha) achieved weed densities of 9.74 and 10.54 plants/m², respectively, demonstrating their effectiveness in integrated weed management. Other treatments, such as T5 (Triafamone @40 g a.i./ha) and T6 (Bispyribac Sodium @300 g a.i./ha), resulted in moderately higher weed densities of 10.82 and 11.00 plants/m², respectively. These findings suggest that a combination of pre-emergence and post-emergence herbicides is more effective than individual applications. The results indicate that T3, T4, and T2 were the most effective herbicide treatments, significantly reducing weed infestation compared to the untreated control (T1). However, while manual hand weeding (T7) provided the best weed control, it remains labor-intensive and less feasible for large-scale farming.

The effectiveness of different herbicide treatments in controlling weed infestation at 120 days after treatment (DAT) varied significantly, as shown in Table 5. The untreated control (T1) recorded the highest total weed density (7.64 plants/m²), with *Cyperus iria* (1.94 plants/m²) and *Cyperus rotundus* (0.97 plants/m²) being the most dominant species. Although weed density was lower at 120 DAT compared to earlier observations, the persistence of certain weed species in the untreated plots highlights the long-term competitive effects of weeds on crop growth and yield. Among the weed management strategies, T7 (Hand Weeding) was the most effective, achieving the lowest total weed density

(0.73 plants/m²), effectively suppressing all weed species. Among the herbicide treatments, T3 (Butachlor @750 g a.i./ha + Bispyribac Sodium @150 g a.i./ha) recorded the lowest weed density (2.86 plants/m²), confirming its broad-spectrum efficacy in controlling both grassy and broadleaf weeds over a longer period. This was followed by T4 (Butachlor @1500 g a.i./ha) and T2 (Butachlor @750 g a.i./ha + Triafamone @40 g a.i./ha), which had total weed densities of 3.99 and 4.32 plants/m², respectively, indicating their effectiveness in sustained weed suppression. Other treatments, such as T5 (Triafamone @40 g a.i./ha) and T6 (Bispyribac Sodium @300 g a.i./ha), resulted in moderately higher weed densities of 4.44 and 4.51 plants/m², respectively, suggesting that while effective, these individual herbicides did not provide as strong or prolonged weed control as the combined herbicide treatments. These results demonstrate that T3, T4, and T2 were the most effective herbicide treatments, significantly reducing weed pressure compared to the untreated control (T1). However, while manual hand weeding (T7) provided the best weed control, it remains labor-intensive and impractical for large-scale farming.

The efficacy of different herbicide treatments in controlling weed infestation at various growth stages of Kala Namak aromatic rice varied significantly, as shown in Table 6. The untreated control (T1), which received 100% RDF without herbicide application or hand weeding, exhibited the lowest weed control efficiency, ranging from 2.50% at 30 DAT to 2.97% at 120 DAT, highlighting the severe competition posed by weeds under unmanaged conditions. Among the herbicide treatments, T3 (100% RDF + Butachlor @750 g a.i./ha + Bispyribac Sodium @150 g a.i./ha) demonstrated the highest weed control efficiency, reaching 74.43% at 30 DAT and increasing to 88.20% at 120 DAT, indicating its superior ability to suppress both grassy and broadleaf weeds over an extended period. Other effective treatments included T2 (100% RDF + Butachlor @750 g a.i./ha + Triafamone @40 g a.i./ha), which achieved a weed control efficiency of 64.40% at 30 DAT and 76.33% at 120 DAT, and T6 (100% RDF + Bispyribac Sodium @300 g a.i./ha), which showed a similar trend with values ranging from 64.17% at 30 DAT to 76.03% at 120 DAT. T5 (100% RDF + Triafamone @40 g a.i./ha) provided moderate weed control, reaching 70.43% at 120 DAT, while T4 (100% RDF + Butachlor @1500 g a.i./ha) showed relatively lower efficacy, with a maximum of

55.87% at 120 DAT, suggesting that higher doses of a single herbicide may not be as effective as a combination approach. The most effective weed management was observed in T7 (100% RDF + Hand Weeding), which achieved 96.93% weed control efficiency at 30 DAT, reaching 100% at 60 DAT, demonstrating its ability to completely eliminate weed competition in the early growth stages. However, its efficiency slightly declined to 89.93% at 90 DAT and 87.27% at 120 DAT, likely due to weed resurgence after manual removal. While hand weeding remains the most effective method, its labor-intensive nature makes it impractical for large-scale farming. Overall, T3 (Butachlor @750 g a.i./ha + Bispyribac Sodium @150 g a.i./ha) emerged as the most effective herbicide treatment, providing long-lasting weed control comparable to hand weeding. The findings emphasize that integrating herbicide applications with effective weed management strategies is crucial for improving weed control efficiency and similar findings were also reported by Singh et al., (2016) and Ramesha et al., (2017).

4. CONCLUSION

The study clearly demonstrated that effective weed management significantly influences weed density and control efficiency in transplanted black rice under Eastern Uttar Pradesh conditions. The untreated control consistently recorded the highest weed density and the lowest weed control efficiency across all growth stages, indicating severe competition from dominant weed species like *Cyperus iria* and *Cyperus rotundus*. Among all treatments, hand weeding proved to be the most effective strategy, achieving the lowest weed density and maximum suppression of all weed species throughout the crop cycle. However, 100% RDF + Butachlor @750 g a.i./ha + Bispyribac Sodium @150 g a.i./ha emerged as the most efficient, consistently reducing total weed density and achieving the highest weed control efficiency reaching up to 88.20%. These findings highlight the importance of integrated weed management approaches, particularly the use of herbicide combinations, in achieving sustainable and broad-spectrum weed control in black rice cultivation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image

generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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