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Evaluation of Bentazone as Post-emergence Against Weed Flora of Direct Seeded Rice (*Oryza sativa* L.)

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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

In direct-seeded rice (DSR) production systems, both rice seedlings and weeds emerge at the same time, as there is no flood water to prevent weed germination, growth, and development when the rice crops begin to sprout. Consequently, weeds are the primary obstacle to successful DSR, often leading to a significant reduction in yield. This research aimed to develop a strategy for effective weed management in DSR, focusing on enhancing growth and production through the use of

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herbicides. Therefore, a field experiment was conducted at the Breeder Seed Production Unit, Adhartal, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) during the *Kharif* season of 2016 to evaluate the effectiveness of various doses of Bentazone herbicide in direct-seeded rice. The experimental soil was clayey with a neutral pH of 7.2, medium organic carbon content (0.62%), available nitrogen (365 kg/ha), available phosphorus (16.34 kg P_2O_5/ha), and high available potassium (327.16 kg K_2O/ha). Weed control treatments included Bentazone at 600, 800, 1000, 1200, 1600, 1800, and 2000 g/ha; 2,4-D at 380 g/ha; two hand weedings at 20 and 40 days after sowing (DAS); and an unweeded control. These treatments were arranged in a randomized block design with three replications. The primary weeds in the experimental field were monocots (*Echinochloa colona, Dinebra retroflexa*), sedges (*Cyperus iria*), and broad-leaved weeds (*Mollugo pentaphylla, Alternanthera philoxeroides*). The post-emergence application of Bentazone at 1600 g/ha was found to be the most economically effective for controlling dicot weeds in direct-seeded rice, resulting in the lowest weed index. This treatment also improved growth parameters (such as plant height, number of tillers per square meter, and plant dry weight), yield attributes (such as grains per panicle), and grain yield compared to other weed control treatments. Therefore, Bentazone at 1600 g/ha is recommended to farmers for achieving higher economic returns and effective weed control in direct-seeded rice.

Keywords: Bentazone; direct-seeded rice; grain yield; herbicides; weeds; weed index.

1. INTRODUCTION

Rice (*Oryza sativa* L.) serves as a staple food for over 60% of the world's population and is primarily grown as a kharif crop [1]. It is cultivated in various agro-ecosystems and soil conditions. India ranks as the second largest producer and consumer of rice globally. Rice provides 50-80% of the daily calorie intake for many consumers [2]. In India, it is grown in nearly 43.39 m ha area with the production of 104.32 MT and productivity of 2404 kg/ha. In Madhya Pradesh, it occupies an area of 2.02 m ha with the production of 3.58 MT and productivity of 1768 kg/ha [3].

The transplantation method of rice cultivation is widespread in various parts of India but is labor-intensive, costly, and requires substantial water for puddling, transplanting, and establishing seedlings. Many farmers in Madhya Pradesh are marginal and face difficulties with these operations. Additionally, unpredictable and insufficient monsoon rains significantly impact rice productivity. Therefore, Direct Seeding of Rice (DSR) offers several advantages over traditional transplanting, including easier planting, timely sowing, reduced labor, earlier crop maturity by 7 to 10 days, lower water requirements, improved soil conditions for subsequent crops, lower production costs, and higher profits [4].

Weeds present a significant challenge by competing for nutrients, light, space, and moisture from the moment they emerge and throughout the entire growing season [5,6,7,8]. Weeds are the primary challenge in direct-seeded rice, as the natural weed control provided by standing water during crop establishment is absent. High weed infestation in direct-seeded rice can lead to grain yield losses of up to 90% [9]. Weeds germinate alongside rice seeds and compete for resources from the initial stages, leading to reduced crop yields, increased cultivation costs, decreased input efficiency, interference with agricultural operations, impaired crop quality, and adverse effects on the ecosystem, native biodiversity, human, and cattle health [10,11,12]. The shift from transplanting to direct seeding alters the weed community, with species such as *Dactyloctenium aegyptium, Digitaria ciliaris, Eragrostis spp., Eleusine indica, Acrachne racemosa, Commelina benghalensis, Cyperus compressus, Cyperus rotundus, Digera arvensis, Phyllanthus niruri, Amaranthus viridis,* and *Trianthema portulacastrum* becoming more prevalent, alongside traditional weeds like *Echinochloa crusgalli, Echinochloa colona, Leptochloa chinensis, Cyperus iria, Cyperus difformis, Eclipta alba, and Sphenochloa zeylanica*. Consequently, new weed management strategies are needed to address the more competitive weed flora in direct-seeded rice. A weed-free period of the first 25-45 days after sowing is crucial to prevent yield loss in dry direct-seeded rice [13].

Hand weeding, while environmentally friendly and effective, is labor-intensive and often hindered by labor shortages during peak periods [14,15]. Early-stage weeding is particularly challenging due to the morphological similarity between rice seedlings and weeds. Identifying herbicides with broad-spectrum weed control capabilities is essential for efficient and economical weed management, which is crucial for enhancing crop potential [16,17,18]. Pre-emergence herbicides like Pretachlor, Butachlor, Anilophos, and post-emergence herbicides like 2,4-D and Almix are commonly used to control grassy and broadleaf weeds in direct-seeded rice. Although effective, these herbicides are usually specific to a narrow range of weed species, and continuous application can lead to shifts in weed flora and herbicide resistance. This necessitates ongoing research to develop and evaluate new and alternative herbicides to address herbicide resistance. Bentazone, a post-emergence herbicide effective against broadleaf weeds in soybeans, is being investigated for its efficacy in direct-seeded rice under the central zone.

2. MATERIALS AND METHODS

A field experiment was conducted at the Breeder Seed Production Unit, Adhartal, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.), to evaluate the effectiveness of Bentazone against weeds in direct-seeded rice during the *kharif* season of 2016. The study took place under the specific edaphic and climatic conditions of Jabalpur (M.P.), located at 23°9' North latitude and 79°58' East longitude, with an altitude of 411.78 meters above mean sea level. The climate in this region is typically sub-humid and sub-tropical, characterized by hot, dry summers and cool, dry winters. Weather conditions during the experiment were generally favorable for rice growth and development. The monsoon began in the first week of June and ended in the fourth week of September, with total rainfall of 926.50 mm distributed over 34 rainy days from the last week of July to the first week of November. The mean minimum and maximum temperatures ranged from 27.0 to 33.0 °C, while relative humidity varied from 87 to 93% in the morning and 24 to 91% in the evening. The mean daily sunshine duration ranged from 1.3 to 9.3 hours. The soil of the experimental field was clayey, neutral in reaction (pH 7.2), with medium organic carbon content (0.62%), available nitrogen (365 kg/ha), and available phosphorus (16.34 kg P_2O_5/ha), and high available potassium (327.16 kg K_2O/ha). Ten treatments were tested: Bentazone at 600, 800, 1000, 1200, 1600, 1800, and 2000 g/ha; 2,4-D at 380 g/ha; hand weeding at 20 and 40 DAS; and a weedy check. These treatments were arranged in a randomized block design with three replications. Seeds were sown on July 26th, 2016, using a seed drill, with rows spaced 20 cm apart at a depth of 2-3 cm, then covered with fine soil. All herbicides were applied post-emergence in the standing paddy crop. Nitrogen (80 kg/ha) was applied in three equal splits, while phosphorus (40 kg/ha) and potassium (30 kg/ha) were applied at seedbed preparation by broadcasting. Data were collected on weed population and dry matter, crop growth, and yield. Weed index and benefit-cost ratio were calculated. Weed data were square-root transformed before statistical analysis. Data analysis was conducted and comparisons were made at the 5% significance level.

$$\text{Weed index (\%)} = \frac{(X - Y)}{X} \times 100$$

Where, X = Yield from weed free plot and,
Y = Yield from treated plot

3. RESULTS AND DISCUSSION

3.1 Weed Density and Weed Dry Weight

During the study, rice was primarily infested by *Echinochloa colona, Dinebra retroflexa, Cyperus iria, Mullogo pentaphylla,* and *Alternanthera philoxeroides.* The emergence of these weed species is mainly attributed to factors such as the initial soil weed seed bank, variations in tillage intensity during land preparation, previous cropping systems, weather conditions during crop growth, and favorable soil environments. Among these emerged monocot weeds, *Echinochloa colona* was the most dominant and *Dinebra retroflexa* also show their presence. *Mullogo pentaphylla* was the most dominant dicot weeds and *Alternanthera philoxeroides* also present in smaller numbers. Among sedges, *Cyperus iria* also recorded in the field [19].

The highest weed density and dry weight were observed in the weedy check plots (Tables 1 & 2). However, the application of herbicides and hand weeding significantly reduced both the density and dry weight of these weeds. The higher doses of Bentazone (1600, 1800, and 2000 g/ha) significantly reduced the density and dry weight of broad-leaf weeds compared to lower doses (600, 800, 1000, 1200 g/ha) and 2,4-D at 380 g/ha. Bentazone, applied as a post-emergence treatment at 1600 g/ha was particularly effective in reducing the density and dry weight of weeds.

The effectiveness of Bentazone is attributed to its inhibition of the ACcase enzyme, which is crucial for the biosynthesis of fatty acids. This inhibition reduces the level of cuticle waxes, exposing weed plants to more desiccation and heat injury, resulting in yellowing leaves and eventual weed mortality. Furthermore, Bentazone inhibits the plant enzyme acetolactate synthase (ALS), which is essential for the synthesis of branched-chain amino acids (valine, leucine, and isoleucine). This inhibition disrupts cell division and leads to the death of susceptible weeds. Similar observations were reported by [20,21,22].

Hand weeding twice, at 20 and 40 DAS, resulted in the maximum reduction of weed density and dry weight compared to herbicidal treatments, as it eliminated all types of weeds during the weeding process. This observation aligns with findings by [23,24] who also reported minimal weed density and dry weight under hand weeding conditions.

Table 1. Weed density (no./m^2) of grasses, sedges and broad-leaf weeds as influenced by different weed control treatments at 15 DAA

Treatments	Grassy weeds		Sedges	Broad-leaf weeds	
	Echinochloa colona	***Dinebra retroflexa***	***Cyperus iria***	***Mullogo pentaphylla***	***Alternanthera philoxeroides***
Bentazone 600 g/ha	6.76 (45.53)	5.16 (26.15)	4.71 (21.69)	4.99 (24.40)	3.12 (9.25)
Bentazone 800 g/ha	6.73 (45.30)	5.09 (25.40)	4.70 (21.56)	4.96 (24.15)	3.11 (9.18)
Bentazone 1000 g/ha	6.72 (44.73)	5.21 (26.69)	4.58 (20.47)	4.82 (22.69)	2.97 (8.31)
Bentazone 1200 g/ha	6.67 (44.06)	5.19 (26.42)	4.72 (21.73)	4.68 (21.42)	2.78 (7.25)
Bentazone 1600 g/ha	6.79 (45.67)	5.02 (24.73)	4.70 (21.56)	4.38 (18.73)	2.60 (6.26)
Bentazone 1800 g/ha	6.70 (44.83)	5.10 (25.50)	4.71 (21.68)	4.10 (16.33)	2.39 (5.23)
Bentazone 2000 g/ha	6.73 (45.37)	5.08 (25.31)	4.69 (21.53)	3.63 (12.68)	2.16 (4.18)
2,4-D 380 g/ha	6.75 (45.68)	5.04 (24.94)	4.69 (21.53)	4.47 (19.46)	2.77 (7.15)
Hand weeding (20 & 40 DAS)	2.29 (4.87)	1.40 (1.46)	1.67 (2.28)	2.79 (7.28)	1.68 (2.31)
Weedy check	6.78 (45.60)	5.04 (24.93)	4.70 (21.61)	6.64 (43.62)	5.10 (25.53)
SEm±	0.39	0.02	0.01	0.02	0.01
CD at 5%	1.15	0.05	0.04	0.07	0.03

Table 2. Weed dry weight (g/m^2) of grasses, sedges and broad-leaf weeds as influenced by different weed control treatments at 15 DAA

Treatments	Grassy weeds		Sedges	Broad-leaf weeds	
	Echinochloa colona	***Dinebra retroflexa***	***Cyperus iria***	***Mullogo pentaphylla***	***Alternanthera philoxeroides***
Bentazone 600 g/ha	6.44 (40.98)	4.43 (19.09)	4.29 (17.93)	3.14 (9.36)	1.96 (3.33)
Bentazone 800 g/ha	6.42 (40.76)	4.36 (18.54)	4.28 (17.83)	3.08 (8.99)	1.95 (3.31)
Bentazone 1000 g/ha	6.38 (40.21)	4.47 (19.49)	4.17 (16.92)	3.06 (8.87)	1.87 (2.99)
Bentazone 1200 g/ha	6.35 (39.85)	4.45 (19.29	4.30 (17.97)	2.89 (7.85)	1.76 (2.61)

Treatments	Grassy weeds		Sedges	Broad-leaf weeds	
	Echinochloa colona	***Dinebra retroflexa***	***Cyperus iria***	***Mullogo pentaphylla***	***Alternanthera philoxeroides***
Bentazone 1600 g/ha	6.45 (41.07)	4.31 (18.06)	4.28 (17.82)	2.57 (6.12)	1.66 (2.26)
Bentazone 1800 g/ha	6.41 (40.58)	4.37 (18.62)	4.29 (17.92)	2.29 (4.75)	1.54 (1.88)
Bentazone 2000 g/ha	6.41 (40.63)	4.36 (18.48)	4.28 (17.80)	2.16 (4.17)	1.42 (1.51)
2,4-D 380 g/ha	6.46 (41.29)	4.33 (18.21)	4.28 (17.80)	2.79 (7.27)	1.75 (2.57)
Hand weeding (20 & 40 DAS)	2.24 (4.52)	1.25 (1.06)	1.54 (1.88)	1.88 (3.03)	1.15 (0.83)
Weedy check	6.47 (41.45)	4.32 (18.20)	4.29 (17.86)	5.69 (31.89)	3.11 (9.19)
SEm±	0.07	0.03	0.02	0.05	0.02
CD at 5%	0.20	0.09	0.07	0.13	0.06

Table 3. Growth parameters, yield attributing traits and grain yield as influenced by different weed control treatments

Treatments	Plant height (cm)	Tillers/m^2	Plant dry weight (g/m^2)	Grains/ panicle	Grain yield (t/ha)
	30 DAS	**30 DAS**	**30 DAS**		
Bentazone 600 g/ha	31.12	502.15	9.93	56.71	3.43
Bentazone 800 g/ha	31.86	543.23	9.95	56.90	3.65
Bentazone 1000 g/ha	33.20	526.50	9.93	57.51	3.99
Bentazone 1200 g/ha	34.79	621.64	10.96	58.25	4.09
Bentazone 1600 g/ha	42.97	742.83	10.97	58.81	5.35
Bentazone 1800 g/ha	38.26	710.41	10.94	57.76	4.93
Bentazone 2000 g/ha	37.86	637.54	10.94	57.71	4.92
2,4-D 380 g/ha	35.53	628.29	10.95	57.97	4.63
Hand weeding (20 & 40 DAS)	46.77	762.34	10.97	59.10	6.16
Weedy check	26.41	372.45	9.91	54.60	2.89
SEm±	0.28	7.58	0.78	0.14	0.15
CD at 5%	0.83	21.77	NS	0.52	0.48

3.2 Growth Parameters, Yield Attributing Traits and Grain Yield

Significantly taller plants, more tillers per square meter, and the maximum plant dry weight were observed with the application of Bentazone at 1600 g/ha compared to the weedy check at 30 DAS (Table 3). This improvement was attributed to the enhanced availability of growth resources, especially nitrogen and space, which facilitated the growth of taller plants and a greater number of tillers per square meter. The increased plant dry weight was due to the reduced weed competition resulting from effective weed control, promoting better growth and development of the rice plants. These findings align with those of [25,26]. However, these treatments were still significantly inferior to hand-weeded plots. Hand weeding twice provided excellent weed control, creating an almost weed-free environment during the critical period of crop-weed competition. This optimal condition led to superior growth and development of the crop plants, resulting in greater plant height and more tillers per square meter [27].

A significantly higher number of total grains per panicle was recorded with both hand weeding twice and Bentazone at 1600 g/ha (Table 3). This increase was due to the better suppression of weeds, creating a weed-free environment that allowed more nutrients for the formation and development of grains. These results are consistent with the findings of [28,29].

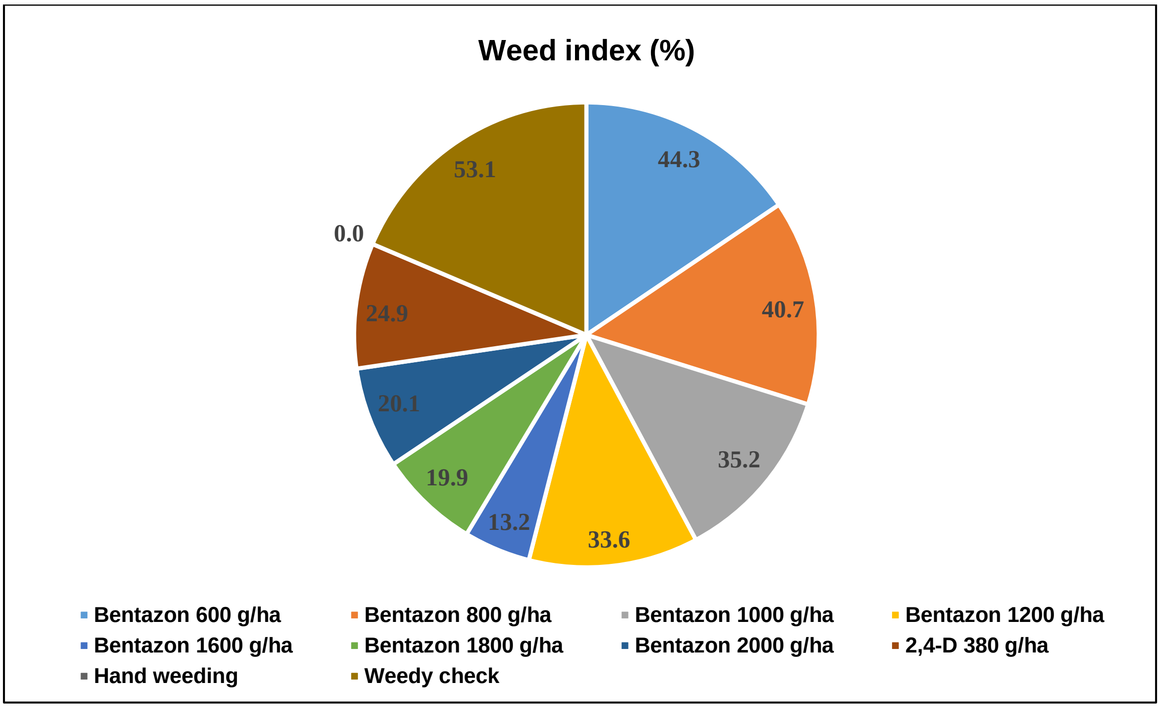

Fig. 1. Weed index as influenced by different weed control treatments

The lowest grain yields were recorded in the weedy check plots, where weeds were allowed to grow throughout the crop season (Table 3). This led to severe competition for growth resources between the crop and weeds, resulting in poor growth and yield attributes, and suboptimal partitioning of dry matter among leaves, stems, and panicles. Consequently, these plots produced the lowest yields. Significant increases in grain yield were observed with various doses of Bentazone at 600, 800, 1000, 1200, 1800, and 2000 g/ha, and with 2,4-D at 380 g/ha when applied post-emergence, with the highest yield (5.35 t/ha) at 1600 g/ha. Hand weeding twice resulted in even higher yields (6.16 t/ha) compared to all other treatments. The increased yields were due to the elimination of weeds, which enhanced the availability of nutrients, space, sunlight, and water, leading to better growth and development of crop plants. This resulted in improved yield attributes and greater dry matter accumulation, ultimately producing the highest yields. These results corroborate the findings of [30,31].

3.3 Weed Index

The greatest yield reduction (53.10%) was observed in the weedy check plots, where weeds were present throughout the crop season (Fig. 1). In contrast, the application of Bentazone at 1600 g/ha reduced yield loss to just 13.22%. This significant reduction in yield loss is attributed to the effective control of weeds, which minimized weed stress during the critical period of crop growth. Similar findings have been reported by [32,33].

4. CONCLUSION

In conclusion, Bentazone at 1600 g/ha proved to be the most effective weed control treatment for direct-seeded rice, achieving the lowest weed index. Bentazone at 1600 g/ha successfully controlled broadleaf weeds and increased rice grain yield but it was not effective in controlling grasses and sedges. However, higher doses of Bentazone showed slight phytotoxicity to the rice crop.

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 manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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