PLANT SCIENCE TODAY
Vol x(x): xx–xx
https://doi.org/10.14719/pst.7024

eISSN 2348-1900

RESEARCH ARTICLE

Impact of pre and post-emergence herbicide applications on mimicry weed (*Echinochloa colona*) in rice cultivation for food security and sustainable agriculture

Athul G B[1], Anita Jaswal[1]*, Rajesh Kumar[2] & Sarang S Hari[3]

[1]Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara 144 411, India
[2]Department of Life Sciences, Sant Baba Bhag Singh University, Khiala, Jalandhar 144 030, India
[3]Department of Agriculture, Health and Environment, University of Greenwich, 30 Park Row, Greenwich, SE10 9LS London, United Kingdom

*Correspondence email - anita.27139@lpu.co.in

Received: 02 January 2025; Accepted: 14 March 2025; Available online: Version 1.0: 31 May 2025

Cite this article: Athul GB, Anita J, Rajesh K, Sarang SH. Impact of pre and post-emergence herbicide applications on mimicry weed (*Echinochloa colona*) in rice cultivation for food security and sustainable agriculture. Plant Science Today (Early Access). https://doi.org/10.14719/pst.7024

Abstract

More than half of the worlds' population relies on rice as their primary food source and India is a major exporter of Basmati rice, known for its fragrant, elongated grains. *Echinochloa colona*, a mimicry weed in rice fields, poses significant challenges for rice cultivation due to its morphological similarity to rice plants, hindering effective weed management. This experiment, conducted at Lovely Professional Universitys' agricultural field during the Kharif season of 2024, evaluated various herbicide treatments combined with manual weeding. The treatments were laid out in a randomized block design with three replications. The predominant weed species observed in the experimental farm was *Echinochloa colona*. Significantly lower weed density at 20, 40 and 60 DAT (1.88,1.72 and 1.37 no. m^{-2}) and weed dry weight m^{-2} (13.99, 3.03 and 0.78 g) were recorded in the weed-free plot, which remained at par with the pre-emergence herbicide butachlor @ 1.5 L/ha combined with hand weeding at 30 DAT. The results showed that the weed-free treatment achieved the maximum plant height (105.68 cm), number of tillers per plant (18.55), maximum chlorophyll index (47.50 SPAD), dry weight (44.51g/plant) and leaf area (74.73 cm^2), closely followed by the butachlor @ 1.5 L/ha combined with hand weeding at 30 DAT. The weedy check plot recorded the minimal values for these parameters, indicating the detrimental effect of weed competition. The research suggests that combining the pre-emergence treatment of butachlor with hand weeding significantly reduces weed competition, thereby enhancing the growth of transplanted Basmati rice.

Keywords: integrated weed management; mimicry weed; pre-emergence herbicides; post-emergence herbicides

Introduction

Rice (*Oryza sativa*) is a staple food for more than half of the worlds' population (1). A bisexual, self–pollinated crop with a 90-130 day growing season, rice (2n=24) is an edible starchy cereal grain that belongs to the *Poaceae* family (2). According to the Agricultural and Processed Food Products Export Development Authority (APEDA), India ships approximately 10-13 million metric tons of basmati rice annually, making it one of the leading rice exporters in the world. India produces almost 70 % of the worlds' basmati rice, while Pakistan, the Philippines and China contribute 30 % (3). In Financial year 2022-23, India exported 11.9 million tons of rice; 7.5 million tons were non-basmati rice and 4.4 mt were basmati rice. Punjab has the most significant area of 31.68 lakh hectares, producing 205.24 lakh tonnes of basmati rice. Pusa basmati 1121 has surpassed all other varieties in popularity among farmers. Farm surveys estimated rice yield loss to 40 % due to weeds, 10.2 % by insects, 1.2 % by diseases, 28.2 % by floods and 20.4 % by other abiotic factors. Weeds compete with rice crops for space, water, light and nutrients. Crop-weed competition during the critical period causes considerable yield losses. *Echinochloa colona* grows best under grasses, *Cyperus rotundus, Cyperus iria* and *Cyperus difformis* grow best under sedges and *Eclipta alba* grows best under broadleaf weeds (4). The increasing use of power tillers and tractors has resulted in growing weeds that spread vegetatively. New and significant weeds, such as *E. colona*, are emerging, bearing similarities to rice crops. Grass, sedges and broad-leaved plants are among the many weed species found in lowland rice fields (5). In addition to being one of the most common weeds in rice fields (6), *E. colona* may serve as a host for various diseases, pests and insects. *E. colona* plant has a hexaploid genome with 2n = 54. Root hairs are absent from *E. colona* stems except at the lowest nodes; the stems can be green or reddish-purple and robust in structure; they can stand upright or collapse and frequently branch out from the base (7). The inflorescence of *E. colona* is upright, 5-10 cm long and accompanied by slender racemes. Eradicating these morphological traits from rice fields during their early vegetative stages is challenging since they resemble rice (8). Additionally, the difficulty of mechanical seed separation makes it simple for weed seeds to spread to new rice fields (9).

Weed control during the critical period of crop-weed competition is essential to reduce weed competition and effectively utilize available resources for enhanced rice productivity. Manual weeding is necessary during the vital stages of crop-weed competition, but it can be laborious and tedious. It does not ensure weed removal at critical stages of crop-weed competition and bad weather conditions. Therefore, the use of herbicides appears essential and provides an affordable alternative. Continuous application of a single herbicide or combination can effectively address weed control issues. Both pre-and post-emergence herbicides are effective in rice crops (10). The substantial volumes of butachlor, pretilachlor and thiobencarb were sprayed as pre-emergence herbicides to control weeds in transplanted rice. These herbicides work better on grasses than on broadleaved or sedge weeds. To further prevent the development of herbicide resistance among weeds, it is necessary to use herbicides with different modes of action for various uses. A common problem with herbicide overuse is the development of weeds that are certain pre-emergence herbicides, like pendimethalin, fall into the category of nitroanilines and are designed explicitly for weeds with broad leaves (10). Its volatility, particularly when exposed to light, necessitates immediate mixing after application. Butachlor, belonging to the anilides category of herbicides, acts as a pre-emergence herbicide, effectively controlling annual grasses and a few broad-leaved weeds. Fenoxaprop-p-ethyl is a post-emergence herbicide that kills grass weeds by penetrating their roots and leaves. The sulfonylurea series of herbicides, including metsulfuron-methyl and ethoxysulfuron, effectively eliminates annual broadleaf weeds. The consistency of post-weed-control strategies depends a lot on the stage of weed growth and the environment. This is especially true when you consider that herbicides are recommended to control *E. crus-galli* in rice crops. Still, the plants' germination and growth can happen at very different times in different fields, often because of the environment. This study aims to evaluate the impact of various herbicides and their combinations on basmati rice growth parameters while identifying the most effective treatments for controlling *E. colona.*

Materials and Methods

The field experiment was carried out in the *kharif* season 2024 at the Agronomy field of Lovely Professional Phagwara (Fig. 1). The agriculture farm is located at latitude 31.25°N and longitude 75°E, with an altitude of 252 m above mean sea level. The soil samples were collected before the start of the experiment from a depth of 0-15cm to analyze the soils' mechanical composition and chemical properties. The experimental field had a clay loam soil texture with an alkaline reaction (pH = 8.1; EC = 0.13mm hos cm^{-1}). The site enjoys a subtropical climate. Pusa Basmati 1121, an aromatic rice variety with an average plant height of 120 cm, was used in this study. The grains have excellent cooking quality. It has the longest-cooked rice length among all the aromatic rice varieties recommended for Punjab (11). After transplanting, it takes around 107 days for it to develop. It is susceptible to all pathotypes of bacterial blight that are common in the state. The experiment included 10 treatments, which are as followed: T_0 - Weedy check (Control), T_1- Hand weeding (20, 40 DAT), T_2- Butachlor @ 3 L/ha, T_3- Pendimethalin @ 3 L/ha, T_4- Fenoxaprop-p-thyl @ 1000 mL/ha, T_5- Ethoxy-sulfuron

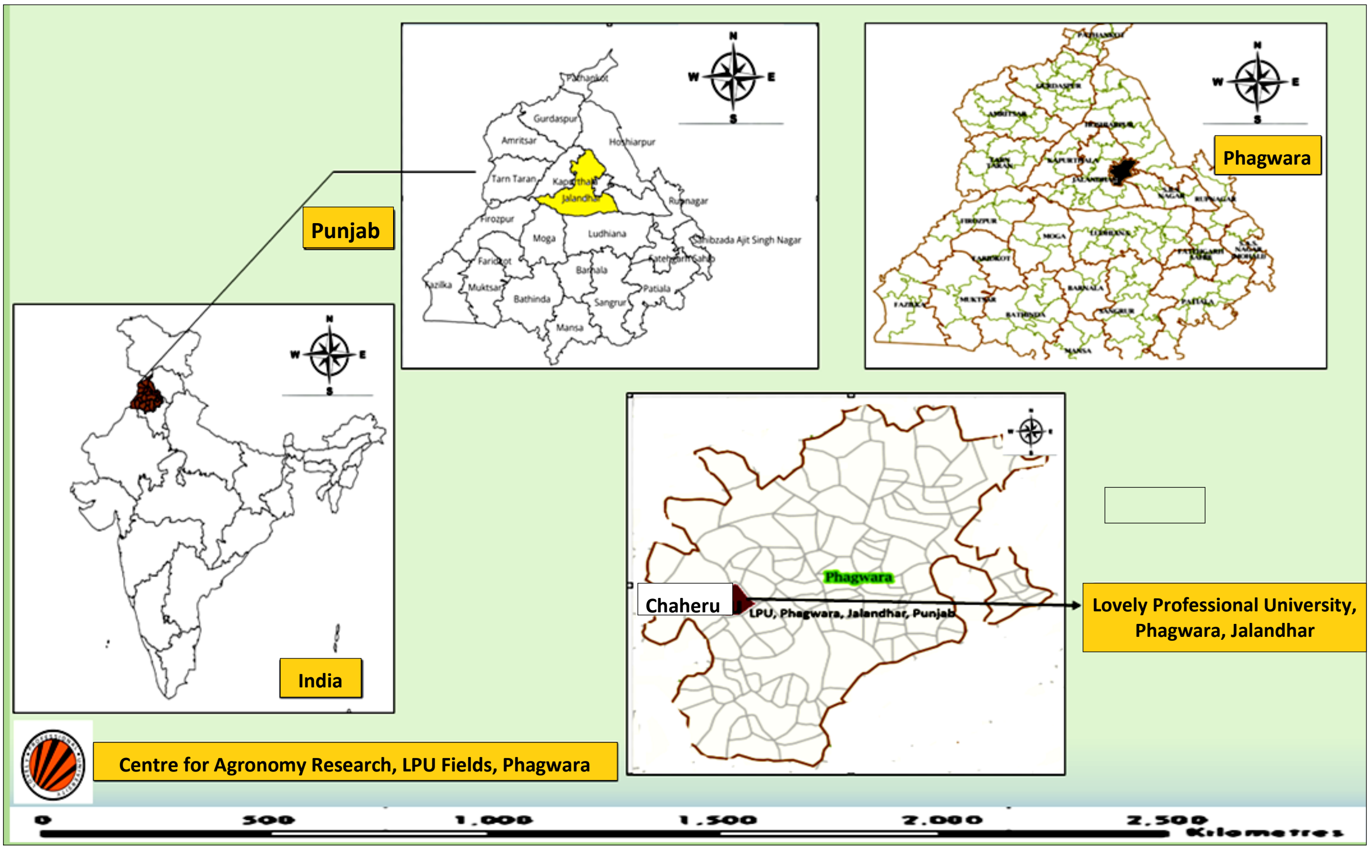

Fig. 1. Experimental location of the study.

@125 g/ha, T_6- Metsul-furon methyl @ 75 g/ha, T_7- Butachlor @ 1.5 L/ha + hand weeding at 30 DAT, T_8- Pendimethalin @ 1.5 L/ha + hand weeding at 30 DAT, T_9- Weed free. A randomized block design was used for the experiment, with three replications spaced 20 × 15 cm apart. 22 days old seedlings of rice were transplanted in the main field.75 kg of super-phosphate per acre before the last puddling and 36 kg urea per acre were applied as a split dose. Subsequent doses were given at the 3rd and 6th weeks after transplantation. Pre- and post-emergence herbicides were applied with knapsack sprayers fitted with flat fan nozzles. Table 1 presents the mode of action of the herbicides used in the experiment. The pre-emergence herbicide was mixed with 60 kg of sand/acre. Plant data such as height, tiller number, leaf number, leaf area, chlorophyll index, crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) were recorded. Weed characteristics include weed density, fresh weight and dry weight measured at 20, 40 and 60 days after transplanting (DAT). Various weed control measures have been calculated to confirm the results according to established formulas.

Weed parameters

Different weed management indices were calculated to advocate the results as per the following formulas:

Weed density (No./m²)

Using the quadrant method, the number of weeds was counted from a randomly selected 0.25 m^2 (quadrant size) area and converted per m^2 basis.

Weed control efficiency

% Formula in Equation 1 was used to calculate the weed control efficiency on a dry weight basis:

$$WCE = \frac{\text{Dry matter of weeds in weedy check- Dry matter of weeds in treated plot}}{\text{Dry matter of weeds in weedy check}} \times 100$$

.......(Eqn. 1)

Weed dry weight (g)

After being removed, the weeds in the quadrant area were placed in brown bags. The weeds were allowed to air dry before being dried at 65-70 ^{0}C in a hot air oven until a consistent weight was reached.

Weed fresh weight (g)

The weed in the quadrant area was uprooted and transferred to a brown bag. After cutting the weed, the fresh weight of the weed samples was taken with the help of weighing balance.

Statistical analysis

Analysis of variance (ANOVA) was employed to evaluate the experimental data, which was organized using a randomized block design. The data was analyzed using OPSTAT software. The Duncan Multiple Range Test (DMRT) is utilized to assess the differences among the treatments. Pearson correlation was employed to ascertain the link between the growth parameters at a 5 % significance level, evaluating both significant and non-significant parameters.

Results and Discussion

The dominant weed flora observed during the experiment was mimicry weed of rice, i.e. *Echinochloa colona* (Swank). No other weed species were observed during the experiment.

Effect of herbicides on rice growth parameters

The study evaluated the influence of different weed control treatments on plant height, tillers per plant, number of leaves per plant, leaf area and chlorophyll index in a rice crop. The results showed significant variation in these parameters across treatments, indicating the impact of chemical herbicides and mechanical weeding on plant growth and vigour.

Plant Height (cm)

Plant height is a key indicator of overall plant vigour and health in rice crops. In this study, plant height ranged from 78.32 cm in the weedy control to 105.68 cm in the weed-free treatment (Table 2). The highest plant height in weed-free conditions demonstrates that eradicating weeds during the growing season promoted optimal plant growth by removing competition for nutrients, water and light. Among the herbicide treatments, butachlor at 1.5 L/ha, followed by hand weeding at 30 DAT and pendimethalin at 1.5 L/ha, also followed by hand weeding at 30 DAT, achieved significant plant heights of 100.85 cm and 99.01 cm, respectively. These results highlight the effectiveness of combining herbicide application with manual weeding. The weedy control had the lowest plant height due to significant competition from weeds, which hindered plant growth. Butachlor, a pre-emergent herbicide, inhibits cell division in the meristematic tissues of emerging weed seedlings, thereby suppressing their growth. It inhibits fatty acid synthesis by interrupting key enzymes involved in the elongation and desaturation of fatty acids; hence, it diminishes the growth of shoots and roots in weed seedlings. As a pre-emergent herbicide, it targets emerging weeds, thus inhibiting competition with the crop for essential nutrients (12-14).

Table 1. Herbicide mode of action, chemical classification and molecular formula

Name	Mode of action	Chemical class	Molecular formula
Butachlor	Selective, Systemic	Chloroacetamide	$C_{17}H_{26}ClNO_2$
Pendimethalin	Selective, Contact	Dinitroaniline	$C_{13}H_{19}N_3O_4$
Fenoxaprop–p–ethyl	Selective, Systemic	Aryloxphenoxypropionate	$C_{18}H_{16}ClNO_5$
Ethoxysulfuron	Selective, Systemic	Sulfonylurea	$C_{15}H_{18}N_4O_7S$
Metsulfuron methyl	Selective, Systemic	Sulfonylurea	$C_{14}H_{15}N_5O_6S$

Table 2. Effect of weed management practices on growth attributes of transplanted rice

Treatments	Plant height (cm)	Tillers per plant	No. of leaves per m²	Leaf area (cm²)	Chlorophyll index (SPAD)	Grain yield (kg/ha)
Weedy check	78.32 ± 9.9	11.44 ± 1.0	53.03 ± 2.0	55.00 ± 1.7	35.27 ± 2.9	2909.0±42.84
Hand weeding	97.00 ± 2.0	15.55 ± 1.7	67.03 ± 2.2	65.26 ± 1.3	41.80 ± 2.3	5033.67±49.67
Butachlor @ 3 L/ha	96.33 ± 2.7	14.55 ± 1.7	64.92 ± 1.4	64.93 ± 1.3	40.63 ± 1.5	5540.67±126.87
Pendimethalin @ 3 L/ha	94.60 ± 2.0	14.11 ± 2.4	57.70 ± 2.0	64.04 ± 2.0	40.47 ± 2.6	5175.33±37.70
Fenox-a-prop p ethyl @ 1 L/ha	82.79 ± 2.2	12.00 ± 0.9	54.11 ± 2.5	58.51 ± 2.3	37.97 ± 2.5	4762.99±94.19
Ethoxysulfuron @ 125 g ha^{-1}	92.09 ± 1.6	13.77 ± 1.2	57.11 ± 2.2	64.01 ± 1.5	39.23 ± 2.0	4508.0± 68.03
Metsulfuron methyl @ 75 g/ha	89.76 ± 2.3	13.00 ± 2.7	54.78 ± 2.0	63.19 ± 2.1	39.03 ± 1.4	4480±69.94
Butachlor @ 1.5 L/ha *fb* hand weeding at 30DAT	100.85 ± 2.8	17.11 ± 1.2	73.03 ±1.7	68.19 ± 1.0	44.07 ± 2.0	5389.327±36.46
Pendimethalin @ 1.5 L/ha *fb* HW at 30 DAT	99.01 ± 1.5	16.22 ± 1.7	71.00 ± 1.9	66.21 ± 2.2	42.97 ± 2.1	5266.03±82.20
weed free	105.68 ± 2.1	18.55 ± 1.0	75.44 ± 1.3	74.73 ± 1.7	47.50 ± 1.0	5876.54±64.20
CD(p<0.05)	3.68	2.719	2.957	3.227	3.827	228.379

Tillers per plant

Tiller count is a critical yield determinant, as each tiller contributes to panicle formation. The tiller count ranged from 11.44 in the weedy control to 18.55 in the weed free treatment. The absence of weeds in the weed free plot facilitated optimal tillering, while the application of butachlor at 1.5 L/ha, followed by manual weeding at 30 DAT (17.11) and pendimethalin at 1.5 L/ha, followed by one hand weeding at 30 DAT (16.22), resulted in a higher number of tillers per plant due to effective weed management, which reduced competition during critical stages of tiller development. The herbicide only applications, comprising butachlor at 3 L/ha and pendimethalin at 3 L/ha, demonstrated moderate tiller counts of 14.55 and 14.11, respectively. On the other hand, fenoxaprop-p-ethyl at 1 L/ha and metsulfuron-methyl at 75 g/ha led to lower tiller counts of 12.00 and 13.00, respectively. This meant that extra manual weeding was needed to encourage tiller growth. The combination of a butachlor application and manual weeding at 30 DAT guarantees extended weed control. Butachlors' initial weed suppression promotes crop establishment without competition, while hand weeding at 30 DAT eradicates any subsequently germinating weeds. This dual method reduces competition during tiller development, increasing the count. Fenoxaprop-p-ethyl and metsulfuron-methyl are post-emergent herbicides, which means they work after weeds have started to grow and compete with crops for resources. In managing particular weed species, they may permit other weeds, especially those influenced by their method of action, to compete with the crop. The absence of following hand weeding allows certain weeds to persist, diminishing the resources available to the crop and resulting in reduced tiller counts. Similar results were reported previously (14-16).

Number of leaves per plant

Leaf count, an indicator of photosynthetic potential, varied significantly across treatments, with the highest (75.44) recorded in the weed free treatment. This treatment allowed the unhindered growth of leaves due to the absence of weeds. Among the herbicide treatments, the application of Butachlor at 1.5 L/ha, followed by hand weeding at 30 DAT (73.03) and pendimethalin at 1.5 L/ha, followed by one hand weeding at 30 DAT (71.00), resulted in higher leaf counts, indicating the effectiveness of integrated herbicide and manual weeding strategies in stimulating leaf growth. The control had the lowest leaf count (53.03), indicating the detrimental effect of weed competition on leaf production. Alternative treatments showed moderate leaf counts, suggesting that herbicides alone were somewhat helpful in weed control; however, they were not as efficient as when combined with hand weeding. Pre-emergence herbicides such as Butachlor and Pendimethalin inhibit initial weed development (17). The combination of herbicide application and manual weeding diminished weed competition and improved light absorption in the crop canopy. An enhanced crop with increased foliage signifies superior photosynthetic efficiency, resulting in higher growth and greater leaf yield (18).

Leaf area (cm²)

Leaf area is an essential indicator of a plants' photosynthetic capacity, as larger leaves can absorb more sunlight, facilitating enhanced growth and development. The maximum leaf area was observed in the weed-free condition (74.73 cm^2), which encountered no weed interference over the entire crop cycle. Butachlor at 1.5 L/ha, followed by hand weeding at 30 DAT (68.19 cm^2) and Pendimethalin at 1.5 L/ha, followed by one hand weeding at 30 DAT (66.21 cm^2), exhibited significant leaf areas, illustrating the advantages of combining herbicide application with hand weeding. The weedy control displayed the lowest leaf area (55.00 cm^2) because of significant weed competition that likely inhibited leaf growth. The herbicide only treatments exhibited moderate leaf areas, emphasizing the need for integrated weed management strategies to attain superior outcomes (19). The weed free treatment allowed the crop to fully utilize all available resources, including nutrients, water and sunlight, as there was no weed competition through-out the crop cycle. This unlimited access optimized the crops' development potential, resulting in the maximum leaf area. Both butachlor and pendimethalin are effective herbicides for controlling weeds during the initial growth stages, thereby reducing weed competition. Despite some manual weeding at 30 DAT, combining chemicals and hand weeding allowed the crop to develop mostly uninterrupted by weed competition during the essential vegetative phase (20).

Chlorophyll index (SPAD)

The chlorophyll index, assessed with a SPAD meter, indicates the chlorophyll of leaves and indirectly measures the plants' photosynthetic efficiency. The weed free treatment exhibited the highest chlorophyll index (47.50 SPAD), suggesting that eliminating weeds allowed enhanced nutrient absorption and more effective photo-synthesis. The application of butachlor at 1.5 L/ha, followed by hand weeding 30 DAT (44.07 SPAD), resulted in an increased chlorophyll index, thereby demonstrating the benefits of combining herbicides with manual weeding to maintain higher levels of chlorophyll in the foliage. The weedy control had the lowest chlorophyll index (35.27 SPAD), likely due to nutritional competition with weeds, which hindered the plants' ability to maintain sufficient chlorophyll levels. The weed free treatment completely eradicated the weeds, enabling the crop to utilize all available nutrients, water and sunlight exclusively. The lack of competition enabled the crop to absorb more significant nutrients, such as nitrogen, magnesium and iron, vital for chlorophyll synthesis (19, 20). Butachlor is a pre-emergent herbicide that predominantly targets annual grasses and certain broadleaf weeds. It functions by obstructing the manufacture of lipids, proteins and nucleic acids, which are crucial for cellular division and growth in young weed seedlings. By targeting weed seedlings before emergence, Butachlor markedly diminishes weed competition during the initial phases of crop development. This initial regulation enables the crop to assimilate additional nutrients during the essential vegetative stage, hence enhancing chlorophyll synthesis (18, 21).

Fresh weight (g)

The fresh weight of rice plants exhibited significant variation among treatments in case of weight. The weed free treatment had the highest fresh weight (88.23 g), indicating optimal growth due to the absence of weed competition (Table 3). Applying butachlor at 1.5 L/ha and then hand weeding 30 DAT resulted in a significant fresh weight of 85.70 g, demonstrating the effectiveness of combining pre-emergence herbicide application with manual weeding in reducing weed pressure and enhancing biomass accumulation (21, 22). The practical butachlor action method generally suppressed weeds early, while hand weeding further reduced competition, facilitating optimal growth. Among the various treatments, pendimethalin was applied at 1.5 L/ha, followed by manual weeding at 30 DAT, which resulted in a fresh weight of 77.73 g. This result indicates that adding human weeding enhanced herbicides' effectiveness, resulting in improved plant growth. Conversely, the weedy check had the lowest fresh weight (51.39 g), as weeds significantly competed with the rice plants for resources, including light, nutrients and water. The weed–free treatment consistently yielded optimal conditions for rice cultivation throughout the crop cycle (22, 23). The complete eradication of weeds ensured that rice plants had unlimited access to all available resources (light, nutrients, water and space) during the growing season. This facilitated the rice plants' optimal growth potential, resulting in the maximum fresh weight.

Dry weight (g), crop growth rate (CGR) and relative growth rate (RGR)

Dry weight accurately reflects plant biomass by eliminating water content. The results exhibited similar trends to the fresh weight data. The weed-free experiment recorded a maximum dry weight of 44.51 g, indicating optimal development conditions free from weed competition. Using butachlor at 1.5 L/ha and hand weeding at 30 DAT led to a significant dry weight of 42.67 g. This shows that integrated weed control systems using chemicals and hand weeding help plants grow. The combination treatment of pendimethalin at 1.5 L/ha and hand weeding at 30 DAT produced a dry weight of 39.03 g, which was higher than the herbicide-only treatments and shows how important it is to use your hands to reduce weed competition. The weedy control exhibited the lowest dry weight (26.60 g), indicating that weed competition significantly restricts the biomass accumulation of rice plants. Butachlor is a pre-emergent herbicide targeting annual grasses and certain broadleaf weeds (21, 22). It obstructs cellular division in sprouting weed seeds, mainly targeting the creation of lipids, proteins and nucleic acids, which are vital for weed development. By inhibiting the early development of weeds in the crop cycle, butachlor markedly diminishes weed competition during the crucial growth stages of rice plants. The timely management of weeds guarantees that rice plants may fully utilize soil nutrients, water and sunlight throughout their early growth phases when establishing roots, stems and leaves (20, 21). This continuous access to resources enables the rice plants to accumulate greater biomass, as the increased dry weight shows. The weed-free treatment also recorded the highest CGR (0.575 $g/m^2/day$) and RGR (0.011 $g/g/m^2/day$), followed closely by butachlor @1.5 L/ha followed by (*fb)* hand weeding at 30 DAT with CGR of 0.559 $g/m^2/day$ and RGR of 0.0107 $g/g/m^2/day$, reflecting the effectiveness of these treatments in promoting crop relative growth.

Grain yield (kg/ha)

Different weed management practices significantly influenced grain yield. The highest yield (5876.54 kg/ha) was recorded in the weed-free treatment, followed by Butachlor @ 3L/ha (5540.67 kg/ha, indicating effective early weed suppression. The combined approach of Butachlor @ 1.5 L/ha + hand weeding at 30 DAS (T_7) and pendimethalin @ 1.5 L/ha + hand weeding at 30 DAS resulted in 5389.33 kg ha^{-1} and 5266 kg ha^{-1},

Table 3. Effect of different weed management practices on dry matter accumulation (g) and its attributes

Treatments	Fresh weight (g)	Dry weight (g)	CGR (g/m²/day)	RGR (g /g/m²/day)
Weedy check	51.39 ± 1.8	26.60 ± 1.9	0.288±0.040	0.004±0.0013
Hand weeding	75.10 ± 1.7	38.23 ± 2.7	0.435±0.074	0.005±0.0008
Butachlor @ 3 L/ha	74.70 ± 1.8	38.13 ± 1.4	0.420±0.054	0.005±0.0006
Pendimethalin @ 3 L/ha	73.05 ± 2.2	35.70 ± 3.3	0.409±0.046	0.004±0.0020
Fenox-a-prop p ethyl @ 1L/ha	53.07 ± 2.4	30.30 ±1.2	0.294±0.140	0.005±0.0008
Ethoxysulfuron @ 125 g ha	66.00 ± 2.1	34.80 ± 1.1	0.394±0.062	0.005±0.0008
Metsulfuron methyl @ 75g/ha	53.70 ± 1.8	31.83 ± 1.9	0.359±0.103	0.006±0.0009
Butachlor @ 1.5 L/ha *fb* hand weeding at 30DAT	85.70 ± 2.6	42.67 ± 1.5	0.559±0.063	0.0107±0.0018
Pendimethalin @1.5 L/ha *fb* HW at 30 DAT	77.73 ± 1.6	39.03 ± 1.2	0.448±0.053	0.010±0.0008
weed free	88.23 ± 2.1	44.51 ± 2.7	0.575±0.023	0.011±0.0011
CD(p<0.05)	3.205	3.456	0.02	0.143

respectively, highlighting the benefits of integrating chemical and manual weed control. The weedy checks' lowest yield (2909 kg ha^{-1}) confirmed severe yield losses due to weed competition. The results highlight the importance of integrated weed management, where pre-emergence herbicides supplemented with manual weeding enhance weed control and yield. Chemical weed control, particularly with Butachlor and Pendimethalin, proved effective, aligning with previous studies on herbicide efficacy in minimizing weed interference. These results are similar to the findings, which suggest that adopting a combined approach of herbicide application and manual weeding can optimize yield while ensuring sustainable weed management in crop production (20).

Effect of pre and post-emergence herbicides on weed density, weed biomass and weed control efficiency %

The effect of various treatments on weed density (No. m^{-2}) and weed biomass was observed at 20, 40 and 60 days after transplanting (DAT). The data provides insights into the efficacy of different weed management strategies in controlling the population of weeds, particularly *E. colona*, in rice fields (Table 3). At 20 DAT, the weedy check had the highest weed density (20.73 no.m^{-2}), indicating the absence of weed management measures. The increased density demonstrates the rapid proliferation of weeds in the absence of weed management. Without control measures, weeds face little competition from the crop, allowing them to establish, grow and reproduce rapidly. Crops typically compete for nutrients, water and light, but weeds gain an advantage in unmanaged conditions. The weed-free plot exhibited the lowest weed density at 1.97 no.m^{-2}, thereby confirming the efficacy of the total weed eradication. Weed densities were lower with butachlor at 3 L/ha and pendimethalin at 3 L/ha, measuring 6.13 no.m^{-2} and 7.80 no.m^{-2}, respectively. This shows that pre-emergence herbicides effectively stop weeds from coming up during the early stages of growth.

On the other hand, treatments with ethoxy sulfuron at 125 g/ha and fenoxaprop-p-ethyl at 1 L/ha had more weeds (15.23 No./m^2 and 16.30 No./m^2, respectively). The time of application may have diminished the efficacy of these post-emergence herbicides in reducing weed density at this early stage. Butachlor inhibits cellular division in roots and shoots, thereby impeding the establishment of weeds (22). Pendimethalin obstructs microtubule assembly, interfering with cellular division and initial development. The observed low weed densities indicate that these pesticides effectively inhibited numerous weed species' germination or early growth. Post-emergence herbicides precisely target weeds after their emergence (23). Their efficacy depends upon the weeds' development stage at the time of application and the selectivity of the herbicide. At 40 DAT, the weed density in the control group increased to 23.33 No./m^2, indicating the continued proliferation of weeds without management techniques. The weed-free treatment consistently exhibited the lowest weed density at 1.97 No./m^2. Butachlor at 1.5 L/ha, followed by hand weeding at 30 DAT and pendimethalin at 1.5 L/ha, also followed by hand weeding at 30 DAT, demonstrated superior weed control with 3.23 and 5.80 No densities./m^2, respectively. This result indicates that combining pre-emergence herbicides and manual hand weeding reduces weed populations at the critical growth phase. Conversely, the roots and coleoptiles of sprouting weeds absorb butachlor, preventing the growth of roots and shoots (23). This inhibits the germination of weed seedlings, mainly grassy species such as *Echinochloa colona*, from accessing the soil surface. Pendimethalin hinders microtubule assembly during cell division; hence, it effectively obstructs the development of new cells in weed seedlings. This inhibits the elongation of shoots and roots, thereby reducing the proliferation of weeds (24). Metsulfuron methyl at 75 g/ha and ethoxysulfuron at 125 g/ha caused higher weed densities (17.70 and 9.32 No./m^2, respectively), which might be due to both mesopleuron-methyl and ethoxysulfuron inhibiting acetolactate synthase (ALS), an enzyme involved in branched -chain amino acid synthesis. These herbicides are primarily effective against broadleaf weeds and sedges but show weak action against grasses. sing both pre-emergence herbicides and subsequent manual weeding, both treatments greatly reduced the number of weeds. This shows that an integrated strategy works well. Weed seedlings undergoing germination fail to develop roots and shoots due to the uptake of butachlor by the radicles and coleoptiles, which disrupts cellular division and elongation processes (24, 25). This is especially true for grassy species like *Echinochloa colona*, where the initial interruption hinders the establishment and manual weeding of any surviving or newly developing weeds at 30 DAT. Pendimethalin obstructs microtubule assembly during cellular division, which impedes shoot and root growth in weed seedlings.

Implementing hand weeding at a pivotal period (30 DAT) leverages the diminished weed population to decrease weed prevalence further. The fewer weeds in these treatments show that using both herbicides and manual methods together can help control weeds for longer periods of time and make up for the lack of pesticides, especially for weeds that grow later (23, 20). The mechanisms of action of herbicides account for the differential control of weeds. It worked better with herbicides like butachlor and pendimethalin that stop weeds from growing roots and shoots early on. Later on, the weeds were already well established with acetolactate synthase inhibitors and ethoxy sulfuron, which target enzymatic pathways, making those herbicides less effective. At 60 days after transplanting, the weed density in the weedy check reached 28.37 No./m^2, highlighting the persistent, uncontrolled proliferation of weeds, likely resulting in considerable competition with the rice crop. Among the treatments, the weed-free control exhibited the lowest weed density at 1.07 No./m^2, followed closely by butachlor at 1.5 L/ha, then hand weeding at 30 DAT with 5.47 No./m^2 and pendimethalin at 1.5 L/ha, followed by hand weeding with 6.50 no./m^2. The results indicate that integrated management strategies are the most effective in sustaining low weed densities even 60 days after treatment when weed competition can considerably impact crop output (24). Butachlor prevents the establishment of weed seedlings, markedly decreasing weed density during the early stages (20 DAT). Prompt eradication is essential for minimizing competition for nutrients, water and light between crops and weeds. Pendimethalin is notably efficacious against a wide range of weeds, encompassing annual grasses, such as *Echinochloa crus–galli* and certain broadleaf species (25). It provides extended residual control, reducing weed populations at later intervals (40 and 60 DAT). Conversely, metsulfuron methyl exhibited elevated weed densities, attaining 16.90 No./m^2, suggesting that this herbicide may be less efficacious for long-term weed management.

Also, ethoxysulfuron at 125 g/ha caused more weeds to grow at 60 DAT (13.47 No./m^2), supporting the idea that post-emergence herbicides might not work for a long time when used by themselves. The maximum total weed density was observed in the weedy check at 72.43 No./m^{-2}. The lowest weed density was recorded in the weed-free condition, with merely 5.00 no.m^{-2}. The herbicide treatments that had the fewest weeds were butachlor at 1.5 L/ha followed by hand weeding at 30 DAT (16.13 No./m^2), closely followed by butachlor at 3 L/ha (15.90 No./m^2), which shows that they worked well to control the weeds. Conversely, ethoxysulfuron at 125 g/ha and metsulfuron methyl at 75 g/ha exhibited elevated weed densities of 38.02 and 49.03 No./m^2, respectively.

Weed biomass

At 20 DAT, the weed free strategy resulted in the lowest fresh and dry weight of weeds, with values of 41.76 g and 13.99 g, respectively (Table 4). The hand-weeding treatment demonstrated a considerable reduction in weed biomass relative to the untreated control, with fresh weight (FW) and dry weight (DW) measurements of 118.97 g and 36.00 g, respectively. Pendimethalin at 3 L/ha and butachlor at 3 L/ha both significantly reduced the amount of weed biomass, resulting in 92.80 g of FW and 25.81 g of dry weight (DW), as well as 97.50 g of FW and 30.87 g of DW. Conversely, ethoxysulfuron at 125 g/ha resulted in the highest FW of 185.65 g and DW of 50.86 g at 20 DAT, suggesting reduced efficacy in the early stages of weed management. Fenoxaprop -p-ethyl at 1 L/ha exhibited relatively high weed biomass, with 161.37 g FW and 40.84 g DW, suggesting limited effectiveness in the early stages of weed control. At 40 DAT, the weed-free plot maintained the lowest fresh and dry weights of weeds, measuring 12.76 g and 3.03 g, respectively. Applying pendimethalin at 1.5 L/ha, followed by a single hand weeding at 30 DAT, significantly diminished weed biomass to 30.03 g fresh weight and 11.05 g dry weight. Similarly, Butachlor applied at 1.5 L/ha, followed by manual weeding at 30 DAT, resulted in minimal weed biomass, measuring 37.19 g FW and 18.56 g DW. Both butachlor at 3 L/ha and pendimethalin at 3 L/ha exhibited efficient weed control, yielding fresh weights of 70.64 g and 85.35 g and dry weights of 31.55 g and 24.29 g, respectively. Fenoxaprop-p-ethyl and ethoxysulfuron led to more weeds at 40 DAT, which means they weren't as effective as other treatments. At 60 DAT, the weed-free treatment sustained the lowest weed biomass, recording values of 12.43 g FW and 2.73 g DW. With pendimethalin at 1.5 L/ha, hand weeding and butachlor at 1.5 L/ha, the integrated weed management treatments effectively stopped weed growth, leading to lower fresh weights of 40.48 g and 36.85 g and lower dry weights of 19.83 g and 13.63 g. The herbicide-only treatments that worked best were butachlor at 3 L/ha, which got 77.31 g of fresh weight and 76.23 g of dry weight. Pendimethalin at 3 L/ha ranked second, with 95.35 g of FW and 60.93 g of DW. At 60 DAT, fenoxaprop-p-ethyl and ethoxysulfuron had the most weed biomass. Ethoxy-sulfuron had the highest fresh weight at 171.03 g and the highest dry weight at 89.37 g. Fenoxaprop-p-ethyl came in second with 132.73 g fresh weight and 56.97 g dry weight. The weedy check consistently exhibited the largest weed biomass during the experiment, measuring 262.10 g FW and 89.67 g DW at 20 DAT, 278.71 g FW and 148.39 g DW at 40 DAT and 294.05 g FW and 94.73 g DW at 60 DAT. This emphasizes the significance of weed management in mitigating weed competition and optimizing resource distribution for the crop. The weed-free treatment and integrated methods incorporating manual weeding were the most effective in diminishing weed biomass, consistently yielding the lowest fresh and dry weights at all stages (24, 25). Butachlor at 3 L/ha and pendimethalin at 3 L/ha worked better than post-emergence herbicides like fenoxaprop-p-ethyl and ethoxysulfuron in the herbicide-only treatments (26). The untreated weedy control

Table 4. Impact of weed management practices on dry matter accumulation of weeds

Treatments	Weed fresh weight (g/m^2) at 20 DAT	Weed fresh weight (g/m^2) at 40 DAT	Weed fresh weight (g/m^2) at 60 DAT	Weed dry weight (g/m^2) at 20 DAT	Weed dry weight (g/m^2) at 40 DAT	Weed dry weight (g/m^2) at 60 DAT	Total dry matter accumulation of weeds (g/m^2)
Weedy check	16.22 (262.10±3.2)	16.72 (278.71±1.8)	17.16 (294.04±3.2)	9.52 (89.7±3.1)	12.2 (148.4±1.7)	9.758 (94.73±3.6)	18.27 (332.79±2.95)
Hand weeding	10.95 (118.97±1.2)	8.81 (76.723.7)	9.38 (87.5±2.8)	6.08 (36±2.5)	6.49 (41.23±2.3)	5.614 (31.03±2.0)	10.45 (108.26±2.09)
Butachlor @ 3 L/ha	9.68 (92.80±3.5±2.8)	8.46 (70.64±2.7)	8.00 (77.31±3.1±2.6)	5.17 (25.81±3.4)	5.7 (31.55±1.7)	8.757 (76.23±1.7)	11.6 (133.59±1.68)
Pendimethalin @ 3 L/ha	9.92 (97.50±2.5)	9.29 (85.35±2.6)	9.790 (95.35±2.6)	5.64 (30.87±2.3)	5.02 (24.29±2.5)	7.838 (60.93±1.5)	10.82 (116.10±2.56)
Fenox-a-prop p ethyl @ 1L/ha	12.74 (161.37±3.2)	11.20 (124.47±2.9)	11.542 (132.7±1.8)	6.46 (40.8±0.5)	7.71 (58.50±1.5)	7.580 (56.96±2.4)	12.54 (156.31±2.8)
Ethoxysulfuron @ 125 g ha	13.661 (185.65±1.2)	11.56 (132.83±3.2)	13.097 (171.02±2.1)	7.2 (50.86±1.9)	8.74 (75.49±2.2)	8.62 (66.36±2.9)	13.9 (192.38±1.98)
Metsulfuron methyl @ 75g/ha	11.419 (129.40±2.1)	11.33 (127.5±2.6)	12.272 (150.1±2.8)	6.21 (37.5±2.5)	8.68 (74.47±1)	8.070 (64.633±0.8)	13.32 (176.65±2.87)
Butachlor @ 1.5 L/ha *fb* hand weeding at 30DAT	9.789 (94.83±1.9)	6.17 (37.19±0.60)	6.111 (36.85±1.1)	5.29 (27.0±3.0)	4.42 (18.56±0.5)	3.755 (13.63±1.6)	7.75 (59.19±2.16)
Pendimethalin @ 1.5 L/ha *fb* HW at 30 DAT	9.860 (96.23±2.5)	5.57 (30.03±1.6)	6.402 (40.483±0.60)	5.70 (31.6±3.1)	3.47 (11.05±1.3)	4.509 (19.83±0.4)	7.96 (62.47±2.13)
weed free	6.53 (41.76±2.8)	3.70 (12.76±0.80)	3.595 (12.43±0.50)	3.85 (13.99±2.5)	1.99 (3.03±0.7)	1.789 (2.73)	4.54 (19.75±2.73)
CD(p<0.05)	0.225	0.256	0.18	0.421	0.314	0.305	0.331

Original data given in parenthesis were subjected to square root √(x+1) transformation before analysis.

plot noted the maximum dry matter accumulation at 332.79 g/m^2. This signifies the uncontrolled proliferation of weeds without any management strategies. The weed-free treatment exhibited minimal dry matter accumulation at 19.75 g m^{-2}, emphasizing the efficacy of sustaining a weed-free environment during the growth period.

Weed control efficiency (%)

The weed-free treatment recorded the maximum weed control efficacy (WCE) at 84.36 % at 20 DAT, followed by butachlor at 3 L/ha at 71.13 % and pendimethalin at 3 L/ha at 65.50 %, as shown in Table 5. Ethoxysulfuron, at 125 g/ha, exhibited the lowest WCE at 43.20 %, indicating a lower early weed control efficacy than other treatments. At 40 days after treatment, the WCE increased for most treatments, with weed-free showing the highest efficiency at 97.96 %. The use of butachlor at 1.5 L/ha, in conjunction with hand weeding, significantly improved the efficacy of weed control, reaching 92.54 %. Pendimethalin at 3 L/ha demonstrated efficacy of 83.61 %. Nonetheless, treatments such as ethoxysulfuron at 125 g/ha and metsulfuron methyl at 75 g/ha exhibited comparatively low WCE values of 49.11 % and 49.81 %, respectively. At 60 DAT, the weed-free plot had a high WCE of 97.12 %, demonstrating effective weed suppression. Butachlor at 1.5 L/ha followed by hand weeding attained an 85.58 % weed control efficacy, whereas pendimethalin at 1.5 L/ha followed by hand weeding recorded a 79.05 % efficacy. On the other hand, butachlor at 3 L/ha decreased WCE to 19.40 %. metsulfuron methyl at 75 g/ha and ethoxysulfuron at 125 g/ha had even lower efficacies, at 31.72 % and 30.26 %, respectively. The findings demonstrate that the hand-weeding and weed-free treatments yielded superior weed control at all stages, with the highest WCE values observed. Using a chemical treatment along with hand weeding (for example, butachlor at 1.5 L/ha followed by hand weeding) led to better long-term weed control, as shown by significantly better weed control 60 days after treatment (26). This indicates that integrating mechanical and chemical techniques improves the efficacy of weed control. Both butachlor and pendimethalin, which are pre-emergent herbicides, worked well when used in the right amounts, but they became less effective over time if they weren't combined with hand-weeding, as seen in the WCE at 60 DAT. During the research, post-emergent herbicides like ethoxysulfuron and metsulfuron-methyl consistently had lower WCE values, which showed that they weren't very good at controlling the weed population (21, 22, 26).

Correlation between Weed density, dry matter accumulation of weeds and WCE %

A strong positive correlation (0.94) exists between total weed density and total dry matter of weeds, signifying that increased weed density results in more dry matter accumulation, as represented in Fig. 2. The WCE % at 20 and 40 DAT exhibits a strong negative correlation with total weed density (-0.93 and -0.97, respectively) and total dry matter of weeds (-0.94 and -0.98, respectively). Increased weed management efficiency reduces weed density and biomass during these initial stages. The WCE % at 60 DAT exhibits a diminished but significant negative correlation with total weed density (-0.73) and dry matter (-0.89). This indicates that the efficacy of weed manage-ment diminishes over time. The WCE (%) at 20 and 40 DAT exhibit a strong positive correlation (0.96), suggesting that efficient weed management at 20 DAT is a reliable predictor for weed control at 40 DAT. The WCE (%) at 60 DAT exhibits a moderate positive association with the WCE % at 20 DAT (0.7) and 40 DAT (0.79), indicating that initial weed control measures influence long-term efficacy to a lesser extent than during the earlier phases.

Correlation between weed density, dry matter accumulation of weeds and grain yield

A strong negative correlation (-0.95) suggests that higher weed density leads to a significant reduction in grain yield as indicated in Fig. 3. This highlights the competitive effect of weeds on crops. A robust negative correlation (-0.98) suggests that increased weed biomass significantly reduces grain yield, emphasizing the importance of effective weed management.

Table 5. Effect of weed management practices on weed density (No/m^2) and weed control efficiency % at different interval

Treatments	Weed density at (20 DAT) (no/m^2)	Weed density at (40 DAT) (no/m^2)	Weed density at (60 DAT) (no/m^2)	Total weed density (no/m^2)	WCE % at 20DAT	WCE % at 40DAT	WCE % at 60DAT
Weedy check	5.052 (20.73±1.1)	5.163 (23.33±0.81)	5.66(28.37±1.66)	8.56 (72.43±2.57)	–	–	–
Hand weeding	4.173 (13.50±0.9)	3.087(7.60±0.89)	2.29(3.83±0.68)	5.09 (24.93±1.68)	59.85±2.1	72.22±1.4	67.20±2.2
Butachlor @ 3 L/ha	2.975 (6.13±0.5)	2.406(4.30±0.36)	2.66(5.47±1.21)	4.11(15.9±0.82)	71.13±3.8	78.74±1.0	19.40±3.7
Pendimethalin @ 3 L/ha	3.288 (7.80±1.2)	3.101(7.67±0.50)	3.10(7.70±1.15)	4.91 (23.17±2.54)	65.50±2.8	83.61±1.9	35.61±2.5
Fenox-a-prop p ethyl @ 1L/ha	4.535 (16.30±1.4)	3.025(7.27±1.0)	3.07(7.50±1.01)	5.65 (31.07±2.81)	54.35±3.7	60.57±1.2	39.84±2.2
Ethoxysulfuron @ 125 g ha	4.402 (15.23±0.9)	3.384(9.32±0.89)	4.00(13.47±0.74)	6.24 (38.02±0.88)	43.20±3.3	49.11±2	30.26±2.7
Metsulfuron methyl @ 75g/ha	4.297 (14.43±1.1±1.1)	4.539(17.7±1.01)	4.44(16.90±1.48)	7.07 (49.03±0.70)	58.03±3.3	49.81±0.40	31.72±1.9
Butachlor @ 1.5 L/ha *fb* hand weeding at 30DAT	3.222 (7.43±1.1)	2.130(3.23±0.35)	2.66(5.47±1.15)	4.13 (16.13±1.86)	69.85±2.9	92.54±1.0	85.58±1.6
Pendimethalin @1.5 L/ha *fb* HW at 30 DAT	3.895 (11.53±0.9)	2.737(5.80±0.85)	2.88(6.50±1.05)	4.98 (23.83±1.21)	64.80±2.3	87.50±0.20	79.05±0.50
weed free	1.887(0.7)	1.729(1.97±0.47)	1.37(1.07±0.12)	2.44(5.0±1.20)	84.36±2.5	97.96±0.50	97.12±0.70
CD(p<0.05)	0.262	0.250	0.338	0.315	5.198	2.450	4.978

Original Data given in parenthesis were subjected to square root √(x+1) transformation before analysis.

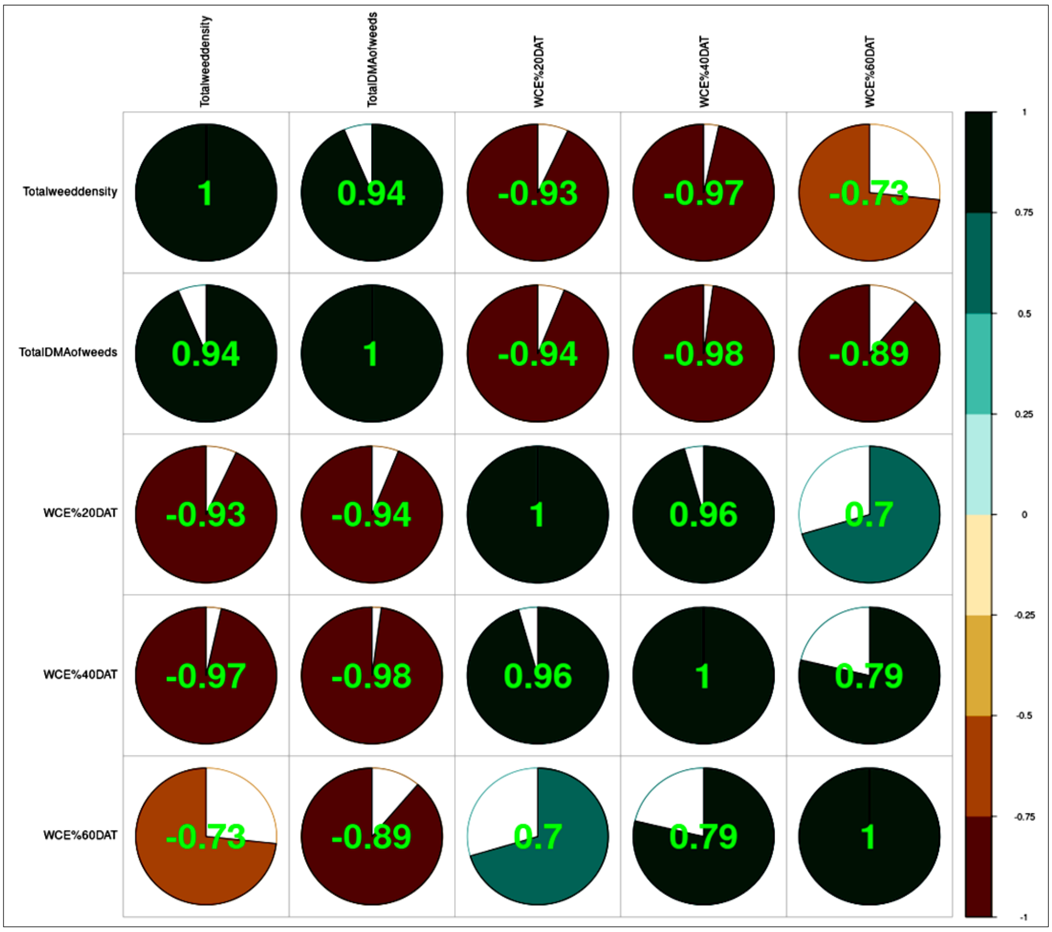

Fig. 2. Correlation of weed density, weed biomass and weed dry matter.

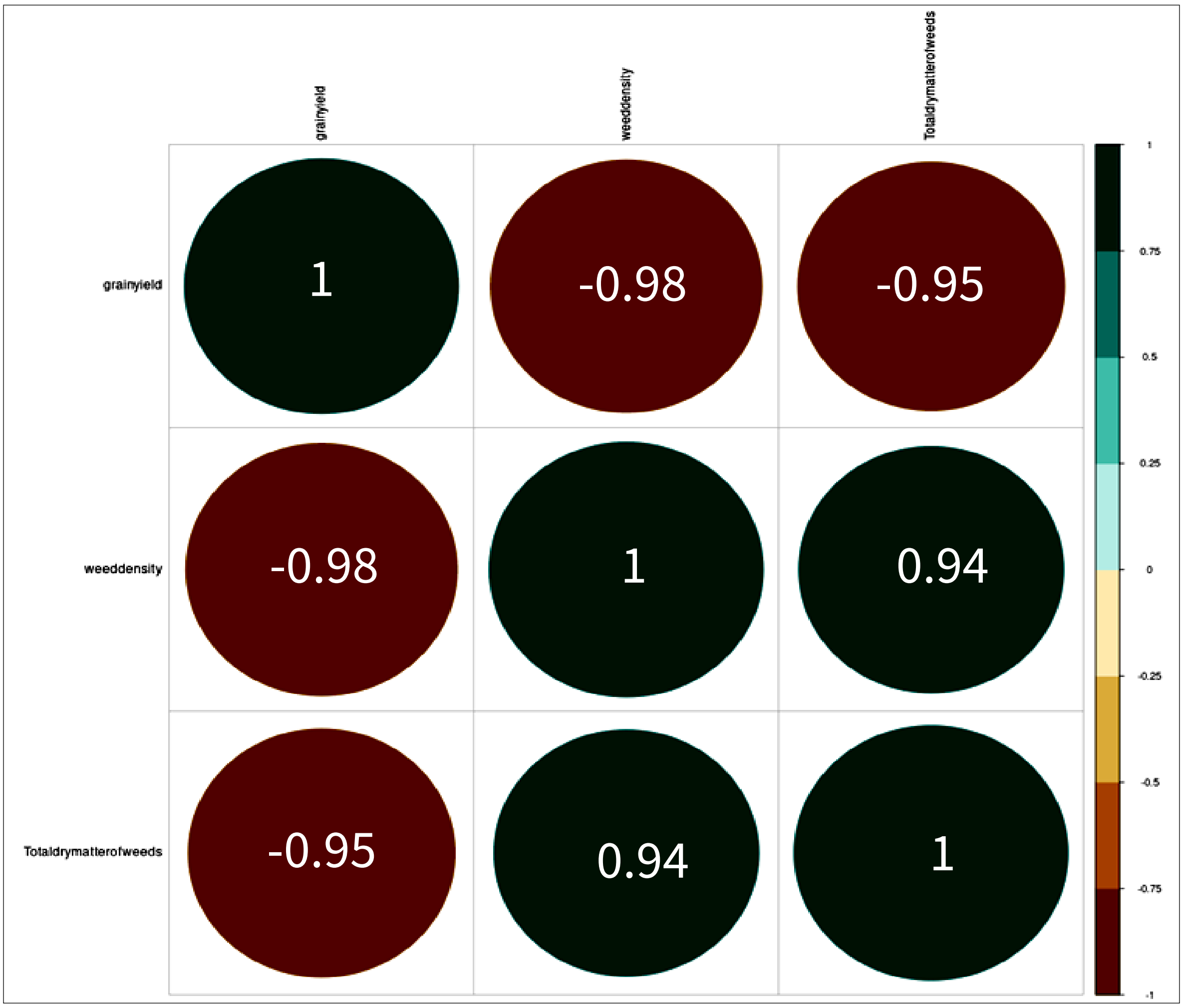

Fig. 3. Correlation of weed density, weed biomass and grain yield.

A strong positive correlation (0.94) suggests that as weed density increases, the total dry matter of weeds also increases. This confirms that a higher number of weeds results in greater biomass accumulation.

Principal component Analysis

The two axes in Fig. 4 likely represent two main components, PC1 and PC2, each of which represents a percentage of the variance the data explains. The scale ranges from -1 to 1 on both axes. The closest arrows signify a positive connection between the variables. The closeness of WCE 20 DAT and WCE 40 DAT indicates a positive correlation between them. Arrows directed in opposing directions signify a negative correlation. Weeds' DMA arrow points opposite the WCE 60 DAT arrow, suggesting a significant negative correlation between the two variables. The colour bar on the proper side transitions from cool (cyan/blue) to warm (orange/red), signifying the correlation or variance contribution intensity for each variable. Warm colours (orange/red) signify variables that probably exert a more substantial influence or exhibit a stronger association, whereas cool colours (blue/cyan) denote lower contributions.

Conclusion

The research highlights early weed managements' significance, mainly by applying pre-emergence herbicides like Butachlor and Pendimethalin. These herbicides effectively inhibit weed establishment during the crucial initial phases of crop development. However, their effectiveness gradually decreases if hand weeding, hoeing, or other techniques. Integrated weed management, which incorporates chemical and mechanical control, is the best sustainable approach for successful, prolonged-term weed suppression. Conversely, post-emergence herbicides, specifically ethoxysulfuron and metsulfuron-methyl, exhibited restricted long-term effectiveness, suggesting they are less appropriate for sole application. The results indicate that a comprehensive weed management strategy is crucial for effective weed control and improving rice crop yield.

Acknowledgements

Authors are thankful to Lovely Professional University, Phagwara.

Authors' contributions

AGB prepared the research plan and analysis. AJ provided guidelines and research methodology during the research work. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declared that they have no conflict of interest concerning this work.

Ethical issues: None

References

1. Mohapatra PK, Sahu BB. Panicle architecture of rice and its relationship with grain filling. Cham: Springer International Publishing; 2022. https://doi.org/10.1007/978-3-030-67897-5_2
2. Tiwari S, Nutan KK, Deshmukh R, Sarsu F, Gupta KJ, Singh AK, et al. Seedling￾stage salinity tolerance in rice: decoding the role of transcription factors. Physiol Plant. 2022;174(2):e13685. https://doi.org/10.1111/ppl.13685
3. Chauhan BS, Awan TH, Abugho SB, Evengelista G. Effect of crop establishment methods and weed control treatments on weed

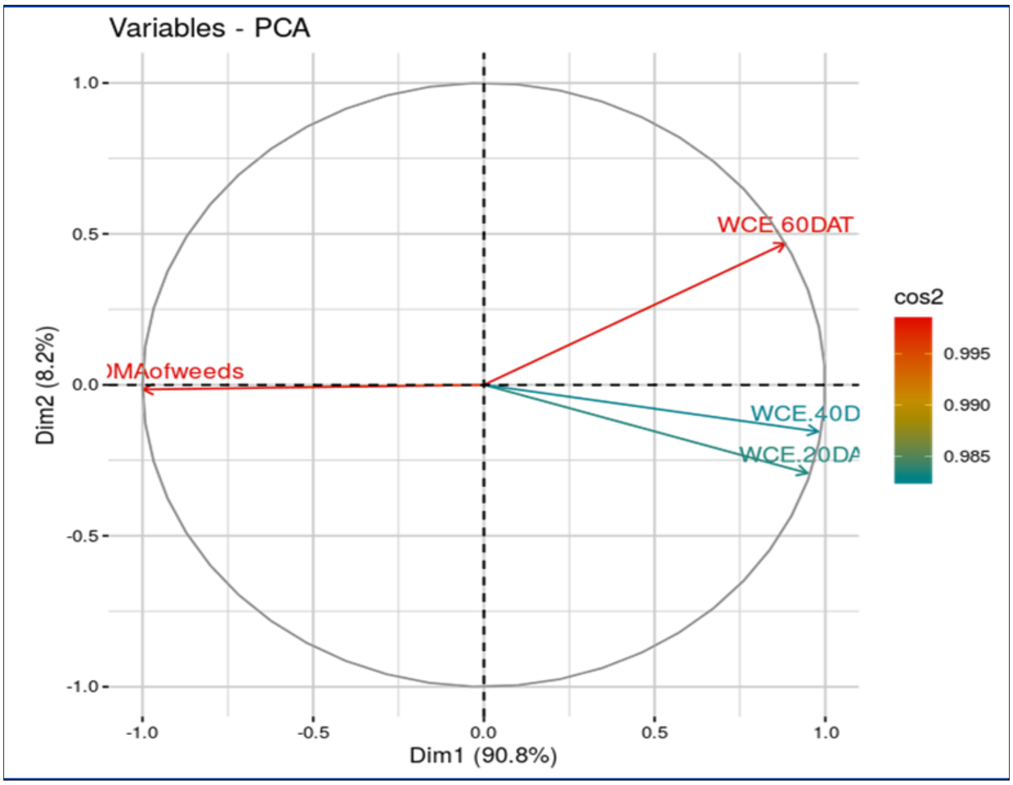

Fig. 4. Principal Component Analysis (PCA) biplot or correlation circle plot, showing the relationship between multiple variables based on principal component analysis.

management and rice yield. Field Crops Res. 2015;172:72–84. https://doi.org/10.1016/j.fcr.2014.12.011

4. Dass A, Shekhawat K, Choudhary AK, Sepat S, Rathore SS, Mahajan G, et al. Weed management in rice using crop competition-a review. Crop Prot. 2017;95:45–52. https://doi.org/10.1016/j.cropro.2016.08.005

5. Mahajan G, Chauhan BS, Kumar V. Integrated weed management in rice. In: Chauhan B S, Mahajan G, editors. Rec Adv Weed Manage. New York: Springer; 2014.p.125–53. https://doi.org/10.1007/978–1–4939–1019–96

6. Hruševar D, Mitić B, Sandev D, Alegro A. *Echinochloa colona* (L.) Link (Poaceae), a new species in the flora of Croatia. Acta Bot Croat. 2015;74(1):159–64. https://doi.org/10.1515/botcro-2015-0013

7. Galon L, Agostinetto D. Comparison of empirical models for predicting yield loss of irrigated rice (*Oryza sativa*) mixed with *Echinochloa* spp. Crop Protect. 2009;28(10):825–30. https://doi.org/10.1016/j.cropro.2009.06.005

8. Onwuchekwa-Henry CB, Ogtrop VF, Roche R, Tan DK. Evaluation of pre-emergence herbicides for weed management and rice yield in direct-seeded rice in Cambodian lowland ecosystems. Farming Syst. 2023;1(2):100018. https://doi.org/10.1016/j.farsys.2023.100018

9. Singh V, Singh AK, Mohapatra T, S GK, Ellur RK. Pusa Basmati 1121 -a rice variety with exceptional kernel elongation and volume expansion after cooking. Rice. 2018;11:1–10. https://doi.org/10.1186/s12284-018-0213-6

10. Biswas B, Timsina J, Garai S, Mondal M, Banerjee H, Adhikary S, et al. Weed control in transplanted rice with post-emergence herbicides and their effects on subsequent rapeseed in Eastern India. Int J Pest Manag. 2023;69(1):89–101. https://doi.org/10.17311/tas.2023.76.81

11. Gangireddy G, Subramanyam D. Bio-efficacy of pre-and post-emergence herbicides on weed control and yield of rainfed lowland rice. Indian J Weed Sci. 2020;52(2):179–82. https://doi.org/10.5958/0974-8164.2020.00032.5

12. Jehangir IA, Hussain A, Sofi NR, Wani SH, Ali OM, Latef AA, et al. Crop establishment methods and weed management practices affect grain yield and weed dynamics in temperate rice. Agron. 2021;11(11):2137. https://doi.org/10.3390/agronomy11112137

13. Reddy MSS, Ameena M. Efficacy of pre-and post-emergence ready -mix herbicides in rainfed lowland wet-seeded rice. Ind J Weed Sci. 2021;53(1):88–91. https://doi.org/10.5958/0974-8164.2021.00014.9

14. Aparna KK, Menon MV, Prameela P. Efficacy of pre and post-emergence herbicides on *Echinochloa* spp. J Trop Agric. 2017;55 (1):91–95. https://jtropag.kau.in/index.php/ojs2/article/view/505

15. Gharde Y, Singh PK, Dubey RP, Gupta PK. Assessment of yield and economic losses in agriculture due to weeds in India. Crop Protect. 2018;107:12–18. https://doi.org/10.1016/j.cropro.2018.01.007

16. Mohapatra S, Tripathy SK, Mohanty AK. Sequential application of pre-and post-emergence herbicides for the control of weeds in transplanted rice at Hirakud command areas of Odisha. Indian J Weed Sci. 2021;53(2):132–35. https://doi.org/10.5958/0974-8164.2021.00066.6

17. Pramanik K, Shah MH, Gupta RK, Singhal M. Bio-efficacy of ready-mix herbicide on weed flora and productivity of transplanted rice. Int J Bio-resour Stress Manag. 2020;11(2):132–37. https://doi.org/10.23910/IJBSM/2020.11.2.2073a

18. Anand SR, Murthy N, Lingappa BS. Evaluation of pre and post-emergence herbicides for weed control in rice bean (*Vigna umbellata*) crop under rain-fed condition. J Crop Weed. 2020;16 (2):176–80. https://doi.org/10.22271/09746315.2020.v16.i2.1334

19. Kokilam MV, Rathika S, Ramesh T, Baskar M. Weed dynamics and productivity of direct wet-seeded rice under different weed management practices. Indian J Agric Res. 2023;57(3):347–51. https://doi.org/ 10.18805/IJARe.A-5586

20. Sen S, Kaur R, Das TK. Weed management in dry direct–seeded rice: Assessing the impacts on weeds and crop. Indian J Weed Sci. 2020;52(2):169–74. https://doi.org/10.5958/0974-8164.2020.00030.1

21. Chaudhary P, Naresh VRK, Dhyani BP, Chandra MS. Effect of weed management practices on weed dynamics, growth, yield and yield attributes of rice (*Oryza sativa* L.). Int Res J Pure Appl Chem. 2020;21(19):40–52. https://doi.org/10.9734/irjpac/2020/v21i1930276

22. Mounisha J, Menon MV. Broad-spectrum weed management in wet–seeded rice by pre-mix herbicide combinations. Indian J Weed Sci. 2020;52(4):378–80. https://doi.org/10.5958/0974-8164.2020.00074.X

23. Dangol R, Pandey SR, Shrestha B, Magar TDB, Bhattarai N. Effects of different weed management practices on growth and yield of direct –seeded spring rice in Jhapa, Nepal. Cogent Food Agric. 2020;6 (1):1825040. https://doi.org/10.1080/23311932.2020.1825040

24. Ghosh P, Ghosh P, Dolai AK, Priya A. Weed Management in Direct Seeded Rice: A Review. Plant Archi. 2025;25(Suppl 1):2543–51. https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-1.348

25. Chauhan BS, Johnson DE. Growth response of direct-seeded rice to oxadiazon and bispyribac-sodium in aerobic and saturated soils. Weed Sci. 2011;59(1):119–22. https://doi.org/10.2307/23018715

26. Dubey R, Singh D, Mishra A. Effect of weed management practices and establishment methods on growth, productivity and economics of rice. Int J Curr Microbiol Appl Sci. 2017;6(3):65–72. https://doi.org/10.20546/ijcmas.2017.603.006

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.