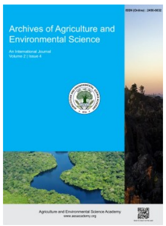
Archives of Agriculture and Environmental Science 10(1): 103-112 (2025)
https://doi.org/10.26832/24566632.2025.1001015

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes



ORIGINAL RESEARCH ARTICLE

CrossMark

Impact of reduced rate of pre-emergence herbicide with aqueous extract of mustard crop residues on different weed management indices and yield of transplanted *aman* rice

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ARTICLE HISTORY

Received: 06 January 2025
Revised received: 04 March 2025
Accepted: 11 March 2025

Keywords

Aman rice
Grain yield
Pre-emergence herbicides
Resistant weeds
Weed control efficiency

ABSTRACT

Effective weed management with herbicides and crop extracts boosts rice yield and growth. In this respect, a field experiment was conducted from July to December 2023 at the Agronomy Field Laboratory (AFL), Bangladesh Agricultural University (BAU), Mymensingh, to evaluate the effect of mustard crop residue extract combined with reduced herbicide doses on the yield and attributes of T. *aman* rice. The study involved three rice varieties BRRIdhan49, BRRI dhan87, and Binadhan-7 and seven treatments: no weeding (control), recommended dose of herbicide at pre-emergence (RDHP), mustard crop extract (MCE), 80% RDHP + MCE, 70% RDHP + MCE, 60% RDHP + MCE, and weed-free conditions. Results showed the highest weed growth in control treatment and the lowest in the weed-free treatment, with 80% RDHP + MCE showing the second-lowest weed growth. The weed-free treatment achieved the highest weed control index (WCI), weed control efficiency (WCE), and herbicide efficiency index (HEI), while minimizing weed index (WI), weed population index (WPI), weed mass index (WMI), and the Ammonia Index (AMI), followed by 80% RDHP + MCE. BRRI dhan87 produced the highest grain yield (5.36 t ha^{-1}), while BRRI dhan49 had the lowest (4.54 t ha^{-1}). The highest yield was recorded in the weed-free treatment (5.80 t ha^{-1}), followed by 80% RDHP + MCE (5.35 t ha^{-1}), and the control produced the lowest yield (2.63 t ha^{-1}). The study concludes that using 80% RDHP combined with MCE is an effective weed control strategy that enhances T. *aman* rice yield by reducing herbicide dependency.

Citation of this article: Arif, N. R., Rahat, R. A., Khatun, M., Ridoy, M. Y.A. K., Ahmed, M. T., Talukder, N. K., Sarker, U. K., Hasan, A. K., & Uddin, M. R. (2025). Impact of reduced rate of pre-emergence herbicide with aqueous extract of mustard crop residues on different weed management indices and yield of transplanted *aman* rice. *Archives of Agriculture and Environmental Science*, *10*(1), 103-112, https://dx.doi.org/10.26832/24566632.2025.1001015

INTRODUCTION

Rice (*Oryza sativa*) is the most significant crop in Bangladesh, providing the primary staple food for its population and contributing considerably to the national economy. With a per capita annual consumption of 144.5 kg (Yunus *et al.*, 2019), rice cultivation is widespread across the country, and its agricultural sector contributes approximately 11.20% to the national GDP (BBS, 2023). As of 2023, the total area under Transplanted *Aman* rice cultivation is estimated at 5,725.91 thousand hectares, yielding approximately 15,426 thousand metric tons annually (BBS, 2023). However, rice production in Bangladesh is facing significant challenges, particularly from the widespread problem of weed infestations and suboptimal crop management practices.

Weeds compete with rice for essential resources such as light, water, space, and nutrients, which leads to a reduction in crop growth, yield, and quality. Despite its importance, rice production in Bangladesh faces considerable challenges, particularly due to weed infestations that severely impact crop growth and yield. Weeds compete with rice for essential resources such as light, water, space, and nutrients, which can result in yield losses ranging from 16% to 88%, and in extreme cases, up to 100% if not effectively managed (Khanh *et al*., 2013). Thus, effective weed control is crucial to ensure the sustainability of rice production and food security in the country.

Traditional methods of weed control in rice cultivation, such as hand weeding, tillage, and chemical herbicide applications, have been widely practiced. However, these methods have limitations, such as labor shortages, unfavorable weather conditions, and the detrimental effects of chemical herbicides on crop health (Chauhan *et al*., 2012). In recent years, there has been growing interest in alternative approaches to weed management, particularly the use of crop residues. Crop residues, which are the leftover parts of crops after harvest, have been shown to possess allelopathic properties, which can suppress the growth of weeds. Many studies have demonstrated the effectiveness of using agricultural residues, such as grass pea, mustard, sorghum, and sunflower, to manage weeds and improve crop yield (Uddin *et al*., 2012a; Sarker *et al*., 2020; Rahman *et al*., 2020; Ashraf *et al*., 2021). Sorgoleone has been shown to inhibit growth and affect chlorophyll fluorescence in various weed species under in vivo conditions (Park *et al*., 2011; Uddin *et al*., 2012b). Among these, mustard crop residues have gained attention due to their significant allelopathic effects, which can suppress weed growth and enhance the growth of subsequent crops like rice (Dola *et al*., 2024). However, despite the potential of mustard allelopathy, there is still limited research on its application in rice production systems, particularly in Bangladesh.

This study holds great significance for improving rice yield and sustainable agricultural practices in Bangladesh. Given the challenges of weed infestation in rice fields and the limited availability of labor, this research offers an alternative, cost-effective, and environmentally friendly approach to weed control. By utilizing mustard crop residues, which are readily available in the country, this research could offer a practical solution for rice farmers to enhance productivity while minimizing the negative environmental impacts of chemical herbicides. Furthermore, this research aligns with the growing emphasis on sustainable agriculture and integrated weed management practices in Bangladesh and other parts of the world. While previous studies have explored the use of various crop residues for weed management in rice, the specific use of mustard crop residues, particularly in the form of aqueous extracts, remains under-researched. The allelopathic potential of mustard has been recognized in other crops, but its application in transplanted *Aman* rice production systems has not been adequately studied. This research aims to fill this gap by investigating the effects of mustard crop residue extracts on weed control and rice yield performance. The novelty of this work lies in its focus on mustard, a widely cultivated crop in Bangladesh, and its potential for improving rice cultivation through natural, biological weed suppression methods. The primary aim of this study is to assess the effect of aqueous extracts of mustard crop residues on various weed management indices, including weed density, biomass, and weed control efficiency, as well as its impact on the yield performance of Transplanted *Aman* rice. By doing so, the study aims to contribute valuable insights into sustainable weed management practices for rice farmers in Bangladesh, particularly in the context of utilizing crop residues as a natural resource for enhancing agricultural productivity.

MATERIALS AND METHODS

Experimental site

A study was conducted at the Agricultural Field Laboratory (AFL) of Bangladesh Agricultural University (BAU), Mymensingh, from July to December 2023, to evaluate the effects of rice variety and aqueous extract of mustard crop residues, combined with reduced herbicide doses, on the yield and yield attributes of Transplanted *Aman* (T. *aman*) rice. The experimental site is located at coordinates 24°25' N latitude and 90° 50' E longitude, with an elevation of 18 meters above sea level. The site is characterized by non-calcareous dark grey floodplain soil, which is classified under the Sonatola series of the Old Brahmaputra Floodplain within Agro-ecological Zone 9 (AEZ-9) (FAO & UNDP, 1988). The soil at the site has a neutral pH of 6.8 and is noted for its low organic matter content and fertility. The topography of the region is moderately to highly undulating, and the soil texture is classified as silty loam. The region experiences a tropical climate, with high temperatures and substantial rainfall during the Kharif season (April to September) and relatively cooler temperatures with limited rainfall during the Rabi season (October to March).

Experimental design and treatment factors

The experiment was conducted using a Randomized Complete Block Design (RCBD) with three replications, resulting in a total of 63 experimental plots. Each plot measured 4 m × 2.5 m, with a 0.5 m gap between individual plots and a 1.0 m separation between replications. The experimental design incorporated two factors. Factor A consisted of three rice cultivars: BRRI-dhan49 (V_1), BRRI dhan87 (V_2), and Binadhan-7 (V_3). Factor B included seven treatment combinations: Control (T_1), Reduced Dose of Herbicide Plus Mustard Crop Residue (RDHP) (T_2), Mustard Crop Residue (MCR) (T_3), 80% RDHP + MCR (T_4), 70% RDHP + MCR (T_5), 60% RDHP + MCR (T_6), and Weed-Free (T_7).

Collection and preparation of experimental material

In this study, crop residues of AEM were employed. The crops were cultivated at the AFL of BAU and harvested at the ripening stage to collect the residues. Following collection, the residues were air-dried in a shaded area on the covered threshing floor of the AFL. The dried residues were then finely chopped using a sickle. The small-sized mustard crop residues were soaked in water at a 1:10 (w/v) ratio for 24 hours at ambient room temperature. After soaking, the mixture of leaves and water was boiled for 3-4 hours and then filtered through a coarse mesh to remove plant residues. The seeds of the rice cultivars utilized in this study BRRI dhan49, BRRI dhan87, and Binadhan7 were sourced from the Bangladesh Rice Research Institute (BRRI) and the Bangladesh Institute of Nuclear Agriculture (BINA).

Preparation of plots and crop husbandry

The experimental plot was prepared using a tractor-drawn disc plough, followed by laddering to ensure proper soil aeration. Weeds and stubble were removed, and the plot was thoroughly cleaned. For the rice cultivars BRRI dhan49 and BRRI dhan87, the experimental plots were fertilized with urea, triple super phosphate (TSP), muriate of potash (MOP), gypsum, and zinc sulfate at rates of 80, 28, 40, 20, and 2.8 kg ha^{-1}, respectively. The full quantities of TSP, MOP, gypsum, zinc sulfate, and one-third of the urea were applied during the final land preparation. The remaining urea was applied in two equal splits at 15 and 30 days after transplanting (DAT). For the Binadhan-7 variety, the experimental plots were fertilized with urea, TSP, and MOP at rates of 160, 110, and 60 kg ha^{-1}, respectively. The complete quantities of TSP, MOP, gypsum, and zinc sulfate were applied during the final land preparation, and urea was applied in two equal splits at 10 and 35 DAT.

To prepare the aqueous extract, finely chopped mustard crop residues were soaked in water at a ratio of 1:5 (w/v) for 24 hours at ambient room temperature. The aqueous extract was then applied at a rate of 1 liter per square meter for each treatment.

Harvesting and data collection

Harvesting was conducted when the crops reached full maturity. 1 m² area in the central section of each plot was selected to measure grain yield (GY) and straw yield (SY). Grain yield was adjusted to a moisture content of 14% and expressed in metric tons per hectare. Data on the total number of tillers per hill (NTT $hill^{-1}$) and total dry weight per hill (DW $hill^{-1}$) were recorded from five tagged hills in each plot at 30 days after transplanting (DAT). During harvest, measurements were taken for plant height (PH), number of effective tillers per hill (NET $hill^{-1}$), panicle length (PL), number of seeds per panicle (NSP), thousand grain weight (TGW), GY, and SY. The biological yield (BY) and harvest index (HI%) were subsequently calculated. Data on weed population at 35 days after transplanting (DAT) were collected using a 0.25 m × 0.25 m quadrat from each rice plant plot, following the methodology described by Cruz *et al.*, (1986). The weeds within each quadrat were counted, and the total count was adjusted to represent the number of weeds per square meter by multiplying the count by four. After determining the weed density, the weeds within each quadrat were uprooted, cleaned, and sorted by species. The samples were then sun-dried before being placed in an electric oven set at 80°C for 72 hours for further drying. The dry weight (DW) of each weed species was measured using an electric balance and expressed in grams per square meter (g/m²). Various weed management indices were calculated to assess the results, based on the following formulas:

Weed Control Index (WCI):

$$WCI = \frac{WP_C - WP_T}{WP_C} \times 100$$

Where, WP_C = Weed population in control (unweeded) plot, WP_T= Weed population in treated plot

Weed Control Efficiency (WCE):

$$WCE = \frac{W_C - W_T}{W_C} \times 100$$

Where, WC = Weed dry weight in control (unweeded) plot, WT= Weed dry weight in treated plot

Weed Index (WI):

$$WI = \frac{Y_{WF} - W_T}{Y_{WF}} \times 100$$

Where, Y_{WF}= Yield from weed free plot, Y_T= Yield from treated plot.

Weed Persistence Index (WPI):

$$WPI = \frac{W_T}{W_C} \times \frac{W_{PC}}{W_{PT}}$$

Where, W_C= Weed dry weight in control (unweeded) plot, W_T= Weed dry weight in treated plot. W_{PC} = Weed population in control (unweeded) plot. W_{PT}= Weed dry weight in treated plot.

Herbicide Efficiency Index (HEI):

$$HEI = \frac{\frac{Y_T - Y_C}{Y_C}}{\frac{W_T}{W_C}}$$

Where, Y_T = Yield of treated plot, Y_C= Yield of control (unweeded) plot. W_C = Weed dry weight in control (unweeded) plot. W_T= Weed dry weight in treated plot.

Weed Management Index (WMI):

$$WMI = \frac{\frac{Y_T - Y_C}{Y_C}}{\frac{W_C - W_T}{W_C}}$$

Where, YT = Yield of treated plot, YC= Yield of control (unweeded) plot. WC = Weed dry weight in control (unweeded) plot. WT= Weed dry weight in treated plot.

Agronomic Management Index (AMI):

$$WMI = \frac{\frac{Y_T - Y_C}{Y_C} - \frac{W_C - W_T}{W_C}}{\frac{W_C - W_T}{W_C}}$$

Where, Y_T = Yield of treated plot. Y_C= Yield of control (unweeded) plot, W_C = Weed dry weight in control (unweeded) plot. W_T= Weed dry weight in treated plot.

Statistical analysis

The data collected for various criteria was compiled, organized into tables, and subjected to statistical analysis. Analysis of variance (ANOVA) was performed using RStudio. Duncan's Multiple Range Test (DMRT), as described by Gomez & Gomez (1984), was employed to determine the significant differences between the treatment means.

RESULTS AND DISCUSSION

Infested weed species in the experimental field

The experimental field was infested with five weed species from four distinct families. Among these species, two were annual grasses and three were perennial herbs. The local names, scientific names, families, morphological types, and life cycles of the weeds present in the experimental plot are summarized in Table 1. The most prominent weeds in the experimental plots were *Digitaria ischaemum*, *Echinochloa crus-galli*, *Panicum repens*, *Oxalis corniculate* L., and *Colocasia esculenta*. Similarly, the experimental boro rice field was infested by nine weed species across five families, including grasses, broadleaves, and sedges, with species such as *Echinochloa crusgalli*, *Monochoria hastata*, and *Panicum repens* predominating. This diversity reflects varying ecological adaptations and life cycles, underscoring the complexity of weed management in agricultural systems (Islam *et al*., 2024).

Interaction effect on weed population and dry weight of weeds

Significant interactions between rice varieties and the combination of herbicide with aqueous extract of mustard crop residues were observed in weed population (WP) and dry weight (DW). For Choto anguli (*D. ischaemum*), the highest WP (13.66) and the highest weed DW (0.82 gm^{-2}) were found in the BRRI dhan87 variety with no weeding treatment, while the lowest WP (0.00) and lowest DW (0.00 gm^{-2}) were observed in all varieties under weed-free conditions (Table 2). Dola *et al.* (2024) observed similar significant interactions between wheat varieties and aqueous extract of mustard crop residues with herbicides, where *C. dactylon* (durba), *E. crusgalli* (shama), and *P. lapathifolia* (bishkatali) exhibited the highest weed populations and dry weights in BWMRI Gom-1 under no weeding treatment, with the lowest values recorded in BARI Gom-32 with RDH. Furthermore, *O. corymbose* (khetpapri) followed a similar pattern, emphasizing the critical role of selecting appropriate wheat varieties and residue management strategies to enhance weed control and reduce weed biomass. In the case of Shama (*E. crus-galli*), the highest WP (8.00) was found in Binadhan-7 with control treatment, and the lowest WP (0.00) was observed in all varieties with the weed-free treatment (Table 2). The highest weed DW (6.80 gm^{-2}) was found in Binadhan-7 with the control treatment, while the lowest weed DW (0.00 gm^{-2}) was recorded in all varieties with the weed-free condition (Table 2). For Angta (*P. repens*), the highest WP (8.00) and highest DW (3.78 gm^{-2}) were observed in BRRI dhan87 with the control treatment, where the lowest WP (0.00) and lowest DW were recorded under weed-free conditions. The results of this study are consistent with previous findings, highlighting significant interactions between wheat varieties and AESM crop residues that influence weed populations and dry weight (DW). For example, *C. dactylon* showed the highest population (8.00) and DW (4.52 g) in BARI Gom-32 with no weeding control, with similar patterns observed for *E. colonum*, *O. corymbosa*, and *P. hydropiper*. These results emphasize the importance of residue management in controlling weed growth, as evidenced by the consistently high values found in BWMRI Gom-1 under no weeding control treatments (Akondo *et al*., 2024). For Amrul (*O. corniculate*), the highest WP (13.66) was recorded in Binadhan-7 with the control treatment, while the lowest WP (0.00) was found in all varieties under the weed-free treatment (Table 2). The highest weed DW (0.54 gm^{-2}) was found in Binadhan-7 with the control treatment, and the lowest weed DW (0.00 gm^{-2}) was recorded in all varieties with the weed-free condition (Table 2). Regarding Pani kochu (*C. esculenta*), the highest WP (13.66) was found in BRRI dhan49 with the control treatment, while the lowest WP (0.00) was recorded in BRRI dhan49, BRRI dhan87, and Binadhan-7 under the weed-free condition. The highest weed DW (5.02 gm^{-2}) was found in BRRI dhan49 with the control treatment, and the lowest DW (0.00 g/m^2) was observed in all varieties with the weed-free condition (Table 2). The results demonstrate significant interactions between wheat varieties and the application of AES crop residues, with BWMRI Gom-1 exhibiting the highest weed pressure (WP) and dry weight (DW) across all weed species, such as *C. dactylon* (WP 9.00, DW 3.00 g), *E. colonum* (WP 19.00, DW 4.90 g), *P. hydropiper* (WP 15.33, DW 4.00 g), and *O. corymbosa* (WP 12.00, DW 2.90 g) under no weeding, while BARI Gom-32 with RDH treatment consistently resulted in the lowest WP and DW, such as *C. dactylon* (WP 1.33, DW 1.39 g), *E. colonum* (WP 10.00, DW 1.57 g), *P. hydropiper* (WP 5.67, DW 0.97 g), and *O. corymbosa* (WP 3.33, DW 0.73 g), highlighting the crucial role of wheat variety selection and effective weed management strategies for optimal weed suppression (Tonni *et al*., 2024).

Table 1. Infesting weed species found growing in the experimental plots in rice.

S. No.	Local name	Scientific name	Family	Morphological type	Life cycle
1	Choto anguli	*Digitaria ischaemum*	Cyperaceae	Herb	Annual
2.	Shama	*Echinochloa crus-galli*	Poaceae	Grass	Annual
3.	Angta	*Panicum repens*	Poaceae	Grass	Perennial
4.	Amrul	*Oxalis corniculata* L.	Oxalidaceae	Herb	Perennial
5.	Pani kochu	*Colocasia esculenta*	Araceae	Herb	Perennial

Table 2. Interaction effect of variety and aqueous extract of mustard crop residue and herbicide on weed number, dry weight of weeds.

Interaction	Number of weeds					Total weed density weeds/m^2	Total weed density weeds/m^2 (Original data to square root x+1 transformation)	Dry weight of weed					Total weed dry weight g/m^2	Total dry weight g/m2 (Original data to square root x+1 transformation)
	Angta (no/m^2)	Pani kochu (no/m^2)	Shama (no/m^2)	Choto anguli (no/m^2)	Amrul (no/m^2)			Angta (g/m^2)	Pani kochu (g/m^2)	Shama (g/m^2)	Choto anguli (g/m^2)	Amrul (g/m^2)		
V_1T_1	7.00a	13.66a	7.00a	13.33a	11.33b	52.33b	7.29a	3.15b	5.02a	5.94a	0.80a	0.36b	15.28a	4.02a
V_1T_2	2.33defg	2.66efg	2.00def	3.33gh	2.33hi	12.66f	3.68e	0.95efg	0.99ef	1.59efgh	0.18hi	0.08k	3.81efg	2.18ef
V_1T_3	4.00b	5.66b	3.66bc	7.00c	6.00cd	26.33c	5.21b	1.58c	2.11b	3.04bc	0.39cd	0.18ef	7.32b	2.87b
V_1T_4	1.33g	2.33fg	1.33f	2.33hi	1.33i	8.666g	3.10f	0.58g	0.84ef	1.11h	0.12ij	0.03l	2.69g	1.91h
V_1T_5	2.66cdef	3.66de	2.66cde	4.66ef	3.66fg	17.33e	4.32d	1.07defg	1.26de	1.91defgh	0.24fgh	0.11hijk	4.60de	2.36de
V_1T_6	3.33bcd	4.33cd	3.00bcd	5.66de	5.00de	21.33d	4.72c	1.31cde	1.51cd	2.23cdefg	0.32de	0.15fghi	5.54cd	2.54cd
V_1T_7	0.00h	0.00h	0.00g	0.00j	0.00j	0.000h	1.00g	0.00h	0.00g	0.00i	0.00k	0.00l	0.00h	1.00i
V_2T_1	8.00a	13.00a	7.33a	13.66a	13.33a	55.33a	7.50a	3.76a	4.67a	6.23a	0.82a	0.53a	16.01a	4.12a
V_2T_2	2.33defg	2.33fg	1.66ef	3.66fg	3.33gh	13.33f	3.78e	0.94efg	0.87ef	1.40gh	0.21gh	0.10ijk	3.54efg	2.12fg
V_2T_3	3.66bc	5.33bc	4.00b	7.00c	7.00c	27.00c	5.28b	1.49cd	1.97b	3.38b	0.41c	0.25cd	7.52b	2.91b
V_2T_4	1.66fg	1.66g	1.33f	2.66gh	2.33hi	9.333g	3.20f	0.71fg	0.85ef	1.17h	0.16hi	0.08k	2.98fg	1.98gh
V_2T_5	2.66cdef	3.33def	2.33def	4.66ef	4.66ef	17.66e	4.31d	1.11cdef	1.15de	1.96defgh	0.27efg	0.15fgh	4.67de	2.37de
V_2T_6	3.00bcde	3.66de	2.66cde	5.66de	5.66de	20.66d	4.65c	1.22cdef	1.25de	2.85bcd	0.33de	0.22de	5.88c	2.61c
V_2T_7	0.00h	0.00h	0.00g	0.00j	0.00j	0.000h	1.00g	0.00h	0.00g	0.00i	0.00k	0.00l	0.00h	1.00i
V_3T_1	7.33a	13.33a	8.00a	11.33b	13.66a	53.66ab	7.38a	3.44ab	4.88a	6.80a	0.71b	0.54a	16.39a	4.16a
V_3T_2	2.00efg	2.66efg	2.33def	2.33hi	3.66fg	13.33f	3.77e	0.84efg	1.00ef	1.98defgh	0.13ij	0.13ghij	4.08ef	2.24ef
V_3T_3	3.33bcd	6.00b	3.66bc	6.00cd	7.00c	26.00c	5.19b	1.47cd	1.95b	3.10bc	0.35cde	0.27c	7.16b	2.85b
V_3T_4	1.33g	2.00g	1.66ef	1.33i	2.66gh	9.000g	3.15f	0.59g	0.71f	1.43fgh	0.07jk	0.10jk	2.92g	1.97gh
V_3T_5	2.33defg	4.33cd	2.66cde	3.66fg	4.66ef	17.66e	4.31d	1.00defg	1.51cd	2.35cdef	0.21gh	0.16fg	5.25cd	2.49cd
V_3T_6	2.66cdef	5.00bc	3.00bcd	5.00de	5.66de	21.33d	4.72c	1.10cdef	1.79bc	2.53bcde	0.29ef	0.23cde	5.97c	2.63c
V_3T_7	0.00h	0.00h	0.00g	0.00j	0.00j	0.000h	1.00g	0.00h	0.00g	0.00i	0.00k	0.00l	0.00h	1.00i
LSD $_{(0.05)}$	1.22	1.20	1.09	1.25	1.25	2.48	0.21	0.50	0.42	0.54	0.07	0.04	1.13	0.19
Level of significance	*	**	*	**	**	**	**	*	**	**	**	**	**	**
CV (%)	2,5.53	16.14	23.08	15.48	15.48	7.47	3.15	24.51	15.81	23.67	16.08,	16.93	11.90	4.71

In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability, V_1 = BRRI dhan49, V_2 = BRRI dhan87 and V_3 = Binadhan – 7, T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = Mustard crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + mustard crop residues, T_5 = Pre-emergence (70% recommended dose) + mustard crop residues, T_6 = Pre-emergence (60% recommended dose) + mustard crop residues and T_7 = Weed free.

Interaction effect between variety and aqueous extract of mustard crop residue and herbicide on weed Management indices

Weed Control Index (WCI), Weed Control Efficiency (WCE), Weed Index (WI), Weed Persistence Index (WPI), Herbicide Efficiency Index (HEI), Weed Management Index (WMI), and Agronomic Management Index (AMI) were significantly influenced by interaction between variety and aqueous extract of mustard crop residue and herbicide on Weed Management indices. Across all varieties, weed free consistently achieved the highest WCI and WCE (both 100.00), indicating the most effective weed control, with the lowest WI and WPI (0.00 and 0.00 respectively). control exhibited the poorest performance, showing no weed control (WCI and WCE both 0.00) and the highest WI (47.98 to 55.30) and WPI (1.00). Among the treatments, 80% recommended dose at pre-emergence herbicide + mustard crop residues and recommended dose at pre-emergence herbicide showed high efficacy with significant reductions in WI and moderate WPI values across all varieties, highlighting their effectiveness in weed management. Notably, HEI values were highest in weed free (4.98 to 4.89), followed by 80% recommended dose at pre-emergence herbicide + mustard crop residues (2.18 to 2.13) across all varieties, indicating superior herbicide efficiency (Table 3). WMI values were lowest in weed free (0.17 to 0.22), followed by 80% recommended dose at pre-emergence herbicide + mustard crop residues (1.94 to 2.36) across all varieties, indicating superior herbicide efficiency (Table 3). AMI values were lowest in weed free (0.17 to 0.22), followed by 80% recommended dose at pre-emergence herbicide + mustard crop residues (0.23 to 0.27) across all varieties, indicating superior herbicide efficiency (Table 3). This comprehensive analysis demonstrates significant interaction effects between rice varieties and weed control treatments, with weed-free treatments consistently outperforming others in weed management efficiency. The results show significant variation in weed control efficacy (WCE) at 30 days after treatment (DAT), with the highest WCE of 91.09% observed when double the recommended dose of herbicide was applied, while the control treatment exhibited no weed control efficacy (0.00%). This suggests that increasing the herbicide dosage significantly enhances its effectiveness in controlling weeds, highlighting the importance of proper dosing for optimal weed management (Nur-A-Alam *et al.*, 2024).

Table 3. Interaction effect between variety and aqueous extract of mustard crop residue and herbicide on Weed Management indices.

Interaction	Weed Control Index (WCI)	Weed Control Efficiency (WCE)	Weed Index (WI)	Weed Persistence Index (WPI)	Herbicide Efficiency Index (HEI)	Weed management Index (WMI)	Weed management Index (AMI)
V_1T_1	0.00g	0.000h	55.30a	1.00a	0.00j	0.00h	0.00j
V_1T_2	75.67c	75.05cd	9.710fg	0.50def	1.87cd	2.21cd	0.35cd
V_1T_3	49.51f	51.91g	22.67c	0.66b	1.08i	2.69a	0.50a
V_1T_4	83.42b	82.30b	8.920g	0.41f	2.18b	1.98f	0.26efgh
V_1T_5	66.85d	69.88de	11.22fg	0.50de	1.67def	2.36bc	0.38bc
V_1T_6	59.19e	63.77f	13.84ef	0.55cd	1.46gh	2.51ab	0.45ab
V_1T_7	100.00a	100.00a	0.00h	0.00g	4.98a	1.63g	0.22ghi
V_2T_1	0.00g	0.000h	54.38a	1.00a	0.00j	0.00h	0.00j
V_2T_2	75.89c	77.60bc	7.843g	0.43ef	1.98bc	2.14def	0.31cdef
V_2T_3	51.29f	53.09g	20.70c	0.66b	1.04i	2.52ab	0.38bc
V_2T_4	83.15b	81.23b	7.166g	0.43ef	2.15b	2.00ef	0.27efg
V_2T_5	68.13d	70.96de	11.61efg	0.49def	1.63efg	2.23cd	0.32cde
V_2T_6	62.67e	62.99f	15.84de	0.59bc	1.33h	2.35bc	0.34cde
V_2T_7	100.00a	100.00a	0.00h	0.00g	4.90a	1.53g	0.18hi
V_3T_1	0.00g	0.000h	47.98b	1.00a	0.00j	0.00h	0.00j
V_3T_2	76.38c	74.97cd	9.933fg	0.48def	1.78cde	2.09def	0.28defg
V_3T_3	51.38f	55.86g	20.05cd	0.62bc	1.08i	2.37bc	0.33cde
V_3T_4	83.25b	82.02b	7.430g	0.41ef	2.13b	1.94f	0.23fghi
V_3T_5	67.01d	67.73ef	13.59ef	0.54cd	1.47fgh	2.20cde	0.29defg
V_3T_6	60.19e	63.62f	15.97de	0.56cd	1.30h	2.24cd	0.31cdef
V_3T_7	100.00a	100.00a	0.00h	0.00g	4.89a	1.54g	0.17i
$LSD_{(0.05)}$	3.54	5.77	4.59	0.08,	0.20	0.20	0.08
Level of significance	**	**	**	**	**	**	**
CV (%)	3.43	5.51	16.49	10.31	6.85	6.76	18.60

Here, in a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability, V_1 = BRRI dhan49, V_2 = BRRI dhan87 and V_3 = Binadhan – 7, T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = Mustard crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + mustard crop residues, T_5 = Pre-emergence (70% recommended dose) + mustard crop residues, T_6 = Pre-emergence (60% recommended dose) + mustard crop residues and T_7 = Weed free.

Table 4. Interaction effect of variety and aqueous extract of mustard crop residue and herbicide on the yield contributing characters and yield of transplant *aman* rice.

Interaction	Plant height (cm)	Number of total tillers hill^{-1}	Number of effective tillers hill^{-1}	Number of non-effective tillers hill^{-1}	Panicle length (cm)	Number of grains panicle^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
V_1T_1	90.20kl	6.87j	5.37i	1.49e	16.98l	69.32l	17.63o	2.45l	4.26h	6.71l	36.54h
V_1T_2	100.75h	9.71fgh	8.05defg	1.66de	20.99gh	96.27defg	22.78cde	4.95fg	5.81de	10.76f	46.04cdef
V_1T_3	95.14j	8.09i	6.54ghi	1.55e	18.27jk	77.19k	19.22mn	4.33j	5.040g	9.37j	46.24cde
V_1T_4	101.94h	9.97fgh	8.29cdef	1.67de	21.41fg	98.79bcde	23.27bcd	5.00efg	5.85d	10.85f	46.07cdef
V_1T_5	98.46i	9.08hi	7.20fgh	1.87de	19.95hi	91.65ghi	20.35ijkl	4.87g	5.67def	10.54fg	46.23cde
V_1T_6	95.47j	8.50i	6.94fghi	1.56e	19.32ij	86.99ij	19.83klm	4.73h	5.520ef	10.25gh	46.19cde
V_1T_7	104.45g	10.79ef	9.43abcd	1.36e	22.94de	103.22abc	24.32a	5.49d	5.87d	11.36e	48.32a
V_2T_1	109.37f	9.23ghi	7.29fgh	1.94de	17.72kl	69.49l	18.28no	2.94k	5.63def	8.57k	34.33i
V_2T_2	115.40c	13.35bc	9.85abc	3.50abc	20.47gh	101.79bcd	23.23bcd	5.94b	6.92ab	12.87b	46.20cde
V_2T_3	110.83e	10.33efg	8.10defg	2.23cde	18.34jk	88.41ij	20.52ijk	5.11e	6.51c	11.63e	44.00g
V_2T_4	118.61b	14.34ab	10.25ab	4.08a	21.06g	104.42ab	23.63abc	5.99b	7.14a	13.13b	45.61def
V_2T_5	114.87c	12.28cd	9.19abcd	3.09abcd	19.32ij	98.01cdef	22.17efg	5.70c	6.82b	12.53c	45.52def
V_2T_6	113.21d	11.30de	9.07bcde	2.23cde	18.62jk	95.27efgh	21.00hij	5.43d	6.70bc	12.13d	44.76efg
V_2T_7	120.13a	14.62a	10.67a	3.95ab	22.18ef	108.22a	24.17ab	6.45a	7.21a	13.66a	47.24abc
V_3T_1	86.81m	8.90hi	6.40hi	2.49bcde	21.36fg	59.13m	19.50lm	2.51l	4.403h	6.91l	36.32h
V_3T_2	94.91j	11.13de	7.42fgh	3.70abc	24.46bc	96.65defg	22.00efg	4.92g	5.63def	10.55fg	46.63bcd
V_3T_3	89.85l	9.23ghi	6.72fghi	2.51bcde	22.90de	83.15jk	20.15jklm	4.37j	5.423f	9.79i	44.62fg
V_3T_4	96.02j	11.20de	7.56efgh	3.63abc	25.02ab	98.43bcde	22.43def	5.06ef	5.65def	10.71f	47.23abc
V_3T_5	91.45k	9.95fgh	7.13fgh	2.82abcde	23.98bcd	92.07fghi	21.58fgh	4.72h	5.61def	10.33gh	45.69def
V_3T_6	90.75kl	9.68fgh	6.99fgh	2.69abcde	23.40cd	89.57hi	21.23ghi	4.59i	5.460f	10.05hi	45.70def
V_3T_7	96.03j	12.81c	10.25ab	2.56bcde	26.03a	101.03bcde	23.67abc	5.46d	5.90d	11.36e	48.11ab
$LSD_{(0.05)}$	1.37	1.15	1.59	1.49	1.11	6.26	0.97	0.12	0.30	0.32	1.49
Level of significance	**	**	**	**	**	**	**	**	**	**	**
CV (%)	2.82	6.66	12.02	16.22	3.18	4.18	2.75	2.59	3.13	2.84	2.03

Means with the same letters within the same column do not differ significantly as per DMRT, ** = Significant at 1% level of probability, * = Significant at 5% level of probability, V_1 = BRRI dhan49, V_2 = BRRI dhan87 and V_3 = Binadhan – 7, T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = Mustard crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + mustard crop residues, T_5 = Pre-emergence (70% recommended dose) + mustard crop residues, T_6 = Pre-emergence (60% recommended dose) + mustard crop residues and T_7 = Weed free.

Effect of interaction between variety and combination of herbicides along with mustard crop extract on yield and yield contributing characters of rice

The interaction between rice variety and aqueous extract of mustard crop residues had a significant impact on various growth and yield parameters (Table 4). For plant height (PH), the tallest plants (120.13 cm) were observed in BRRI dhan87 with the weed-free treatment, while the shortest plants (86.81 cm) were found in Binadhan-7 with the control treatment. Regarding the total number of tillers hill^{-1}, the highest value (14.62) was observed in the BRRI dhan87 and weed-free combination, while the lowest number (6.87) was recorded in the Binadhan-7 and control combination. The number of effective tillers hill^{-1} was similarly influenced by the interaction between variety and aqueous extract. BRRI dhan87 in combination with weed-free treatment produced the highest number of effective tillers (10.67), whereas BRRI dhan49 combined with the control treatment had the lowest number (5.37). For the number of non-effective tillers hill^{-1}, the highest number (4.08) was produced by BRRI dhan87 with 80% recommended dose of pre-emergence herbicide and mustard crop residues, while the lowest number (1.36) was recorded in BRRI dhan49 with the weed-free treatment. The panicle length was significantly influenced by the interaction, with the longest panicle (26.03 cm) observed in Binadhan-7 with the weed-free treatment, and the shortest panicle (16.98 cm) in BRRI dhan49 with the control treatment. Similarly, the number of grains per panicle was highest (108.22) in BRRI dhan87 with the weed-free treatment, while the lowest number (69.32) was observed in Binadhan-7 with the control condition. The weight of 1000 grains were significantly affected by the variety and aqueous extract interaction. The highest 1000-grain weight (24.32 g) was recorded in BRRI dhan49 with the weed-free treatment, and the lowest weight (17.63 g) was found in BRRI dhan49 with the control treatment. Finally, the harvest index was also significantly influenced by the interaction between variety and aqueous extract. The highest harvest index (48.32%) was observed in BRRI dhan49 with the weed-free treatment, while the lowest (34.33%) was found in BRRI dhan87 with the control treatment (Table 4). A similar trend was observed, where treatment with hot water extract of grass pea, particularly when applied both pre- and post-emergence, significantly enhanced the growth and yield of BAU dhan3, with the highest performance in treatment T_3, showing improvements in plant height (106.00 cm), tiller number (9.33), panicle length (21.67 cm), seeds per panicle (79.67), thousand grain weight (23.67 g), and harvest index (45.14%) reported by Alam *et al.* (2024).

Effect of variety on grain yield and straw yield

The studied variety differed significantly in respect of grain yield (GY) and straw yield (SY) (Table 4). The highest GY (5.36 t ha^{-1}) was obtained in BRRI dhan87. The lowest GY (4.52 t ha^{-1}) was obtained in Binadhan-7 (Figure 1). The study indicates that rice variety significantly influences grain yield (GY), straw yield (SY), and biological yield (BY), with BAU dhan3 recording the highest GY (5.81 t ha^{-1}), SY (7.57 t ha^{-1}), and BY (13.39 t ha^{-1}), attributed to a lower number of sterile spikelets, while BRRI dhan28 exhibited the lowest GY (3.63 t ha^{-1}), SY (5.52 t ha^{-1}), and BY (9.16 t ha^{-1}), likely due to its genetic potential (Zinnat *et al.*, 2024). The highest SY (6.70 t ha^{-1}) was found in BRRI dhan87 and the lowest SY 5.43 t ha^{-1} was found in BRRI dhan49 (Figure 2). Similarly, these findings are consistent with previous studies, which show significant variation in straw yield (SY) among the rice varieties tested. BRRI dhan87 exhibited the highest SY (6.19 t ha^{-1}), while BRRI dhan52 recorded the lowest SY (5.76 t ha^{-1}), emphasizing the strong influence of rice variety on both yield components (Mim *et al.*, 2024).

Effect of herbicides along with aqueous extract of mustard on grain yield and straw yield

Grain yield (GY) and straw yield (SY) were significantly influenced by the application of aqueous extract of mustard crop residues. The highest GY (5.80 t ha^{-1}) was achieved under the weed-free treatment, whereas the lowest GY (2.63 t ha^{-1}) was observed in the control treatment (Figure 3). The incorporation of aqueous extract of mustard along with 80% of the recommended herbicide dose effectively reduced weed emergence, leading to an increase in GY. Similarly, the highest SY (6.32 t ha^{-1}) was recorded in the weed-free treatment, while the control treatment resulted in the lowest SY (4.76 t ha^{-1}) (Figure 4). These results align with findings by Ashraf *et al.* (2021), who reported that the highest SY (7.65 t ha^{-1}) was obtained in the hand-weeding treatment (T_5) for BR11, while the lowest SY (5.32 t ha^{-1}) was observed in Binadhan-7 under no crop residue treatment (T_1). Their study emphasized the positive impact of crop residues, particularly grass pea and mustard, on weed suppression and overall crop performance in T. *aman* rice.

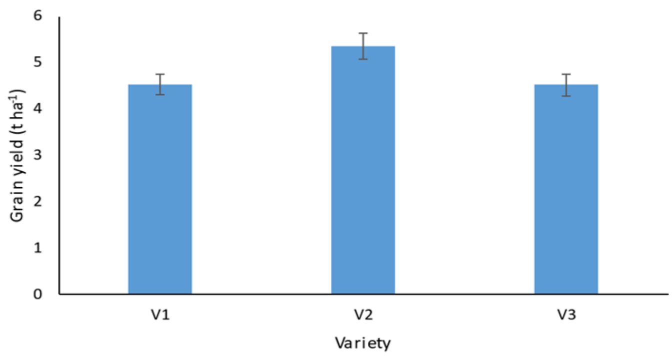

Figure 1. *Effect of variety on the grain yield of transplanted aman rice. Here, V_1 = BRRI dhan49, V_2 = BRRI dhan87 and V_3 = Binadhan-7.*

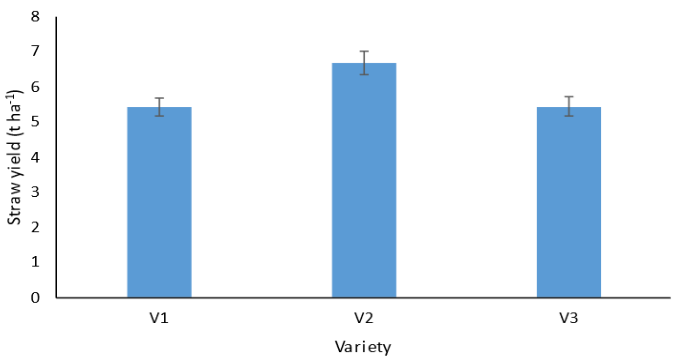

Figure 2. *Effect of variety on the straw yield of transplanted aman rice. Here, V_1 = BRRI dhan49, V_2 = BRRI dhan87 and V_3 = Binadhan-7.*

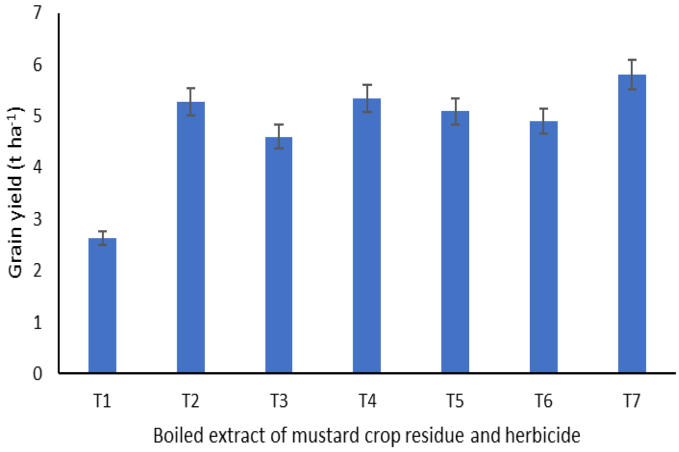

Figure 3. *Effect of aqueous extract of mustard on the grain yield of transplanted aman rice. Here, T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = Mustard crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + mustard crop residues, T_5 = Pre-emergence (70% recommended dose) + mustard crop residues, T_6 = Pre-emergence (60% recommended dose) + mustard crop residues and T_7 = Weed free.*

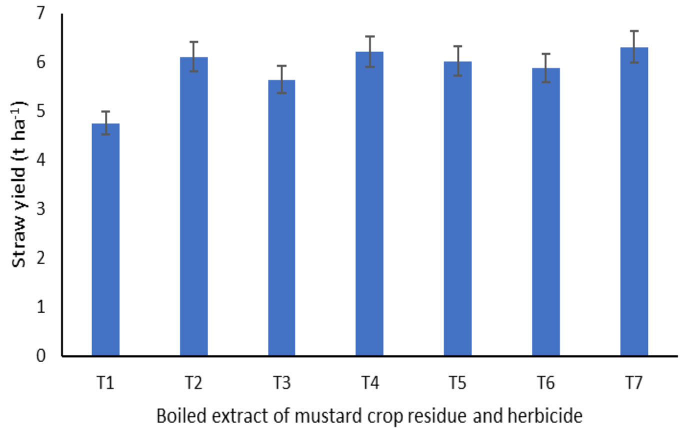

Figure 4. *Effect of aqueous extract of mustard on the straw yield of transplanted aman rice. Here, T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = Mustard crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + mustard crop residues, T_5 = Pre-emergence (70% recommended dose) + mustard crop residues, T_6 = Pre-emergence (60% recommended dose) + mustard crop residues and T_7 = Weed free.*

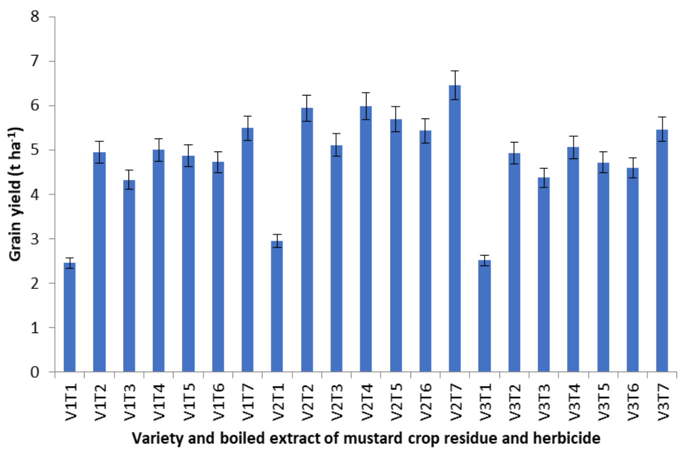

Figure 5. *Interaction effect of variety and aqueous extract of mustard on the grain yield of transplanted aman rice. Here, V_1 = BRRI dhan49, V_2 = BRRI dhan87 and V_3 = Binadhan – 7, T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = Mustard crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + mustard crop residues, T_5 = Pre-emergence (70% recommended dose) + mustard crop residues, T_6 = Pre-emergence (60% recommended dose) + mustard crop residues and T_7 = Weed free.*

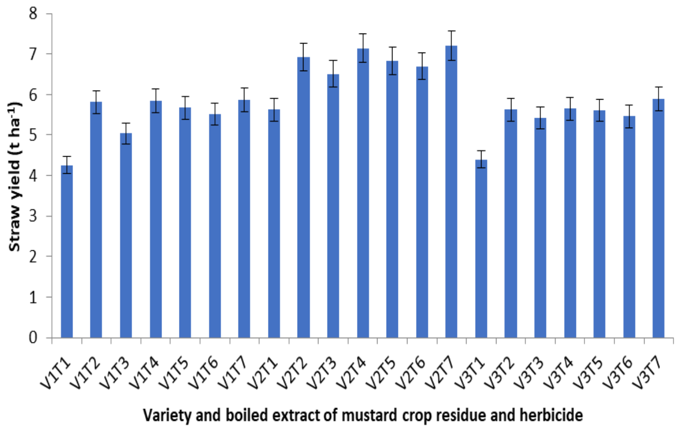

Figure 6. *Interaction effect of variety and aqueous extract of mustard on the straw yield of transplanted aman rice. Here, V_1 = BRRI dhan49, V_2 = BRRI dhan87 and V_3 = Binadhan – 7, T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = Mustard crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + mustard crop residues, T_5 = Pre-emergence (70% recommended dose) + mustard crop residues, T_6 = Pre-emergence (60% recommended dose) + mustard crop residues and T_7 = Weed free.*

Effect of interaction between variety and combination of herbicides along with mustard crop extract on grain yield and straw yield

Grain yield (GY) and straw yield (SY) were significantly influenced by the interaction between rice varieties and aqueous extract of mustard crop residues. The highest GY (6.45 t ha^{-1}) was achieved by BRRI dhan87 in combination with the weed-free treatment, while the lowest GY (2.45 t ha^{-1}) was recorded for BRRI dhan49 with the control treatment (Figure 5). These results are consistent with the findings of Afroz *et al.* (2018), who examined the impact of different T. *aman* rice varieties and weed management strategies using buckwheat and marsh pepper crop residues. In terms of straw yield, the highest value (7.14 t ha^{-1}) was observed in BRRI dhan87 with the 80% recommended dose of herbicide at pre-emergence and mustard crop residues, while the lowest SY (4.26 t ha^{-1}) was produced by BRRI dhan49 under the control treatment (Figure 6). Similar results were reported by Rahman *et al.*, (2024), the highest grain yield for BAU dhan3 was recorded at approximately 8.5 t ha^{-1} with hot water extract of lentil and grass pea as post-emergence at 10 days after transplanting, while the lowest yield was observed in the control treatment for BRRI dhan28, which produced around 5.5 t ha^{-1}. These results emphasize the effectiveness of integrated weed management strategies, the application of crop residue extracts, in boosting rice productivity.

Conclusion

The results of the study revealed that BRRI dhan87 outperformed other varieties in terms of yield-contributing characters and overall yield. In terms of weed management, the weed-free treatment applied 10 days after transplanting proved to be the most effective for T. *aman* rice cultivation. Additionally, the application of aqueous extracts from mustard crop residues positively impacted weed growth, yield-contributing traits, and the overall yield of T. *aman* rice. These findings highlight the potential of mustard crop residue extracts as a promising and sustainable weed management strategy, enhancing both crop performance and yield.

DECLARATIONS

Author contribution statement

Conceptualization: N.R.A., M.T.A., U.K.S., A.K.H. and M.R.U.; Methodology: N.R.A.; Software and validation: M.T.A. and R.A.R.; Formal analysis and investigation: N.R.A.; Resources: N.R.A.; Data curation: N.R.A.; Writing—original draft preparation: N.R.A., R.A.R., M.K. and M.Y.A.K.R; Writing—review and editing: M.T.A., N.K.T., U.K.S., A.K.H. and M.R.U; Visualization: N.R.A.; Supervision: M.R.U.; Project administration: M.R.U.; Funding acquisition: M.R.U. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Ethics approval: Not applicable.

Consent for publication: Yes.

Data availability: Data will be made available on request.

Supplementary data: There is no supplementary data used.

Funding: The authors extend their appreciation to the Ministry of Science and Technology (MOST), Government Peoples' Republic of Bangladesh for financial support.

Additional information: No additional information is available for this paper.

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