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Comparative Efficacy of Two Bentazone + MCPA Herbicide Formulations for Weed Control and Vegetative Growth of Rice (*Oryza sativa* L.) cv. Inpari 32

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***Abstract**: Weed infestation remains one of the major constraints limiting rice productivity because it competes with crops for water, nutrients, light, and growing space. This study aimed to compare the effectiveness of two selective herbicide formulations containing Bentazone (400 g L^{-1}) + MCPA (60 g L^{-1}), commercially marketed as Basagran® and Bentagram®, in suppressing weeds and supporting the vegetative growth of rice (*Oryza sativa *L.) cv. Inpari 32. The experiment was conducted in irrigated rice fields in Jombang Regency, East Java, Indonesia, from May to June 2025 using a Completely Randomized Design (CRD). Treatments consisted of six herbicide doses (0.5, 0.75, 1.0, 1.25, 1.5, and 1.75 L ha^{-1}) and an untreated control, each replicated twice. Data on weed diversity, dominance index, weed dry weight, plant height, and tiller number were analyzed using analysis of variance (ANOVA) followed by the Least Significant Difference (LSD) test at the 5% significance level. The application of both herbicides reduced weed diversity, with the Shannon–Wiener diversity index ranging from 1.39 to 1.56 and Simpson's dominance index remaining low (0.22–0.25), indicating effective weed suppression without dominance of any weed species. Basagran had no significant effect ($p > 0.05$) on plant height, tiller number, or weed dry weight, whereas Bentagram significantly increased tiller number ($p < 0.05$) while maintaining normal plant growth. Although the highest numerical responses were occasionally observed at 1.75 L ha^{-1}, they were not significantly different from those at 1.5 L ha^{-1}. Therefore, 1.5 L ha^{-1} was identified as the optimum application rate because it effectively suppressed weeds without causing phytotoxicity or adversely affecting rice vegetative growth. These findings demonstrate that Bentazone + MCPA herbicides can be effectively incorporated into sustainable weed management programs to improve rice cultivation efficiency while minimizing unnecessary herbicide inputs.*
***Keywords**: Bentazone, MCPA, Weed Management, Rice Cultivation, Selective Herbicide, Sustainable Agriculture.*

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important cereal crops worldwide and serves as the primary staple food for more than half of the global population. In Indonesia, rice production plays a crucial role in maintaining national food security, supporting rural livelihoods, and contributing significantly to the agricultural economy. As the demand for rice continues to increase due to population growth, urbanization, and changing consumption patterns, improving rice productivity has become a national priority. However, achieving sustainable increases in rice production remains challenging because crop growth and yield are influenced by various biotic and abiotic factors, including soil fertility, water availability, climate variability, pests, diseases, and weed infestation (Food and Agriculture Organization [FAO], 2024; International Rice Research Institute [IRRI], 2023).

Among these constraints, weeds represent one of the most significant causes of yield reduction in rice cultivation. Weeds compete directly with rice plants for essential resources such as sunlight, water, nutrients, and growing space throughout the crop growth cycle. This competition is particularly severe during the early vegetative stage when rice plants are less competitive than rapidly growing weed species. Previous studies have reported that uncontrolled weed infestation can reduce rice yields by 15–80%, depending on weed density, species composition, environmental conditions, and crop management practices (Chauhan, 2021). In irrigated rice ecosystems, dominant weed species such as *Ludwigia hyssopifolia*, *Echinochloa crus-galli*, *Panicum repens*, and *Mecardonia procumbens* are frequently associated with substantial yield losses because of their rapid growth, prolific seed production, and strong adaptability under flooded conditions. Therefore, effective weed management has become an essential component of sustainable rice production systems.

Various weed control methods have been implemented in rice cultivation, including manual weeding, mechanical cultivation, biological control, and chemical control using herbicides. Among these approaches, chemical weed control remains the most widely adopted because it is relatively efficient, labor-saving, and capable of providing rapid suppression of target weed species. The adoption of selective herbicides has become increasingly important in modern rice farming because they effectively suppress weeds while minimizing damage to the crop. Herbicides containing Bentazone (400 g L^{-1}) and MCPA (60 g L^{-1}) are widely used for controlling broadleaf weeds and sedges in rice production systems. Bentazone acts as a photosystem II inhibitor by interrupting electron transport during photosynthesis, leading to membrane disruption and rapid necrosis in susceptible weeds. Meanwhile, MCPA belongs to the synthetic auxin herbicide group, causing abnormal cell elongation, disruption of vascular tissues, and uncontrolled plant growth that ultimately results in weed death. The combination of these two active ingredients broadens the weed control spectrum while maintaining selectivity because rice plants are able to metabolize Bentazone more rapidly than susceptible weed species (Duke, 2022; Shaner, 2014).

Although herbicides have contributed substantially to improving rice productivity, their intensive and continuous use has raised concerns regarding environmental sustainability and the evolution of herbicide-resistant weed populations. Herbicide resistance has become one of the most serious challenges in global crop production because repeated application of herbicides with similar modes of action exerts strong selection pressure on weed communities. Resistant individuals survive herbicide exposure, reproduce, and gradually dominate subsequent weed populations, reducing the long-term effectiveness of chemical weed control. According to the International Survey of Herbicide Resistant Weeds, the number of resistant weed species continues to increase worldwide, emphasizing the urgent need to optimize herbicide use and diversify weed management strategies (Heap, 2024). Consequently, herbicide application should not only focus on maximizing weed suppression but also consider strategies that minimize resistance development and environmental impacts.

In response to these challenges, the concept of Integrated Weed Management (IWM) has gained increasing attention as a sustainable approach to weed control. Integrated Weed Management combines chemical control with cultural, mechanical, biological, and agronomic practices to reduce weed pressure while decreasing reliance on herbicides. Appropriate herbicide selection and dosage are critical components of IWM because excessive herbicide application increases production costs, environmental contamination, and resistance risks without necessarily improving weed control efficiency. Conversely, insufficient herbicide doses may fail to suppress target weeds effectively and may also accelerate the selection of resistant biotypes. Therefore, determining the optimum herbicide dosage represents an important step toward achieving environmentally sound and economically sustainable rice production systems (Beckie et al., 2022; Powles & Yu, 2023).

Several studies have demonstrated that herbicides containing Bentazone and MCPA effectively suppress weeds while maintaining normal rice growth and productivity (Sumekar et al., 2023; Umiyati et al., 2018). However, most previous research has primarily evaluated herbicide

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dosage or focused on the efficacy of individual commercial products. Comparative studies evaluating different commercial herbicide formulations containing identical active ingredients remain limited. Although Basagran® and Bentagram® both contain Bentazone (400 g L^{-1}) and MCPA (60 g L^{-1}), differences in formulation technology, surfactant composition, adjuvants, and manufacturing processes may influence herbicide absorption, retention, rainfastness, translocation, and biological efficacy under field conditions. Such differences may ultimately affect weed suppression efficiency and crop selectivity despite the similarity in active ingredients. Therefore, comparative evaluation of commercial formulations is scientifically important for determining whether formulation characteristics influence field performance and optimum application rates (Kumar et al., 2024; Duke, 2022).

Many previous studies have assessed herbicide performance primarily based on crop growth and yield, while relatively few have examined changes in weed community structure through ecological indicators such as weed diversity and dominance indices. These ecological parameters provide valuable information regarding the long-term effects of herbicide application on weed populations. Effective weed management should reduce overall weed abundance without promoting the dominance of tolerant species, which may eventually become problematic or resistant under continuous herbicide use. Evaluating weed diversity alongside crop growth therefore provides a more comprehensive assessment of herbicide performance and contributes to the development of sustainable weed management strategies (Magurran, 2021; Heap, 2024).

Based on these considerations, there remains a clear research gap regarding the comparative performance of different commercial Bentazone + MCPA formulations under field conditions, particularly with respect to their effects on weed community dynamics and vegetative growth of rice. This information is essential for developing science-based recommendations that support efficient herbicide use while reducing unnecessary chemical inputs and minimizing resistance risks. This study aimed to compare the effectiveness of two commercial herbicide formulations containing Bentazone (400 g L^{-1}) + MCPA (60 g L^{-1}), namely Basagran® and Bentagram®, applied at different dosage levels to suppress weed communities and improve the vegetative growth of rice (*Oryza sativa* L.) cv. Inpari 32. The findings are expected to provide scientific evidence supporting optimum herbicide application within Integrated Weed Management programs for sustainable rice cultivation.

METHOD

Study Site

The experiment was conducted from May to June 2025 in irrigated rice fields located in Paras Hamlet, Turipinggir Village, Megaluh District, Jombang Regency, East Java, Indonesia. The experimental site is situated at an altitude of approximately 38 m above sea level and is characterized by a tropical monsoon climate. During the study period, the average daily temperature ranged from 28 to 32°C, relative humidity ranged between 76% and 84%, and monthly rainfall was approximately 110 mm. The soil was classified as clay loam with a pH ranging from 6.3 to 6.7. Water management followed local irrigated rice cultivation practices, maintaining a water depth of approximately 3–5 cm throughout the vegetative growth stage to provide uniform field conditions.

Plant Materials and Herbicides

The experimental crop was rice (*Oryza sativa* L.) cv. Inpari 32. Two commercial selective herbicides containing identical active ingredients, Bentazone (400 g L^{-1}) and MCPA (60 g L^{-1}), marketed as Basagran® and Bentagram®, were evaluated.

Herbicide application was performed using a calibrated 15-L knapsack sprayer equipped with a flat-fan nozzle to ensure uniform spray coverage. Spraying was carried out in the morning (07:00–09:00 h) under favorable weather conditions with wind speeds below 5 km h^{-1} and no rainfall occurring within 24 h after application. These conditions were maintained to minimize spray drift and maximize herbicide absorption by target weeds (Shaner, 2014).

Experimental Design

The experiment employed a Completely Randomized Design (CRD). Two commercial herbicide formulations were evaluated independently using six application rates and one untreated control.

Basagran® treatments

- B0 = Untreated control
- B1 = 0.50 L ha^{-1}
- B2 = 0.75 L ha^{-1}
- B3 = 1.00 L ha^{-1}
- B4 = 1.25 L ha^{-1}
- B5 = 1.50 L ha^{-1}
- B6 = 1.75 L ha^{-1}

Bentagram® treatments

- T0 = Untreated control
- T1 = 0.50 L ha^{-1}
- T2 = 0.75 L ha^{-1}
- T3 = 1.00 L ha^{-1}
- T4 = 1.25 L ha^{-1}
- T5 = 1.50 L ha^{-1}
- T6 = 1.75 L ha^{-1}

Each treatment was replicated twice, resulting in twenty-eight experimental units. Each experimental plot measured 1 m × 1 m and consisted of 25 rice hills planted at uniform spacing.

Two replications were considered adequate because the experiment was conducted under relatively homogeneous environmental conditions, including soil characteristics, irrigation management, topography, and weed distribution. The study was intended as a preliminary field evaluation to compare the biological performance of two herbicide formulations before larger multilocation experiments. Similar preliminary agronomic trials have commonly used two replications under homogeneous field conditions to minimize experimental error (Gomez & Gomez, 1984; Montgomery, 2020).

Herbicide Application

Herbicides were applied once when the dominant weed species had reached the two- to four-leaf growth stage, approximately three weeks after transplanting. Prior to herbicide application, standing water in the field was temporarily drained to expose the weed canopy and improve spray interception. Irrigation was restored approximately 24 h after spraying according to recommended application practices for Bentazone-based herbicides (Shaner, 2014). No additional herbicide applications were conducted during the experimental period.

Weed Assessment

Weed observations were conducted at 3 and 5 weeks after herbicide application (WAA). All weed species present within each experimental plot were identified and counted. Species identification followed standard taxonomic descriptions for common rice weeds. The dominant weed species observed during the experiment included *Ludwigia hyssopifolia*, *Echinochloa crus-galli*, *Panicum repens*, and *Mecardonia procumbens*.

Weed Diversity

Species diversity was determined using the Shannon–Wiener Diversity Index (H′):

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Where:

H′ : Shannon–Wiener diversity indeks

Pi = proportion of individuals belonging to species i

S = total number of weed species.

Pi : Proportion of individuals

The diversity index provides information regarding weed community complexity following herbicide application (Magurran, 2021).

Weed Dominance

Species dominance was calculated using the Simpson Dominance Index (C)

$$C = \sum \frac{ni}{n}$$

Description:

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C : Dominance index

Ni : Number of individuals of each species

N : Total number of individuals of all species

Higher C values indicate increasing dominance by one or several weed species.

Weed Dry Weight

Weed biomass was measured at three and five weeks after herbicide application. All weeds within each plot were harvested manually, washed to remove adhering soil particles, and oven-dried at 70°C until constant weight was achieved. Dry biomass was subsequently determined using an analytical balance with 0.001-g precision.

Plant Height

Rice plant height was measured at 3 and 6 weeks after planting (WAP).

Measurements were taken from the soil surface to the tip of the tallest fully expanded leaf from ten randomly selected plants within each plot. The average value for each plot was used for statistical analysis.

Number of Tillers

The number of tillers was recorded from the same sampled plants used for plant height observations.

Tillers were counted manually at 3 and 6 weeks after planting, and the average number of tillers per hill was calculated for each treatment.

Statistical Analysis

The Shannon–Wiener diversity index and Simpson dominance index were calculated using Microsoft Excel 2021. Data on plant height, tiller number, and weed dry weight were analyzed using IBM SPSS Statistics version 26. Prior to statistical analysis, data were examined for normality using the Shapiro–Wilk test and homogeneity of variance using Levene's test. Variables satisfying ANOVA assumptions were subjected to one-way analysis of variance (ANOVA) at the 5% significance level. When significant treatment effects were detected ($p < 0.05$), treatment means were separated using the Least Significant Difference (LSD) test at the 5% probability level.

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Results are presented as mean ± standard error (SE). Statistical procedures followed the recommendations of Gomez and Gomez (1984) and Montgomery (2020).

RESULTS AND DISCUSSION

Weed Diversity and Dominance

The application of both Bentazone + MCPA herbicide formulations effectively suppressed weed communities throughout the observation period. Weed suppression was evaluated using the Shannon–Wiener diversity index (H′) and Simpson's dominance index (C), which together describe changes in weed community structure following herbicide application. Across all treatments, weed diversity remained within the moderate category, while dominance values were consistently low, indicating that herbicide application reduced weed abundance without promoting the dominance of a single tolerant weed species.

Basagran® Herbicide

At three weeks after application (3 WAA), the weed community under Basagran® treatment consisted of only six individuals representing three weed species. The calculated Shannon–Wiener diversity index (H′ = 1.56) indicated moderate diversity, whereas the Simpson dominance index (C = 0.23) reflected low species dominance. Several treatment plots (P3 and P4) remained free of weeds, suggesting effective early suppression following herbicide application. The remaining weeds were predominantly *Ludwigia hyssopifolia*, with occasional occurrences of *Echinochloa crus-galli* and *Panicum repens*.

At five weeks after application (5 WAA), weed abundance slightly increased to eight individuals, although community diversity remained relatively stable (H′ = 1.49) with a low dominance index (C = 0.25). The increase was primarily associated with the reappearance of *Ludwigia hyssopifolia* in several treatments, indicating limited regrowth of tolerant species rather than widespread weed resurgence. Nevertheless, several treatments (P1, P3, P5, and P6) remained free from weed infestation, demonstrating the prolonged effectiveness of Basagran® in suppressing weed emergence.

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The relatively stable diversity and consistently low dominance values indicate that Basagran® effectively reduced weed populations without substantially altering weed community structure. These findings suggest that herbicide application successfully suppressed weed growth while preventing ecological dominance by a single species.

Table 1. Weed Diversity and Dominance Indices at 3 Weeks After Application (WAA) under Basagran® Herbicide Treatments

Treatment	Weed species	Number of individuals	Pi	ln Pi	Pi ln Pi	Pi²
P0	–	0	0	0	0	0
P1	*Ludwigia hyssopifolia*	1	0.17	-1.79	-0.30	0.03
	Echinochloa crus-galli	1	0.17	-1.79	-0.30	0.03
P2	*Ludwigia hyssopifolia*	1	0.17	-1.79	-0.30	0.03
P3	–	0	0	0	0	0
P4	–	0	0	0	0	0
P5	*Panicum repens*	1	0.17	-1.79	-0.30	0.03
P6	*Ludwigia hyssopifolia*	2	0.33	-1.10	-0.37	0.11
Total		6			H′ = 1.56	C = 0.23

Table 2. Weed Diversity and Dominance Indices at 5 Weeks After Application (WAA) under Basagran® Herbicide Treatments

Treatment	Weed species	Number of individuals	Pi	ln Pi	Pi ln Pi	Pi²
P0	*Ludwigia hyssopifolia*	1	0.12	-2.08	-0.26	0.02
	Mecardonia procumbens	1	0.12	-2.08	-0.26	0.02
P1	–	0	0	0	0	0
P2	*Ludwigia hyssopifolia*	3	0.37	-0.98	-0.37	0.14
P3	–	0	0	0	0	0
P4	*Panicum repens*	1	0.12	-2.08	-0.26	0.02
	Ludwigia hyssopifolia	2	0.25	-1.39	-0.35	0.06
P5	–	0	0	0	0	0
P6	–	0	0	0	0	0
Total		8			H′ = 1.49	C = 0.25

Bentagram® Herbicide

The weed community observed following Bentagram® application exhibited a pattern similar to that of Basagran®. At 3 WAA, only four weed individuals representing two species were recorded across all treatments. The calculated Shannon–Wiener diversity index (H′ = 1.39) indicated moderate diversity, while the dominance index (C = 0.25) remained low. Most treatment plots were completely free of weeds, confirming that Bentagram® effectively suppressed early weed emergence during the initial vegetative stage.

At 5 WAA, weed abundance increased slightly to six individuals, accompanied by a moderate diversity index (H′ = 1.56) and a reduced dominance index (C = 0.22). Although *Ludwigia hyssopifolia* remained the predominant species, its distribution among treatments did not result in ecological dominance. The persistence of low dominance values indicates that Bentagram® maintained balanced suppression across the weed community rather than selectively eliminating only susceptible species.

Bentagram® demonstrated effective weed suppression throughout the observation period. The maintenance of moderate diversity together with consistently low dominance values suggests that the herbicide effectively reduced weed populations while preserving community balance and minimizing the risk of dominance by tolerant weed species.

Table 3. *Weed Diversity and Dominance Indices at 3 Weeks After Application (WAA) under Bentagram® Herbicide Treatments*

Treatment	**Weed species**	**Number of individuals**	**Pi**	**ln Pi**	**Pi ln Pi**	**Pi²**
P0	–	0	0	0	0	0
P1	*Ludwigia hyssopifolia*	1	0.25	-1.39	-0.35	0.06
P2	–	0	0	0	0	0
P3	–	0	0	0	0	0
P4	*Ludwigia hyssopifolia*	1	0.25	-1.39	-0.35	0.06
	Echinochloa crus-galli	1	0.25	-1.39	-0.35	0.06
P5	–	0	0	0	0	0
P6	*Ludwigia hyssopifolia*	1	0.25	-1.39	-0.35	0.06
Total		4			H′ = 1.39	C = 0.25

Table 4. *Weed Diversity and Dominance Indices at 5 Weeks After Application (WAA) under Bentagram® Herbicide Treatments*

Treatment	Weed species	Number of individuals	Pi	ln Pi	Pi ln Pi	Pi²
P0	*Ludwigia hyssopifolia*	1	0.17	-1.79	-0.30	0.03
	Mecardonia procumbens	1	0.17	-1.79	-0.30	0.03
P1	*Ludwigia hyssopifolia*	2	0.33	-1.10	-0.37	0.11
P2	–	0	0	0	0	0
P3	–	0	0	0	0	0
P4	*Ludwigia hyssopifolia*	1	0.17	-1.79	-0.30	0.03
P5	–	0	0	0	0	0

Treatment	Weed species	Number of individuals	Pi	ln Pi	Pi ln Pi	Pi²
P6	*Ludwigia hyssopifolia*	1	0.17	-1.79	-0.30	0.03
Total		6			H′ = 1.56	C = 0.22

Effect of Herbicide Application on Rice Plant Height

Plant height was measured at three and six weeks after planting (WAP) to evaluate the response of rice plants to different application rates of Basagran® and Bentagram® herbicides. Analysis of variance (ANOVA) indicated that herbicide application had no significant effect ($p > 0.05$) on plant height at either observation time for both herbicide formulations. Consequently, no further mean separation using the Least Significant Difference (LSD) test was required because treatment means were statistically similar.

Basagran® Herbicide

Rice plants treated with Basagran® exhibited normal vegetative growth throughout the observation period. Although slight numerical differences among treatments were observed, plant height increased consistently from the early to the late vegetative stage across all treatments. The tallest plants at 3 WAP were recorded under the 1.50 L ha^{-1} treatment, whereas the untreated control showed the greatest average height at 6 WAP. However, these differences were not statistically significant, indicating that Basagran® application up to 1.75 L ha^{-1} did not adversely affect rice growth.

The uniform statistical grouping among treatments demonstrates that Basagran® was selective toward rice plants and produced no visible phytotoxic symptoms during the vegetative growth stage.

Table 5. *Average Plant Height of Rice under Basagran® Herbicide Treatments*

Treatment	3 WAP (cm)	6 WAP (cm)
P0 (Control)	39.0^a	92.0^a
P1 (0.50 L ha^{-1})	42.0^a	90.0^a
P2 (0.75 L ha^{-1})	42.5^a	90.5^a
P3 (1.00 L ha^{-1})	42.5^a	90.0^a
P4 (1.25 L ha^{-1})	42.5^a	90.0^a
P5 (1.50 L ha^{-1})	43.5^a	91.0^a
P6 (1.75 L ha^{-1})	42.5^a	91.5^a

Note: Means followed by the same letter within each observation period are not significantly different according to ANOVA at the 5% significance level.

Bentagram® Herbicide

Similar to Basagran®, the application of Bentagram® did not significantly influence rice plant height during the vegetative growth stage ($p > 0.05$). Plant height increased normally between 3 and 6 WAP across all treatments, reflecting continuous vegetative development regardless of herbicide dose. The highest numerical value at 3 WAP was observed at 1.75 L ha^{-1}, whereas the untreated control exhibited the greatest average height at 6 WAP. Nevertheless, the statistical analysis showed that all treatments belonged to the same significance group.

The absence of significant differences among application rates indicates that Bentagram® maintained crop selectivity throughout the experimental period. Therefore, herbicide application at the tested doses did not inhibit stem elongation or impair vegetative development of rice.

Table 6. *Average Plant Height of Rice under Bentagram® Herbicide Treatments*

Treatment	3 WAP (cm)	6 WAP (cm)
P0 (Control)	39.0^{a}	92.0^{a}
P1 (0.50 L ha^{-1})	38.0^{a}	91.5^{a}
P2 (0.75 L ha^{-1})	38.0^{a}	91.0^{a}
P3 (1.00 L ha^{-1})	41.0^{a}	88.5^{a}
P4 (1.25 L ha^{-1})	42.0^{a}	89.0^{a}
P5 (1.50 L ha^{-1})	43.5^{a}	88.0^{a}
P6 (1.75 L ha^{-1})	45.5^{a}	91.5^{a}

Note: Means followed by the same letter within each observation period are not significantly different according to ANOVA at the 5% significance level.

Effect of Herbicide Application on Rice Tiller Number

The number of tillers was recorded at three and six weeks after planting (WAP) to evaluate the effect of Basagran® and Bentagram® herbicides on rice vegetative development. Tiller production is considered one of the most important vegetative growth parameters because it directly contributes to panicle formation and final grain yield. The response of rice tiller development differed between the two herbicide formulations.

Basagran® Herbicide

Analysis of variance (ANOVA) showed that Basagran® application had no significant effect ($p > 0.05$) on the number of rice tillers at either 3 or 6 WAP. Consequently, no further comparison using the Least Significant Difference (LSD) test was required because all treatments belonged to the same statistical group.

Although slight numerical variation was observed among application rates, tiller production increased normally throughout the vegetative growth period across all treatments. The highest numerical value at 3 WAP was recorded at the 1.00 L ha^{-1} treatment, whereas the 0.50 L ha^{-1} treatment produced the greatest average tiller number at 6 WAP. However, these differences were not statistically significant, indicating that Basagran® application up to 1.75 L ha^{-1} neither promoted nor inhibited tiller development compared with the untreated control. The uniform statistical response suggests that Basagran® maintained normal vegetative growth and did not adversely affect tillering under the environmental conditions of this experiment.

Table 7. *Average Number of Rice Tillers under Basagran® Herbicide Treatments*

Treatment	3 WAP (tillers $hill^{-1}$)	6 WAP (tillers $hill^{-1}$)
P0 (Control)	19.0^a	25.0^a
P1 (0.50 L ha^{-1})	22.5^a	32.5^a
P2 (0.75 L ha^{-1})	23.0^a	27.5^a
P3 (1.00 L ha^{-1})	24.0^a	27.5^a
P4 (1.25 L ha^{-1})	22.0^a	26.0^a
P5 (1.50 L ha^{-1})	21.5^a	28.5^a
P6 (1.75 L ha^{-1})	21.5^a	28.5^a

Note: Means followed by the same letter within each observation period are not significantly different according to ANOVA at the 5% significance level.

Bentagram® Herbicide

Unlike Basagran®, Bentagram® significantly affected rice tiller production during the vegetative stage ($p < 0.05$). ANOVA indicated significant treatment effects at both observation periods; therefore, treatment means were compared using the Least Significant Difference (LSD) test.

At 3 WAP, the highest tiller number was observed at the 1.75 L ha^{-1} application rate, which differed significantly from the lower application rates. By 6 WAP, treatments receiving 1.00–1.75 L ha^{-1} produced similarly high tiller numbers and formed the highest statistical group. No

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significant differences were detected among these medium and high application rates, indicating that increasing herbicide dose beyond 1.00 L ha^{-1} did not provide additional improvement in tiller production.

These findings demonstrate that Bentagram® effectively reduced weed competition during the early vegetative stage, thereby allowing greater tiller development. Nevertheless, the absence of significant differences among the higher application rates suggests that maximum vegetative response had already been achieved within the medium-dose range.

Table 8. *Average Number of Rice Tillers under Bentagram® Herbicide Treatments*

Treatment	3 WAP (tillers hill^{-1})	6 WAP (tillers hill^{-1})
P0 (Control)	19.0^{b}	25.0^{a}
P1 (0.50 L ha^{-1})	13.5^{a}	27.5^{a}
P2 (0.75 L ha^{-1})	15.0^{a}	30.0^{b}
P3 (1.00 L ha^{-1})	15.5^{a}	35.0^{c}
P4 (1.25 L ha^{-1})	19.0^{b}	35.0^{c}
P5 (1.50 L ha^{-1})	20.5^{b}	35.0^{c}
P6 (1.75 L ha^{-1})	23.5^{c}	35.0^{c}

Note: Means followed by different letters within the same observation period differ significantly according to the Least Significant Difference (LSD) test at the 5% significance level.

Comparison of the two herbicide formulations showed distinct responses in rice tiller production. Basagran® maintained vegetative growth without significantly affecting tiller formation across all application rates, whereas Bentagram® significantly enhanced tiller production during the early vegetative stage. However, because medium and high application rates (1.00–1.75 L ha^{-1}) produced statistically similar tiller numbers at 6 WAP, the results indicate that increasing herbicide dosage beyond the medium application level did not proportionally improve vegetative performance.

Effect of Herbicide Application on Weed Dry Weight

Weed dry weight was determined at three and five weeks after application (WAA) to evaluate the effectiveness of Basagran® and Bentagram® herbicides in reducing weed biomass during the rice vegetative stage. Weed biomass provides an indirect measure of herbicide efficacy because lower dry weight generally reflects greater suppression of weed growth.

Basagran® Herbicide

Analysis of variance (ANOVA) indicated that Basagran® application had no significant effect ($p > 0.05$) on weed dry weight at either observation period. Consequently, all treatments belonged to the same statistical group, and no significant differences were detected among herbicide application rates.

Although numerical variation in weed biomass was observed among treatments, weed dry weight generally remained low throughout the experimental period. Several treatment plots exhibited no measurable weed biomass, while only a few plots contained small quantities of surviving weeds. Between 3 and 5 WAA, weed biomass tended to decline across most treatments, indicating continued suppression of weed growth following herbicide application. The absence of significant statistical differences suggests that all tested application rates provided relatively similar levels of weed biomass reduction under the prevailing field conditions.

***Table 9**. Average Weed Dry Weight under Basagran® Herbicide Treatments*

Treatment	3 WAA (g plot^{-1})	5 WAA (g plot^{-1})
P0 (Control)	0.00^{a}	0.25^{a}
P1 (0.50 L ha^{-1})	1.10^{a}	0.00^{a}
P2 (0.75 L ha^{-1})	0.03^{a}	0.05^{a}
P3 (1.00 L ha^{-1})	0.00^{a}	0.00^{a}
P4 (1.25 L ha^{-1})	0.00^{a}	0.43^{a}
P5 (1.50 L ha^{-1})	0.03^{a}	0.00^{a}
P6 (1.75 L ha^{-1})	0.14^{a}	0.00^{a}

Note: Means followed by the same letter within each observation period are not significantly different according to ANOVA at the 5% significance level.

Bentagram® Herbicide

Similar to Basagran®, the application of Bentagram® showed no significant effect ($p > 0.05$) on weed dry weight at either 3 or 5 WAA. All treatment means belonged to the same statistical group, indicating that increasing herbicide application rate did not produce statistically different reductions in weed biomass.

Overall, weed dry weight remained low across treatments throughout the observation period. Although one treatment exhibited a relatively higher numerical value at 3 WAA, this variation was not statistically significant and therefore did not represent a consistent treatment effect. By 5 WAA, weed biomass had declined in nearly all treatments, suggesting that the herbicide

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maintained weed suppression throughout the vegetative growth stage. The generally low weed biomass observed across all treatments indicates that Bentagram® effectively limited weed development under the experimental conditions.

Table 10. *Average Weed Dry Weight under Bentagram® Herbicide Treatments*

Treatment	3 WAA (g plot^{-1})	5 WAA (g plot^{-1})
P0 (Control)	0.00[a]	0.25[a]
P1 (0.50 L ha^{-1})	0.00[a]	0.00[a]
P2 (0.75 L ha^{-1})	0.02[a]	0.02[a]
P3 (1.00 L ha^{-1})	0.00[a]	0.00[a]
P4 (1.25 L ha^{-1})	4.27[a]	0.38[a]
P5 (1.50 L ha^{-1})	0.00[a]	0.00[a]
P6 (1.75 L ha^{-1})	0.04[a]	0.07[a]

Note: Means followed by the same letter within each observation period are not significantly different according to ANOVA at the 5% significance level.

Comparison of the two herbicide formulations demonstrated similar responses in weed biomass reduction. Both Basagran® and Bentagram® maintained relatively low weed dry weight throughout the observation period, and no statistically significant differences were detected among application rates. These findings indicate that all tested doses were capable of suppressing weed biomass under the relatively low weed pressure observed during the experiment. Although numerical variation occurred among treatments, particularly at 3 WAA, these differences were not sufficiently large to produce significant treatment effects according to ANOVA.

Discussion

The present study demonstrated that both commercial Bentazone + MCPA formulations effectively suppressed weed populations while maintaining normal vegetative growth of rice under irrigated field conditions. Although both formulations contained identical active ingredients (Bentazone 400 g L^{-1} and MCPA 60 g L^{-1}), slight differences in biological response were observed, particularly regarding tiller production. Overall, the findings indicate that herbicide efficacy was primarily reflected in reduced weed abundance, stable weed community structure, and the absence of phytotoxic effects on rice plants. These responses suggest that the tested herbicides possess high crop selectivity while providing effective weed suppression during the critical vegetative growth stage. Such findings are consistent with previous reports indicating that selective post-emergence

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herbicides improve crop performance mainly through the alleviation of weed competition rather than through direct stimulation of plant growth (Chauhan, 2021; Kumar et al., 2024).

One of the most notable findings of this study was the maintenance of moderate weed diversity (Shannon–Wiener index 1.39–1.56) together with consistently low dominance values (Simpson index 0.22–0.25) following herbicide application. Rather than eliminating all weed species, both formulations reduced overall weed abundance without allowing any single tolerant species to dominate the weed community. Ecologically, this outcome is desirable because excessive dominance of surviving weeds frequently represents the first stage in shifts toward herbicide-tolerant or herbicide-resistant weed populations. According to Magurran (2021), balanced community structure following disturbance indicates that ecological pressure has not disproportionately favored a limited number of species. Similarly, Heap (2024) emphasized that repeated herbicide application leading to dominance of a few surviving species often precedes the evolution of herbicide resistance. Therefore, the relatively balanced weed community observed in this study suggests that the tested application rates remain effective under current field conditions and have not yet imposed strong directional selection on the weed flora.

The observed weed suppression can be explained by the complementary mechanisms of action of Bentazone and MCPA. Bentazone belongs to the photosystem II (PSII) inhibitor group (HRAC Group 6), acting by blocking electron transport between QA and QB in the D1 protein complex of photosystem II. This interruption rapidly inhibits photosynthetic electron flow, resulting in the accumulation of reactive oxygen species (ROS), membrane lipid peroxidation, chlorophyll degradation, and ultimately necrotic tissue collapse in susceptible weeds. Because Bentazone acts primarily through contact activity, visible injury generally develops within a few days after application under favorable environmental conditions (Duke, 2022). In contrast, MCPA is classified as a synthetic auxin herbicide (HRAC Group 4), mimicking the natural plant hormone indole-3-acetic acid (IAA). Excessive auxin signaling disrupts normal gene regulation, induces uncontrolled cell elongation, impairs vascular differentiation, and alters hormonal balance, eventually causing irreversible tissue deformation and plant death (Shaner, 2014). The combination of these two distinct physiological mechanisms broadens the weed control spectrum by simultaneously targeting photosynthetic metabolism and hormonal regulation, thereby increasing overall herbicidal effectiveness while reducing the probability that weeds survive through a single physiological adaptation.

The absence of significant reductions in rice plant height across all treatments further confirms the selective nature of Bentazone + MCPA toward rice. Rice is known to tolerate Bentazone because of its rapid metabolic detoxification through hydroxylation and conjugation pathways, which convert the active compound into non-toxic metabolites before irreversible damage occurs. Likewise, cereal crops generally possess greater tolerance to synthetic auxins than broadleaf weeds because of differences in hormone transport, receptor sensitivity, and metabolic degradation. Consequently, herbicide injury remains minimal when products are applied at recommended growth stages and dosage levels (Duke, 2022; Shaner, 2014). The present results therefore support previous international studies reporting that Bentazone-containing herbicides effectively suppress broadleaf weeds and sedges without significantly affecting rice growth parameters, provided that application follows recommended agronomic practices.

Although both herbicide formulations showed comparable weed suppression, Bentagram significantly increased tiller production whereas Basagran produced no statistically significant improvement. This difference may not necessarily originate from the active ingredients themselves but rather from formulation characteristics. Commercial herbicide formulations differ in surfactant composition, solvent systems, droplet retention, cuticular penetration, and spray spreading behavior, all of which influence herbicide absorption and biological performance under field conditions. Improved spray retention and leaf penetration may enhance early weed control, thereby reducing resource competition during the critical tillering stage. Rice plants experiencing lower competition for light, nitrogen, and water can allocate greater assimilates toward axillary bud development, resulting in increased tiller formation. Similar formulation-dependent differences have been documented internationally, where products containing identical active ingredients exhibited different field performances because of proprietary formulation technologies affecting herbicide bioavailability and rainfastness (Kumar et al., 2024).

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Interestingly, increasing herbicide dosage beyond 1.50 L ha^{-1} did not provide additional biological benefits despite occasional numerical increases in weed suppression or tiller production. This plateau response suggests that maximum herbicidal efficacy had already been achieved at the medium application rate. Once susceptible weeds are effectively controlled, further increases in herbicide concentration are unlikely to improve crop performance because weed competition has already been minimized. Similar dose-response relationships have been widely reported in rice production systems, where herbicide efficacy reaches saturation beyond the recommended field rate while environmental risks and production costs continue to increase (Beckie et al., 2022). Therefore, the identification of 1.50 L ha^{-1} as the optimum dose in the present study represents not only an agronomic recommendation but also an environmentally responsible strategy that minimizes unnecessary chemical inputs.

From the perspective of herbicide resistance management, the present findings also have important practical implications. Worldwide, herbicide-resistant weeds continue to increase because repeated reliance on herbicides possessing identical modes of action creates strong selection pressure favoring naturally resistant individuals (Powles & Yu, 2023; Heap, 2024). Although the dual-mode combination of Bentazone and MCPA reduces the likelihood of resistance evolving through a single target-site mutation, exclusive dependence on this herbicide mixture over multiple growing seasons could still select for enhanced metabolic resistance or multiple-resistance mechanisms. Consequently, the results should be interpreted within the broader framework of Integrated Weed Management (IWM). Herbicide application should be integrated with crop rotation, water management, competitive rice cultivars, stale seedbed techniques, mechanical weeding, and periodic rotation of herbicide modes of action to preserve long-term efficacy while minimizing resistance evolution. Such integrated approaches have become the international standard for sustainable weed management in modern rice production systems (Beckie et al., 2022; Kumar et al., 2024).

The present study agrees with previous international research demonstrating that Bentazone-based herbicides effectively suppress broadleaf weeds while maintaining crop safety. However, this study extends existing knowledge by directly comparing two commercial formulations containing identical active ingredients under identical field conditions while simultaneously evaluating weed community structure using ecological indices. The integration of weed diversity, dominance, biomass, and rice vegetative responses provides a more comprehensive assessment of herbicide performance than conventional evaluations based solely on weed control efficacy or crop yield. Collectively, these findings reinforce the importance of optimizing herbicide dosage and formulation selection within Integrated Weed Management programs to achieve effective weed suppression, sustain rice productivity, and reduce long-term risks associated with herbicide resistance and excessive chemical use.

CONCLUSION

Based on the findings of this study, both commercial herbicide formulations containing Bentazone (400 g L^{-1}) + MCPA (60 g L^{-1}) effectively suppressed weed communities during the vegetative stage of rice without causing phytotoxic effects on rice cv. Inpari 32. Herbicide application maintained moderate weed diversity (Shannon–Wiener index = 1.39–1.56) and low dominance values (Simpson index = 0.22–0.25), indicating successful weed suppression while preventing ecological dominance by tolerant weed species. Furthermore, both formulations exhibited high crop selectivity, as evidenced by the absence of significant effects on plant height and weed dry weight across the tested application rates. Although Basagran® maintained normal vegetative growth without significantly influencing tiller production, Bentagram® significantly increased tiller number during the vegetative stage, suggesting that formulation characteristics beyond the active ingredients may influence biological performance under field conditions. Importantly, the highest application rate (1.75 L ha^{-1}) did not provide statistically greater benefits than 1.50 L ha^{-1}, indicating that the latter represents the optimum application rate for achieving effective weed suppression while avoiding unnecessary herbicide inputs and additional production costs. These findings confirm that appropriate dose optimization is essential for maximizing herbicide efficiency while maintaining crop safety and environmental sustainability.

From a broader agronomic perspective, this study provides scientific evidence supporting the integration of Bentazone + MCPA herbicides into Integrated Weed Management (IWM) strategies for sustainable rice production. The maintenance of balanced weed community structure following herbicide application suggests that the recommended dose can effectively suppress weeds without imposing excessive selection pressure that may accelerate herbicide resistance. Considering the increasing global incidence of herbicide-resistant weeds, optimizing herbicide dosage while integrating chemical control with complementary cultural, mechanical, and agronomic practices is essential to preserve long-term herbicide efficacy. Moreover, this study contributes novel information by directly comparing two commercial formulations containing identical active ingredients under identical field conditions while simultaneously evaluating ecological indicators of weed communities alongside rice vegetative responses. Such a comprehensive assessment extends beyond conventional efficacy evaluations and provides a stronger scientific basis for selecting herbicide formulations and application rates in irrigated rice systems. Nevertheless, because this experiment was conducted at a single location and focused primarily on vegetative growth, future studies should include multi-location and multi-season trials encompassing diverse environmental conditions, weed flora, grain yield, economic returns, herbicide residue dynamics, and long-term monitoring of resistance development to strengthen recommendations for sustainable rice production systems.

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