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Research Article

Effect of Reduced Rate of Post Emergence Herbicide with Aqueous Extracts of Lentil Crop Residues on Weed Management Indices and Yield of Transplanted *Aman* Rice

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Abstract

An experiment was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh, from July to December 2023, to assess the effectiveness of integrating reduced doses of post-emergence herbicides with aqueous extracts of lentil crop residues on weed management indices and the yield of T. *aman* rice. The experimental design included two factors: rice variety (BRRI dhan49, BRRI dhan87, and Binadhan-7) and herbicide treatments combined with aqueous extracts of lentil residues (control, recommended dose of herbicide, various reduced herbicide doses plus extracts, and weed-free). The study followed a randomized complete block design with three replications. The results indicated that weed population, dry weight, and various weed management indices, such as Weed Control Index (WCI), Weed Control Efficiency (WCE), and Weed Index (WI), were significantly influenced by both variety and the use of crop residue extracts. The highest weed growth was observed in the Binadhan-7 variety, with the lowest in BRRI dhan87. The control treatment exhibited the highest weed growth, while the lowest was found in the weed-free treatment and the 80% recommended dose of post-emergence herbicide with lentil residue extract. The weed-free treatment achieved the highest WCI and WCE values, indicating superior weed control. In contrast, the lowest weed management indices were recorded in the weed free treatment. Grain yield (GY) was highest in BRRI dhan87 (5.34 t ha^{-1}) and lowest in BRRI dhan49 (4.51 t ha^{-1}). The maximum yield (5.83 t ha^{-1}) was observed in the weed-free treatment, followed by the T_4 treatment (5.40 t ha^{-1}). The lowest GY (2.65 t ha^{-1}) was found in the control. Thus, integrating 80% of the recommended herbicide dose with lentil residue extract is suggested for effective weed control and higher yield in transplanted *aman* rice.

Introduction

Rice (*Oryza sativa* L.) is the most important crop in Bangladesh, serving as a key agricultural product both for domestic consumption and export markets. It is a fundamental raw material for various food products manufactured across the country. Rice is the staple food of the population, with an average per capita consumption of 144.5 kg annually (Yunus et al. 2019). The agricultural sector contributes approximately 11.20% to Bangladesh's Gross Domestic Product (GDP) (BBS, 2023). Rice is predominantly grown as a tropical crop, cultivated throughout most regions of Bangladesh. The country experiences three main rice-growing seasons, with Transplanted Aman rice being particularly prevalent, covering an area of 5725.91 thousand hectares and producing approximately 15,426 thousand metric tons annually (BBS, 2023). However, rice production in Bangladesh is facing challenges, including the prevalence of low-yielding varieties, severe weed infestations (WI), and inadequate crop management practices, which have contributed to a decline in average rice yields. Among these factors, WI is identified as one of the primary causes of poor yields, particularly for *aus* rice. Weeds pose a significant threat to crop cultivation, both in Bangladesh and globally, representing a major challenge to agricultural productivity.

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According to the ISWS conference (2020), approximately 11.5% of the global production of essential crops is lost because of WI. Without weed control (WC), rice production can be decreased by 16 to 88% or even 100% (Khanh et al. 2013). The massive loss in yield presupposes that weeds are seriously detrimental to crop production and need to be either prevented from growing or eliminated. For a small, overpopulated nation like Bangladesh, it severely restricts grain productivity. In Bangladesh, rice yield depends on effective WC. Effective WC is crucial for Bangladesh's rice production. Many kinds of weeds prevail in a rice field. Generally, they are categorized under three groups based on their morphological appearance, i.e., grasses, sedges, and broadleaf weeds. Traditional weed management techniques including manual weeding with a hoe, hand pulling, and prior soil tillage are widely used. The former is one of the most widely used hand weeding techniques in the nation. Depending on the type of weeds and their level of infestation, two or three hand weeding are typically given when growing a rice crop. But adverse weather conditions like heavy rainfall, flood, high temperature or lack of labor may constrain WC at critical periods by the traditional method (Chauhan et al. 2015). In transplanted rice, chemical WC using specific herbicides as pre- and post-emergence treatments is also widely used (Mitra et al. 2022). For example, Bispyribac-sodium, in addition to providing the highest yield components, yield, and economics of a transplanted rice field, a post-emergence herbicide effectively manages grassy weeds (Biswas et al. 2020).

Weeds struggle to thrive when crop releases allelochemicals from decomposing plant residues or living plants, which have phytotoxic effects (Belz 2004; Arif et al. 2025). Many plants, including major grain crops such as rice, rye, barley, sorghum, and wheat, are known to inhibit weed growth by producing these phytotoxic compounds (Belz 2004). Previously regarded as mere plant residue, these materials are now recognized as valuable resources; upon breakdown, they can significantly alter soil properties. Numerous studies have confirmed that plant residues can impact various crops, including essential grains like rice, buckwheat, sorghum, wheat, rye, mustard, and other agricultural plants, by inhibiting weed growth (Uddin and Pyon 2010; Uddin et al. 2010; Park et al. 2011; Won et al. 2013; Ferdousi et al. 2017; Hossain et al. 2017; Sheikh et al. 2017; Ahmed et al. 2018; Pramanik et al. 2019; Sarker et al. 2020).

Several studies have already been conducted on controlling weeds using crop residues. For instance, Sarker et al. (2022) demonstrated the efficiency of grass pea residue aqueous extracts in inhibiting weeds and improving wheat cultivars' growth, yield, and yield-contributing traits. Ashraf et al. (2021) demonstrated that in T. *aman* rice, a combination of hand weeding followed by the application of grass pea and mustard crop residue sprays effectively suppressed weed growth. Additionally, Uddin et al. (2012a) noted that sorgoleone, an allelochemical, significantly inhibited growth and reduced chlorophyll fluorescence in various weed species under vivo conditions. Mustard, known for its allelopathic potential, has become an important crop in sustainable agriculture due to its ability to effectively suppress weed growth (Dola et al. 2024). In allelopathic and herbicide research, mixtures of allelochemicals are valued for enhancing efficacy, efficiency, and reducing selectivity. Allelopathic activity generally relies on combinations of two or more compounds, which collectively improve the inhibition of weed growth. In this study, we examined both the pre- and post-emergence herbicidal effects of aqueous extracts from lentil residues on various weed species to assess their potential as bio-herbicides.

Materials and Methods

Description of the experimental site

An experiment was conducted from July to December 2023 at the Agronomy Field Laboratory (AFL) of Bangladesh Agricultural University, Mymensingh, to assess the effects of rice variety, reduced herbicide dosages, and aqueous extract of lentil crop residues on the yield and yield attributes of T. *aman* rice. The experimental site is located within the Sona Tola series of the Old Brahmaputra Floodplain, which falls under Agro-ecological Zone 9 (AEZ-9) as delineated by FAO and UNDP (1988). The region's soil is classified as non-calcareous dark grey floodplain soil. The field was situated at an elevation of 18 meters above sea level, with geographic coordinates of 24°25' N latitude and 90°50' E longitude. The soil at the experimental site exhibited a neutral pH of 6.8 and was categorized as moderately fertile, although it contained low organic matter content. The soil texture was silty loam, and the topography of the area ranged from moderate to high elevation. Furthermore, the pH level of the soil was approximately 6.5, indicating a nearly neutral response with limited organic matter content.

Experimental treatments and design

The experiment was designed with two main factors. Factor A included three rice cultivars: V_1 - BRRI dhan49, V_2 - BRRI dhan87, and V_3 - Binadhan-7. Factor B tested a combination of post-emergence herbicides and lentil crop extract, with the following treatments: T_1 - control, T_2 - recommended dose of herbicide (RDH) at post-emergence, T_3 - aqueous extract of lentil (AEL), T_4 - 80% RDH + AEL, T_5 - 70% RDH + AEL, T_6 - 60% RDH + AEL, and T_7 - weed-free. The experiment followed a Randomized Complete Block Design (RCBD) with three replications, resulting in a total of 63 plots, each measuring 4m x 2.5m. A spacing of 0.5m was maintained between individual plots and 1.0m between replications.

Experimental materials

This study utilized AEL, derived from lentil crops grown at the AFL of BAU. The crops were harvested at the late maturity stage, and the residues were dried on a shaded, covered threshing floor at AFL. The dried residues were subsequently finely chopped using a sickle, after which they were soaked in water at a ratio of 1:5 (w/v) for 24 hours at room temperature to prepare the aqueous extract. Seeds of the rice cultivars used in this study, namely BRRI dhan49 (V_1), BRRI dhan87 (V_2), and Binadhan-7 (V_3), were obtained from the Regional Agricultural Research Station (RARS) of the Bangladesh Agricultural Research Institute (BARI) in Jamalpur.

Crop husbandry

For seedling germination, a specific plot was selected, and the soil was thoroughly puddled using a tractor before being leveled with a ladder. On July 10, 2023, sprouted seeds were uniformly sown in a meticulously prepared nursery bed. Field preparations commenced on July 31, 2023, with tractor-assisted ploughing, followed by leveling with a ladder. After the final site preparation, the field was set up, and all weeds and crop residues were removed from the experimental plots. The experimental area was subsequently divided into blocks with 63-unit plots, ensuring proper spacing between plots. In accordance with the Bangladesh Rice Research Institute (BRRI) guidelines, the recommended fertilizer application rates were as follows: urea, triple superphosphate, muriate of potash, gypsum, and zinc sulfate at 80, 28, 40, 20, and 2.8 kg ha^{-1}, respectively. These fertilizers were applied during the final stage of land preparation. A total of 80 kg of urea was applied in two equal portions, during final land preparation and 15 and 30 days after transplanting.

On August 1, 2023, seedlings were transplanted into a well-prepared, puddled field at a planting density of three seedlings per hill, with row and hill distances of 25 cm and 15 cm, respectively. To ensure optimal growth and development of the crops, necessary intercultural operations were performed. As the experiment was conducted in a rainfed environment, no drainage was necessary. The AEL crop residues were prepared and applied twice 20 and 40 days after sowing following experimental recommendations. The AEL was applied at a 1:20 (w/v) ratio, at room temperature. The application was carried out using a hand sprayer at a rate of 1 L m^{-2} during each application.

Harvesting and Data collection

Weed population data were collected at 35 days after transplanting (DAT) from each plot using a 0.25 m × 0.25 m quadrate, as described by Cruz et al. (1986). The number of weeds within each quadrate was counted and then converted to a per square meter (m²) basis by multiplying the count by a factor of four. After recording the weed density, the weeds within each quadrate were carefully removed, cleaned, and sorted by species. The weed samples were then air-dried under sunlight before being baked at 80°C for 72 hours in an electric oven. The dry weight (DW) of each weed species was measured using an electronic balance and expressed in grams per square meter (g m^{-2}). Various weed management indices were subsequently calculated using the following formulas:

1. 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

2. Weed Control Efficiency (WCE):

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

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

3. 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.

4. 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.

5. Weed Management Index (WMI):

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

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.

6. Agronomic Management Index (AMI):

$$\mathrm{AMI} = \frac{\frac{Y_T - Y_C}{Y_C} - \frac{W_C - W_T}{W_C}}{\frac{W_C - W_T}{W_C}}$$

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.

Yield and yield contributing data

In this study, plant height (PH) and dry weight (DW) were measured 50 days after transplanting (DAT). Aboveground biomass was assessed by measuring PH from the collar zone to the tip of the tallest fully developed leaf. After measuring PH, the samples were first air-dried under direct sunlight and then further dried in an electric oven at 80°C for 72 hours. The DW of the rice plants was measured using an electronic balance and expressed as grams per hill (g hill^{-1}).

Percent inhibition

Per cent inhibition of weed was calculated using the following formula:

$$\%\ \text{Inhibition} = \frac{\text{Dry weight of weed at control} - \text{Dry weight of weed from tretament}}{\text{Dry weight of weed at control}} \times 100$$

Sampling, harvesting and processing

The crops were harvested at physiological maturity, when approximately 90% of the grains had turned yellow, with the harvest taking place on November 8, 2023. Following the harvest, the crops from each plot, except plot 1 (which contained five hills), were collected, bundled, labeled, and transported to the threshing floor. The crops were then threshed, and the fresh weights of both grain and straw were recorded from a 1 m² area at the center of each plot. The grains were cleaned, and their weight was adjusted to a standard moisture content of 14%. The straw was sun-dried, and the yields of both grain and straw from plot 1 were recorded and subsequently converted to a per-hectare basis (t ha^{-1}).

Statistical Analysis

The data collected for various parameters were compiled and organized in a suitable format for statistical analysis. The analysis of variance (ANOVA) was performed using the MSTAT-C software. Treatment methods were compared using Duncan's Multiple Range Test (DMRT), following the procedure outlined by Gomez and Gomez (1984).

Results and Discussion

Infested weed species found in the rice field

Five weed species identified in the experimental field belonged to five different plant families. Data on the local names (LN), scientific names (SN), families, morphological types (MT), and life cycles (LC) of the weeds present in the experimental plots are presented in Table 1. The weed species observed in the experimental plots included *Panicum repens*, *Echinochloa crus-galli*, *Digitaria ischaemum*, *Oxalis corniculata* L., and *Colocasia esculenta*. Among these species, three exhibited herbaceous morphology, while two were grasses. The study also identified three perennial and two annual weed species in the experimental plot.

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

Sl. No.	LN	SN	Family	MT	LC
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 shak	*Oxalis corniculata*	Oxalidaceae	Herb	Perennial
5	Pani kochu	*Colocasia esculenta*	Araceae	Herb	Perennial

Effect of variety on WP and DW of weeds

Varietal differences had a significant effect on the weed population (WP) and dry weight (DW) of weeds. The WP and DW of Angta (*P. repens*) also varied significantly by variety. BRRI dhan49 and Binadhan-7 recorded the highest WP (4.18, 4.17), with the highest DW (1.67 g) observed in BRRI dhan49, while the lowest WP (2.94) and lowest DW (1.53 g, 1.46 g) were recorded in BRRI dhan87 (Table 2). The WP and DW of Pani kochu (*C. esculenta*) also differed by variety. The highest WP (4.71) was recorded in Binadhan-7, while the lowest WP (3.76, 3.90) was observed in BRRI dhan87 and

Binadhan-7. The highest DW (1.61 g) was found in BRRI dhan49, with the second-highest DW recorded in BRRI dhan87 (1.82 g), while the lowest DW (1.61 g) was recorded in Binadhan-7 (Table 2).

Similarly, the rice variety significantly influenced the WP and DW of other weed species. For shama (*E. crus-galli*), BRRI dhan49 exhibited the highest WP at 2.57, while the highest DW (2.59 g) was recorded in Binadhan-7. The lowest WP (2.32, 2.34) was observed in BRRI dhan87 and Binadhan-7, and the lowest DW (2.33 g, 2.27 g) was found in BRRI dhan49 and BRRI dhan87 (Table 2).

For, choto anguli (*D. ischaemum*). The highest WP of *D. ischaemum* was recorded in BRRI dhan49 (2.23), followed by Binadhan-7 and BRRI dhan87, with values of 1.98 and 1.96, respectively. Similarly, the highest DW for this weed species was observed in BRRI dhan49 and BRRI dhan87 (0.36 g m^{-2} and 0.32 g m^{-2}, respectively), while the lowest DW was recorded in Binadhan-7 (0.24 g m^{-2}) (Table 2).

For Amrul (*O. corniculata* L.), the WP and DW were also significantly influenced by the rice variety (Table 2). The highest WP (2.39) was found in Binadhan-7, while the lowest WP (1.21) was observed in BRRI dhan87. The highest DW (0.20 g, 0.19 g) was recorded in Binadhan-7 and BRRI dhan87, and the lowest DW (0.14 g) was found in BRRI dhan49 (Table 2).

These findings are consistent with previous studies that have documented varietal differences in weed suppression. Some varieties have shown inherent resistance to weed infestation. Rahman et al. (2024) observed that hand weeding, combined with hot water extracts of lentil and grass pea, effectively managed weed populations. However, they noted that varietal choice also played a crucial role in maximizing yield and minimizing weed competition. Similarly, Mim et al. (2024) emphasized that selecting high-performing rice varieties, such as BRRI dhan87, can significantly boost yield while managing weed pressure under improved agricultural practices.

Table 2. Effect of variety on weed number, DW of weeds

Variety	Number of weeds (no/m²)					Total weed density weeds/m²	DW of weed (g/m²)					Total weed DW g/m²
	P. repens	*C. esculenta*	E. crusgalli	*D. ischaemum*	*O. corniculata* L.		*P. repens*	*C. esculenta*	E. crusgalli	*D. ischaemum*	*O. corniculata* L.	
V_1	4.18a	3.76b	2.57a	2.23a	2.04b	14.80b	1.67a	2.02a	2.33b	0.36a	0.14b	6.55a
V_2	2.94b	3.90b	2.32b	1.96b	1.21c	12.34c	1.53b	1.82b	2.27b	0.32a	0.20a	6.08b
V_3	4.17a	4.71a	2.34b	1.98b	2.39a	15.54a	1.46b	1.61c	2.59a	0.24b	0.19a	6.11b
$LSD_{(0.05)}$	0.21	0.35	0.19	0.15	0.29	0.54	0.10	0.08	0.19	0.06	0.01	0.12
Level of significance	**	**	*	**	**	**	**	**	**	**	**	**
CV (%)	7.25	13.91	12.96	12.19	24.70	6.19	11.16	7.20	12.72	26.00	17.56	3.27

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

Effect of herbicides along with AEL on WP and DW of weeds

WP, DW of Angta (P. *repens*) were significantly affected by lentil extract (Table 3). The highest weed population (10.77 g m^{-2}) was observed in control treatment and the lowest was observed in T_7 (weed free) treatment. The highest weed DW (3.87 g m^{-2}) was found in T_1 treatment, and the lowest weed DW (0.00 g m^{-2}) was obtained in T_7 treatment (Table 3). The trend of percent inhibition was just reverse of DW. Tonni et al. (2024) also observed that sorghum residue extracts combined with herbicides had a similar inhibitory effect on weed populations, specifically reducing the DW of weeds in wheat fields. This highlights the potential of using crop residue extracts, like AEL, to control weeds without relying entirely on synthetic herbicides.

WP and DW of Pani kochu (*C. esculenta*) were significantly affected by AEL (Table 3). The highest WP (12.32) was recorded in control treatment and the lowest was found in T_7 (weed free) treatment. The highest DW (3.87 g m^{-2}) was found in T_1 treatment and the lowest DW (0.00 g m^{-2}) was found in T_7 treatment (Table 3). The trend of percent inhibition was just reverse of DW. These findings align with those of Mostafa *et al.* (2024), who noted that post-emergence herbicide applications at various dosages effectively managed weed growth in rice cultivation, particularly when combined with other WC practices.

WP, DW of shama (*E. crusgalli)* were significantly affected AEL (Table 3). The highest WP (6.86) was reported in control treatment and the lowest was observed in T_7 (weed free) treatment. The highest weed DW (6.19 g m^{-2}) was found in T_1 treatment, and the lowest weed DW (0.00 g m^{-2}) was obtained in T_7 treatment (Table 3). The trend of percent inhibition was just opposite of DW of weed.

The AEL crop residues had synergistic effects on the WP and DW of Choto anguli (*D. ischaemum*) as presented in Table 3. The WP was the highest in T_1 control treatment (6.42) and the lowest in T_7 (weed free) treatment. The DW value was highest 0.86 g m^{-2} in T_1 treatment, and the lowest weed DW was 0.00 g m^{-2} in T_7 treatment (Table 3). In this case, the trend of the percent inhibition was the exact opposite of that observed for the DW of the weed. Where DW was lower, the percentage inhibition was relatively higher.

The AEL crop residues affected the WP and DW of the Amrul (*O. corniculata L.*) plant to a great extent (Table 3). In the present study, the maximum WP observed was 5.78 g m^{-2} in the plants of control treatment (T_1), while the lowest was 0.00 g m^{-2} in T_7 (weed free) treatment. The mean DW of the weeds was significantly affected by the treatments, the greatest DW of 0.48 g m^{-2} was recorded on the T_1 treatment and the least dry weed of 0.00 g m^{-2} recorded on the T_7 treatment (Table 3). The trend of percent inhibition was just reverse of DW.

Table 3. Effect of AEL crop residue and herbicide on weed number, DW of weeds

Weed control treatments	Number of weeds (no/m²)					Total weed density weeds/m²	DW of weed (g/m²)					Total weed DW g/m²
	P. repens	*C. esculenta*	*E. crusgalli*	*D. ischaemum*	*O. corniculata* L.		*P. repens*	*C. esculenta*	*E. crusgalli*	*D. ischaemum*	*O. corniculata* L.	
T_1	10.77a	12.32a	6.86a	6.42a	5.78a	42.17a	3.87a	5.00a	6.19a	0.86a	0.48a	16.43a
T_2	2.291d	2.325d	1.49d	0.80d	0.90d	7.816d	0.98d	1.01d	1.58d	0.17de	0.10d	3.863d
T_3	5.161b	5.366b	3.17b	2.74b	2.65b	18.95b	2.02b	2.31b	3.39b	0.42b	0.24b	8.420b
T_4	1.480e	1.694e	0.85e	0.51e	0.51d	5.046e	0.73e	0.76e	1.11e	0.12e	0.07e	2.798e
T_5	3.274c	3.474c	2.25c	1.86c	1.78c	12.64c	1.62c	1.82c	2.20c	0.28cd	0.17c	6.040c
T_6	3.387c	3.695c	2.25c	2.08c	1.56c	12.99c	1.67c	1.83c	2.31c	0.29c	0.18c	6.202c
T_7	0.000f	0.000f	0.00f	0.00f	0.00e	0.000f	0.00f	0.00f	0.00f	0.00f	0.00f	0.000f
$LSD_{(0.05)}$	0.32	0.54	0.29	0.23	0.44	0.83	0.16	0.12	0.29	0.10	0.03	0.19
Level of significance	**	**	**	**	**	**	**	**	**	**	**	**
CV (%)	7.25	13.91	12.96	12.19	24.70	6.19	11.16	7.20	12.72	26.00	17.56	3.27

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, T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = lentil crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + lentil crop residues, T_5 = Pre-emergence (70% recommended dose) + lentil crop residues, T_6 = Pre-emergence (60% recommended dose) + lentil crop residues and T_7 = Weed free

Interaction effect on WP and DW of weeds

Significant interactions between rice varieties and the application of aqueous extract of lentil (AEL) crop residues were observed in both weed population (WP) and dry weight DW (Table 4). The interaction between rice variety and AEL significantly influenced the WP and DW of Angta (*P. repens*) (Table 4). The highest WP (12.30) was recorded in BRRI dhan49 under the control treatment. The highest DW (3.93 g m^{-2}, 4.15 g m^{-2}) was observed in BRRI dhan87 and Binadhan-7 under the control treatment, while the lowest WP and DW (0.00 g m^{-2}) were recorded in BRRI dhan49, BRRI dhan87, and Binadhan-7 under the weed-free treatments (Table 4). These results align with the findings of Zinnat et al. (2024), who reported the efficacy of grass pea residue extracts for pre- and post-emergence WC, demonstrating the effectiveness of crop residues in managing weed populations.

Finally, for Pani kochu (*C. esculenta*), the highest WP (13.32) was recorded in Binadhan-7 under the control treatment. The highest DW (5.46 g m^{-2}) was found in BRRI dhan49 under the control treatment, while the lowest WP and DW (0.00 g m^{-2}) were recorded in BRRI dhan49, BRRI dhan87, and Binadhan-7 under the weed-free treatments (Table 4). These results are consistent with the findings of Akondo et al. (2024), who demonstrated that combining crop residue extracts with reduced herbicide applications significantly reduced weed biomass, particularly for resilient weed species in wheat cultivation.

In the case of Shama (*E. crus-galli*), the highest WP (7.00) was recorded in BRRI dhan49 under the control treatment, while the lowest WP (0.00) was observed in BRRI dhan49, BRRI dhan87, and Binadhan-7 under the weed-free treatments (Table 4). The highest DW (7.00 g m^{-2}) was observed in Binadhan-7 under the control treatment, whereas the lowest DW (0.00 g m^{-2}) was recorded in BRRI dhan49, BRRI dhan87, and Binadhan-7 under weed-free treatments (Table 4).

For Choto anguli (*D. ischaemum*), the highest WP (7.00) and DW (1.06 g m^{-2}) were recorded in BRRI dhan49 under the control treatment. Conversely, the lowest WP (0.00) and DW (0.00 g m^{-2}) were observed in BRRI dhan49 under the weed-free treatment, as well as in BRRI dhan87 and Binadhan-7 under the weed-free treatments (Table 4).For Amrul (*O. corniculata* L.), significant interactions between rice variety and AEL were observed for both WP and DW (Table 4). The highest WP (7.69) was recorded in Binadhan-7 under the control treatment. The highest DW (0.53 g m^{-2}, 0.54 g m^{-2}) was recorded in BRRI dhan49, BRRI dhan87, and

Binadhan-7 under the control treatment, while the lowest WP and DW (0.00 g m^{-2}) were observed in the weed-free treatments of all three varieties (Table 4).

Table 4. Interaction effect of variety and AEL crop residue and herbicide on weed number, DW of weeds

Interaction	Number of weeds (no/m²)					Total weed density weeds/m²	DW of weed (g/m²)					Total weed DW g/m²
	P. repens	*C. esculenta*	E. crusgalli	*D. ischaemum*	*O. corniculata* L.		*P. repens*	*C. esculenta*	E. crusgalli	*C. esculenta*	*O. corniculata* L.	
V_1T_1	12.30a	11.66b	7.00a	7.00a	6.00b	43.96b	3.54b	5.46a	5.94b	1.06a	0.36b	16.37b
V_1T_2	2.66h	2.00hij	6.92a	0.67fg	0.67hi	7.660i	1.05gh	0.96gh	1.58ef	0.18efghi	0.08hi	3.860j
V_1T_3	5.670d	5.330d	6.67a	2.66c	2.66de	19.65d	2.47c	2.73d	3.50c	0.51c	0.21de	9.466d
V_1T_4	1.67ij	1.33j	3.33b	0.67fg	0.33hi	4.670j	0.75ij	0.72ij	0.85h	0.12ghi	0.03jk	2.486l
V_1T_5	3.33fg	2.67fgh	3.20b	2.00d	2.67de	13.33f	1.88def	2.14e	2.05de	0.29defg	0.14fg	6.606g
V_1T_6	3.67ef	3.333efg	3.00bc	2.67c	2.00ef	14.36f	2.03d	2.16e	2.38d	0.34cdef	0.17ef	7.093f
V_1T_7	0.00l	0.00k	2.67c	0.00h	0.00i	0.000k	0.00k	0.00k	0.00i	0.00i	0.00k	0.000m
V_2T_1	8.300c	12.00b	2.66c	6.33b	3.66c	36.96c	3.93a	4.89b	5.64b	0.82b	0.53a	15.85c
V_2T_2	1.45j	2.56fgh	2.09d	0.80f	0.33hi	6.470i	1.03ghi	0.94ghi	1.47fg	0.21efgh	0.10ghi	3.766j
V_2T_3	4.00e	4.170e	2.09d	2.90c	2.30def	16.57e	1.64f	2.10e	3.32c	0.41cd	0.25cd	7.743e
V_2T_4	0.72k	1.59ij	2.00de	0.55fg	0.21i	3.940j	0.71j	0.84hij	1.06gh	0.16fghi	0.08ij	2.860k
V_2T_5	3.07gh	3.493ef	2.00de	1.58e	1.00gh	11.24g	1.70ef	1.99e	2.20d	0.33cdef	0.22d	6.180h
V_2T_6	3.07gh	3.493ef	1.66def	1.58e	1.00gh	11.24g	1.70ef	1.99e	2.20d	0.33cdef	0.22d	6.180h
V_2T_7	0.00l	0.00k	1.50efg	0.00h	0.00i	0.000k	0.00k	0.00k	0.00i	0.00i	0.00k	0.000m
V_3T_1	11.73b	13.32a	1.32fgh	5.93b	7.69a	45.61a	4.15a	4.65c	7.00a	0.71b	0.54a	17.07a
V_3T_2	2.76h	2.41ghi	1.00ghi	0.93f	1.72fg	9.320h	0.87hij	1.13fg	1.70ef	0.13ghi	0.13fgh	3.963j
V_3T_3	5.813d	6.600c	0.88hi	2.67c	3.00cd	20.63d	1.95de	2.11e	3.36c	0.35cde	0.27c	8.050e
V_3T_4	2.05i	2.16hij	0.67i	0.33gh	1.00gh	6.530i	0.73j	0.71j	1.42fg	0.07hi	0.10ghi	3.050k
V_3T_5	3.41fg	4.260e	0.00j	2.01d	1.68fg	13.37f	1.28g	1.33f	2.34d	0.21efgh	0.16ef	5.333i
V_3T_6	3.41fg	4.260e	0.00j	2.01d	1.68fg	13.37f	1.28g	1.33f	2.34d	0.21efgh	0.16ef	5.333i
V_3T_7	0.00l	0.00k	0.00j	0.00h	0.00i	0.000k	0.00k	0.00k	0.00i	0.00i	0.00k	0.000m
LSD $_{(0.05)}$	0.55	0.94	0.51	0.41	0.76	1.45	0.28	0.21	0.50	0.18	0.05	0.33
Level of significance	**	**	*	**	**	**	**	**	**	**	**	**
CV (%)	7.25	13.91	12.96	12.19	24.70	6.19	11.16	7.20	12.72	26.00	17.56	3.27

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 = lentil crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + lentil crop residues, T_5 = Pre-emergence (70% recommended dose) + lentil crop residues, T_6 = Pre-emergence (60% recommended dose) + lentil crop residues and T_7 = Weed free

Effect of variety on Weed Management indices

BRRI dhan49 (V_1), BRRI dhan87 (V_2), and Binadhan-7 (V_3), across several weed management indices. The Weed Control Index (WCI) ranges from 65.91 to 66.58, with significant influence. Weed Control Efficiency (WCE) varies significantly, with V_3 achieving the highest efficiency at 64.19, and V_1 the lowest at 59.96. The Weed Index (WI) indicates that V_3 has the highest weed presence (18.36), significantly differing from V_1 and V_2, which are statistically similar. The Weed Persistence Index (WPI) is lowest for V_3 at 0.53, signifying better weed management compared to V_1 and V_2. The Herbicide Efficiency Index (HEI) is highest for V_3 (1.98) and lowest for V_2 (1.69), with significant variations. Weed Management Index (WMI) shows V_1 as the most effective at 1.23, while V_2 scores the lowest at 1.06. The Agronomic Management Index (AMI) reveals V_1 and V_3 as superior, with V_1 scoring 0.37 and V_3 0.27, whereas V_2 scores significantly lower at 0.20 (Table 5). Overall, this analysis underscores significant differences in weed management effectiveness among the three rice varieties. Nur-A-Alam et al. (2024) also concluded that higher WCI values correlated with greater weed suppression, though other indices like HEI and WMI are also critical in assessing overall weed management effectiveness. Similarly, Hossain et al. (2024) explored pre-emergence herbicides, such as Bensulfuron methyl + Acetachlor, which achieved high weed control efficiency (94.58%) and significantly enhanced grain yield. While both approaches effectively reduced weed competition, the environmental concerns associated with herbicide overuse, such as resistance development and ecological degradation, make the use of lentil extracts a more sustainable option.

Table 5. Effect of variety on Weed Management indices

Variety	WCI	WCE	WI	WPI	HEI	WMI	AMI
V_1	66.29ab	59.96c	17.58b	0.60a	1.87b	1.23a	0.37a
V_2	66.58a	61.61b	17.45b	0.58b	1.69c	1.06c	0.20c
V_3	65.91b	64.19a	18.36a	0.53c	1.98a	1.13b	0.27b
LSD $_{(0.05)}$	0.60	0.62	0.76	0.01	0.05	0.03	0.03
Level of significance	*	**	*	**	**	**	**
CV (%)	3.46	3.61	6.88	4.03	5.10	4.76	18.84

Here, in a column means having same letter(s) are statistically identical and those having different letter(s) varies significantly as per 0.05 level of probability, V_1 = BRRI dhan49, V_2 = BRRI dhan87 and V_3 = Binadhan -7

Effect of aqueous extract of lentil crop residue and herbicide on Weed Management indices

Some of the tested parameters include 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 affected by the treatment. The weed-free treatment (T_7) obtained the highest WCI and WCE at 100.0, reflecting perfect weed control, while the control treatment (T_1) records 0.00 for both indices, indicating no control. The WI is highest in T_1 (54.65), signifying severe weed presence, and lowest in T_7 (0.00), denoting no weed presence. The WPI ranges from 1.00 in T_1 to 0.00 in T_7, with lower values indicating better weed control persistence. The highest HEI is noted in T_7 (5.11), highlighting the superior efficiency of complete weed removal, whereas T_1 registers the lowest (0.00). The WMI peaks in T_3 (1.47), utilizing lentil crop residues extracts effectively, while T_1 has the lowest (0.00). For the AMI, T_3 again shows the highest value (0.47), indicating effective agronomic management, while T_1 remains at the lowest (0.00) (Table 6). Overall, this comprehensive analysis demonstrates the varying effectiveness of WC strategies, with the weed-free treatment (T_7) providing optimal results across all parameters. Islam et al. (2024) also emphasized the benefits of integrating crop residues with minimal herbicide use, as it balances WC with environmental preservation.

Table 6. Effect of AEL crop residue and herbicide on WMI

WCT	WCI	WCE	WI	WPI	HEI	WMI	AMI
T_1	0.000f	0.000g	54.65a	1.00a	0.00f	0.00e	0.00e
T_2	81.57c	76.48c	9.822d	0.51d	1.86c	1.29c	0.28c
T_3	55.04e	48.73f	22.52b	0.74b	0.96e	1.47a	0.47a
T_4	88.11b	82.97b	7.464e	0.44e	2.25b	1.25cd	0.25cd
T_5	69.92d	63.15d	14.74c	0.65c	1.39d	1.39b	0.39b
T_6	69.19d	62.14e	15.42c	0.66c	1.35d	1.40b	0.39b
T_7	100.0a	100.0a	0.000f	0.00f	5.11a	1.21d	0.20d
$LSD_{(0.05)}$	0.92	0.95	1.16	0.02	0.08	0.05	0.05
Level of significance	**	**	**	**	**	**	**
CV (%)	3.46	3.61	6.88	4.03	5.10	4.76	18.84

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. T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = lentil crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + lentil crop residues, T_5 = Pre-emergence (70% recommended dose) + lentil crop residues, T_6 = Pre-emergence (60% recommended dose) + lentil crop residues and T_7 = Weed free

Interaction effect between variety and AEL crop residue and herbicide on WMI

WCI, WCE, WI, WPI, HEI, WMI, AMI were significantly affected by the treatment. For WCI and WCE, the weed-free treatment (T_7) consistently shows the highest values (100.00) for all varieties, indicating optimal WC, while the control treatment (T_1) scores 0.00, reflecting no WC. The WI is highest for T_1 across all varieties, with V_3T_1 reaching 55.86, indicating severe weed presence, while T_7 has a WI of 0.000 for all varieties. The WPI is lowest for T_7 (0.00) and highest for T_1 (1.00), signifying better persistence of WC in T_7. HEI is highest in V_3T_7 (5.50) and lowest in T_1 (0.00), indicating superior herbicide efficiency in weed-free treatment. WMI peaks in V_1T_3 (1.71), highlighting effective use of lentil crop residues extracts, whereas T_1 consistently shows 0.00 across varieties. AMI is highest in V_1T_3 (0.72) and lowest in T_1 (0.00), reflecting better agronomic management with lentil crop residues extracts (17). 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. This result aligns with Dola *et al.* (2024), who found that optimal WC could be achieved through integrating residue extracts with other methods, thereby reducing the need for excessive herbicide applications and promoting sustainable practices. The control treatment (T_1), lacking any WC intervention, recorded a WCI and WCE of 0.0, illustrating the critical need for active weed management to minimize weed competition. Similarly, the interaction between rice varieties, aqueous extracts of mustard crop residues, and herbicides significantly influenced several weed management indices, including 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). The weed-free treatment achieved the highest WCI and WCE values (100%), while the control treatment showed zero weed control (WCI and WCE = 0) with the highest WI (47.98–55.30) and WPI (1.00). The combination of 80% herbicide + mustard crop residues and recommended herbicide dose showed effective weed control with reduced WI and moderate WPI. The highest HEI values were recorded in the weed-free treatment (4.98–4.89), followed by the herbicide + crop residue combination (2.18–2.13). The WMI and AMI were lowest in the weed-free treatment (0.17–0.22 for WMI, 0.17–0.22 for AMI), indicating superior weed management, with the 80% herbicide + mustard residues treatment following (WMI = 1.94–2.36, AMI = 0.23–0.27). These findings highlight the importance of integrated weed management strategies combining crop residues with reduced herbicide doses for enhanced weed control and sustainability (Arif et al. 2025).

Table 7. Interaction effect between variety and AEL crop residue and herbicide on WMI

Interaction	WCI	WCE	WI	WPI	HEI	WMI	AMI
V_1T_1	0.00i	0.000k	55.06a	1.00a	0.00l	0.00g	0.00h
V_1T_2	82.67d	76.42d	10.08f	0.54e	1.88fg	1.31cde	0.31cde
V_1T_3	55.25h	42.19j	22.49c	0.84b	0.93k	1.71a	0.72a
V_1T_4	89.32b	84.820b	7.153gh	0.42g	2.39d	1.25de	0.25def
V_1T_5	69.50f	59.67f	13.12e	0.71cd	1.41hi	1.55b	0.55b
V_1T_6	67.32g	56.66g	15.18d	0.73c	1.30ij	1.58b	0.57b
V_1T_7	100.00a	100.00a	0.000i	0.00h	5.16b	1.22ef	0.22f
V_2T_1	0.00i	0.000k	53.03b	1.00a	0.00l	0.00g	0.00h
V_2T_2	82.49d	76.23d	9.103fg	0.53e	1.75g	1.22ef	0.22ef
V_2T_3	55.13h	51.12i	21.98c	0.71cd	0.92k	1.30de	0.30def
V_2T_4	89.33b	81.94c	6.170h	0.48f	2.11e	1.22ef	0.22f
V_2T_5	69.56f	61.00f	15.95d	0.68d	1.20j	1.29de	0.28def
V_2T_6	69.56f	61.00f	15.95d	0.68d	1.20j	1.29de	0.28def
V_2T_7	100.00a	100.00a	0.000i	0.00h	4.69c	1.14f	0.12g
V_3T_1	0.00i	0.000k	55.86a	1.00a	0.00l	0.00g	0.00h
V_3T_2	79.55e	76.79d	10.28f	0.48f	1.96f	1.34cd	0.31cde
V_3T_3	54.76h	52.86h	23.08c	0.69d	1.04k	1.40c	0.40c
V_3T_4	85.67c	82.14c	9.070fg	0.43g	2.26de	1.28de	0.28def
V_3T_5	70.70f	68.77e	15.14de	0.56e	1.56h	1.33cd	0.33cd
V_3T_6	70.70f	68.77e	15.14de	0.56e	1.56h	1.33cd	0.33cd
V_3T_7	100.00a	100.00a	0.000i	0.00h	5.50a	1.26de	0.26def
$LSD_{(0.05)}$	1.59	1.64	0.02	0.03	0.15	0.09	0.08
Level of significance	**	**	**	**	**	**	**
CV (%)	3.46	3.61	6.88	4.03	5.10	4.76	18.84

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

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 = lentil crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + lentil crop residues, T_5 = Pre-emergence (70% recommended dose) + lentil crop residues, T_6 = Pre-emergence (60% recommended dose) + lentil crop residues and T_7 = Weed free

Effect of variety on yield and yield contributing characters of T. aman rice

The study also revealed high variability in both yield and yield-related attributes influenced by varietal differences. Binadhan –7 exhibited the highest panicle length (PL) (23.88 cm) and Harvest Index (HI) (44.50%). BRRI dhan87 showed superior performance in various categories, recording the highest plant height (PH) (114.68 cm), No. of total tillers hill^{-1} (NTT hill^{-1}) (12.31), No. of grains panicle^{-1}(NGP) (95.08) and 1000- grain weight (TGW) (21.85 g) (Table 8). The lowest PL (19.67 cm) and TGW (21.05 g) were noted in BRRI dhan87 and BRRI dhan49, while the lowest values for the PH (91.43cm), NET hill^{-1} (7.30), No. of grains panicle^{-1} (NGP) (88.57), Biological yield (BY) and Harvest Index (HI) (44.14%) were observed in Binadhan -7 (Table 8). The study highlights significant varietal differences in yield and yield-related traits of *Boro* rice. BAU dhan3 outperformed other varieties, showing the highest values for plant height (103.33 cm), effective tillers (8.42), panicle length (20.50 cm), spikelets panicle^{-1} (78.17), thousand grain weight (23.07 g), and harvest index (42.56%), indicating its superior productivity. In contrast, BRRI dhan96 had the shortest plants (87.00 cm), and BRRI dhan28 had the lowest values for effective tillers (6.50), panicle length (18.42 cm), spikelets panicle^{-1} (75.58), thousand grain weight (20.29 g), and harvest index (39.87%), suggesting it may be less efficient in grain production (Alam et al. 2025).

Table 8. Effect of variety on the yield contributing characters and yield of transplanted aman rice

Variety	PH (cm)	NTT $hill^{-1}$	NET $hill^{-1}$	NNET $hill^{-1}$	PL (cm)	NGP	TGW (g)	GY ($t\ ha^{-1}$)	SY ($t\ ha^{-1}$)	BY ($t\ ha^{-1}$)	HI (%)
V_1	96.39b	8.96c	7.39b	1.57b	19.98b	89.06b	21.05b	4.51b	5.54c	10.06c	44.50a
V_2	114.68a	12.31a	9.39a	2.91a	19.67b	95.08a	21.85a	5.34a	6.59a	11.93a	44.37ab
V_3	91.43c	10.27b	7.30b	2.97a	23.88a	88.57b	21.50a	4.52b	5.60b	10.13b	44.14b
LSD (0.05)	0.56	0.51	0.41	0.42	0.42	2.36	0.36	0.04	0.05	0.06	0.34
Level of significance	**	**	**	**	**	**	**	**	**	**	*
CV (%)	3.90	7.92	8.31	27.70	3.18	4.18	2.75	2.37	2.40	2.97	2.25

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, ** = 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

Effects of AEL with herbicide on yield and yield contributing characters of T. aman rice

Incorporating AEL with herbicides greatly affected yield and its contributing factors. The maximum results were recorded when weed free (T_7) condition followed, the highest PH (106.35 cm), NET $hill^{-1}$ (10.30), PL (23.72 cm), NGP (104.16), TGW (24.05 g) and HI (47.75 %) were obtained (Table 9). In contrast, the lowest were noted when, control (T_1) was followed, resulting in the lowest PH (95.03 cm), NET $hill^{-1}$ (6.01), PL (18.69 cm), NGP (65.98), TGW (18.47 g) and HI (37.77%) (Table 9). Sarker et al. (2020) observed that the highest counts and weights of 1000 grain $spike^{-1}$ were achieved following the RDH, whereas the lowest were seen with hand weeding. Similar results were shown by Uddin et al. (2012b), where the aqueous extract of crop residues influenced crop performance. The study demonstrates the significant impact of hot water extracts of grass pea on rice yield and associated agronomic traits. The best performance was observed when three times hand weeding was combined with the extract, resulting in the highest plant height (105.17 cm), number of effective tillers (10.5), panicle length (20.90 cm), number of spikelets $panicle^{-1}$ (99.51), thousand grain weight (21.50 g), and harvest index (43.14%). In contrast, the absence of extract resulted in lower values for these parameters, particularly plant height (88.17 cm) and harvest index (36.73%). Furthermore, the combination of sorghum and mustard extracts with herbicides significantly enhanced wheat yield, with the highest yield (4.09 $t\ ha^{-1}$) achieved using the full herbicide dose, while the combination of 80% herbicide plus crop extract yielded 3.92 $t\ ha^{-1}$. These results highlight the effectiveness of combining crop residue extracts with weed management strategies for improving crop performance (Zinnat et al. 2024).

Table 9. Effect of AEL crop residue and herbicide on the yield contributing characters and yield of transplanted aman rice

Aqueous extract of sorghum crop residue and herbicide	PH (cm)	NTT $hill^{-1}$	NET $hill^{-1}$	NNET $hill^{-1}$	PL (cm)	NGP	TGW (g)	GY ($t\ ha^{-1}$)	SY ($t\ ha^{-1}$)	BY ($t\ ha^{-1}$)	HI (%)
T_1	95.03g	8.33e	6.01e	2.32	18.69e	65.98e	18.47f	2.65f	4.36d	7.01f	37.77f
T_2	102.99c	11.38b	8.68b	2.70	21.97b	98.24b	22.67b	5.26c	6.20b	11.46c	45.91c
T_3	96.88f	9.21d	7.00d	2.21	19.83d	82.92d	19.96e	4.52e	6.07c	10.59e	42.62e
T_4	104.38b	11.82b	9.05b	2.76	22.50b	100.55ab	23.11b	5.40b	6.18b	11.58b	46.61b
T_5	100.87d	10.24c	7.76c	2.48	21.08c	93.91c	21.36c	4.96d	6.08c	11.05d	44.98d
T_6	99.33e	9.84cd	7.37cd	2.47	20.44cd	90.61c	20.68d	4.93d	6.09c	11.02d	44.72d
T_7	106.35a	12.76a	10.30a	2.45	23.72a	104.16a	24.05a	5.83a	6.38a	12.21a	47.75a
LSD (0.05)	0.86	0.79	0.63	0.65	0.64	3.61	0.56	0.06	0.05	0.09	0.52
Level of significance	**	**	**	NS	**	**	**	**	**	**	**
CV (%)	3.90	7.92	8.31	27.70	3.18	4.18	2.75	2.37	2.40	2.97	2.25

In a column means having same letter(s) are statistically identical and those having different letter(s) differ significantly as per 0.05 level of probability, ** = Significant at 1% level of probability, * = Significant at 5% level of probability, T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = lentil crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + lentil crop residues, T_5 = Pre-emergence (70% recommended dose) + lentil crop residues, T_6 = Pre-emergence (60% recommended dose) + lentil crop residues and T_7 = Weed free

Interaction effect between variety and AEL with herbicide on the yield contributing characters and yield of T. aman rice

Significant variations in PH, PL, TGW, NET $hill^{-1}$, NGP, GY, and SY were noted when several rice varieties were treated under combination of AEL and herbicide. The highest PH (120.16 cm), NET $hill^{-1}$ (11.32), NGP (108.22) and TGW (24.17 g) were obtained for BRRI dhan87 with Weed free condition. The maximum PL (26.03 cm) and HI (47.88 %) were observed in Binadhan -7 with weed free condition (Table 10). Conversely, the lowest PH (89.92cm), NET hill^{-1} (5.39), PL (16.98 cm), NGP (69.32) and TGW (17.63 g) were recorded in BRRI dhan49 and control treatment (Table 10). The lowest HI (35.70%) was observed in Binadhan -7 with control treatment. Sarker et al. (2022) also particularly highlighting the effect of crop residues and variety interaction on the weight of a thousand grains. Similarly, Ahmed et al. (2018) discovered that agricultural residue extracts and variety had a successful combination effect. Smiliarly, the interaction between rice varieties and aqueous extracts of mustard crop residues significantly affected agronomic traits such as plant height (PH), tiller number, panicle length, grain number per panicle, 1000-grain weight, and harvest index. BRRI dhan87 exhibited the tallest plants (120.13 cm) and the highest tiller number (14.62 tillers hill^{-1}) with the weed-free treatment, whereas Binadhan-7 in the control treatment showed the shortest plants (86.81 cm) and the lowest tiller count (6.87 tillers hill^{-1}). BRRI dhan87 also produced the highest number of effective tillers (10.67 tillers hill^{-1}) under weed-free conditions. In terms of panicle length, Binadhan-7 with the weed-free treatment had the longest panicles (26.03 cm), while BRRI dhan49 in the control treatment had the shortest (16.98 cm). The highest grain number per panicle (108.22) and 1000-grain weight (24.32 g) were observed in BRRI dhan87 and BRRI dhan49, respectively, with the weed-free treatment. Additionally, BRRI dhan49 showed the highest harvest index (48.32%) under weed-free conditions, indicating greater resource use efficiency (Arif et al. 2025).

Table 10. Interaction effect of variety and aqueous extract of lentil crop residue and herbicide on the yield contributing characters and yield of transplant aman rice

Interaction	PH (cm)	NTT hill^{-1}	NET hill^{-1}	NNET hill^{-1}	PL (cm)	NGP	TGW (g)	GY (t ha^{-1})	SY (t ha^{-1})	BY (t ha^{-1})	HI (%)
V_1T_1	89.92o	6.94m	5.39k	1.55e	16.98l	69.32l	17.63o	2.46l	3.80m	6.26l	39.31i
V_1T_2	99.05i	9.71hijk	8.00efg	1.70de	20.99gh	96.27defg	22.78cde	4.93g	5.77ghij	10.70fg	46.04cde
V_1T_3	2.00lm	7.94lm	6.51hij	1.43e	18.27jk	77.19k	19.22mn	4.25j	5.88fg	10.13i	41.94h
V_1T_4	100.26i	9.90ghij	8.28def	1.61e	21.41fg	98.79bcde	23.27bcd	5.09e	5.73hij	10.82ef	47.01ab
V_1T_5	96.41j	9.03jkl	7.22fghi	1.81cde	19.95hi	91.65ghi	20.35ijkl	4.76h	5.78ghij	10.54gh	45.17ef
V_1T_6	94.43k	8.44kl	6.94ghij	1.49e	19.32ij	86.99ij	19.83klm	4.65i	5.82ghi	10.47h	44.38f
V_1T_7	102.67h	10.77fgh	9.38bcd	1.38e	22.94de	103.22abc	24.32a	5.48d	6.01ef	11.50d	47.68a
V_2T_1	108.84g	9.30ijkl	7.31fgh	1.99cde	17.72kl	69.49l	18.28no	3.04k	4.89k	7.93j	38.31j
V_2T_2	116.76c	13.31bc	9.83bc	3.47ab	20.47gh	101.79bcd	23.23bcd	5.88c	6.99ab	12.87b	45.69de
V_2T_3	110.58f	10.48fghi	8.48de	1.99cde	18.34jk	88.41ij	20.52ijk	5.05ef	6.62d	11.67d	43.28g
V_2T_4	118.49b	14.25ab	10.39ab	3.86a	21.06g	104.42ab	23.63abc	6.07b	6.95b	13.02b	46.62bc
V_2T_5	114.78d	12.17cde	9.37bcd	2.80abcd	19.32ij	98.01cdef	22.17efg	5.44d	6.78c	12.22c	44.49f
V_2T_6	113.17e	11.80def	9.04cde	2.75abcd	18.62jk	95.27efgh	21.00hij	5.44d	6.78c	12.22c	44.49f
V_2T_7	120.16a	14.86a	11.32a	3.53ab	22.18ef	108.22a	24.17ab	6.47a	7.10a	13.57a	47.69a
V_3T_1	86.33q	8.76jkl	5.33k	3.43ab	21.36fg	59.13m	19.50lm	2.44l	4.41l	6.85k	35.70k
V_3T_2	93.17kl	11.13efg	8.21ef	2.92abc	24.46bc	96.65defg	22.00efg	4.97fg	5.84ghi	10.81ef	45.99cde
V_3T_3	88.07p	9.22ijkl	6.00jk	3.21ab	22.90de	83.15jk	20.15jklm	4.26j	5.73ij	9.99i	42.66gh
V_3T_4	94.38k	11.31def	8.50de	2.81abcd	25.02ab	98.43bcde	22.43def	5.04ef	5.86gh	10.90e	46.21bcd
V_3T_5	91.42mn	9.53hijk	6.71hij	2.82abcd	23.98bcd	92.07fghi	21.58fgh	4.70hi	5.68j	10.38h	45.29ef
V_3T_6	90.40no	9.28ijkl	6.12ijk	3.16ab	23.40cd	89.57hi	21.23ghi	4.70hi	5.68j	10.38h	45.29ef
V_3T_7	96.21j	12.65cd	10.21b	2.44bcde	26.03a	101.03bcde	23.67abc	5.54d	6.03e	11.57d	47.88a
LSD $_{(0.05)}$	1.49	1.37	1.10	1.13	1.11	6.26	0.97	0.10	0.13	0.17	0.91
Level of significance	**	**	**	**	**	**	**	**	**	**	**
CV (%)	3.90	7.92	8.31	27.70	3.18	4.18	2.75	2.37	2.40	2.97	2.25

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 = lentil crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + lentil crop residues, T_5 = Pre-emergence (70% recommended dose) + lentil crop residues, T_6 = Pre-emergence (60% recommended dose) + lentil crop residues and T_7 = Weed free

Effect of variety on GY and SY

The study revealed that several varieties significantly influenced both grain yield (GY) and straw yield (SY). BRRI dhan87 showed the highest GY (5.34 t ha^{-1}) and the lowest GY (4.51 t ha^{-1}) was produced by Binadhan -7 (Figure 1). The highest SY (6.59 t ha^{-1}) recorded in BRRI dhan87 and the lowest SY (5.54 t ha^{-1}) was obtained in Binadhan-7 (Figure 2). Similarly, the highest GY of 6.80 t ha^{-1} and SY of 8.23 t ha^{-1} were recorded when the BAU dhan3 variety was combined with three-time hand weeding (Alam et al. 2024). In the study conducted by Dola et al. (2024), BARI Gom-32 consistently outperformed other varieties, producing the highest grain yield (4.46 t ha^{-1}), with BWMRI Gom-1 recording the lowest GY (4.28 t ha^{-1}). Similarly, Akondo et al. (2024) observed that BARI Gom-32 achieved a GY of 3.62 t ha^{-1}, with comparable strong performance from BWMRI Gom-1 and BARI Gom-33. However, despite its lower GY, BWMRI Gom-1 recorded the highest SY (5.70 t ha^{-1}) and BY (9.27 t ha^{-1}), indicating a biomass-focused advantage.

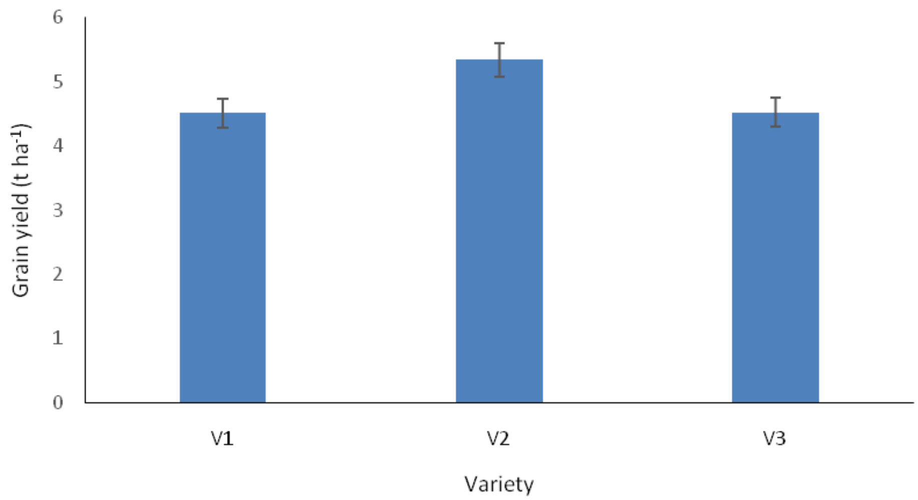

Figure 1. Effect of variety on GY of transplanted aman rice
Here, V_1 = BRRI dhan49, V_2 = BRRI dhan87 and V_3 = Binadhan – 7

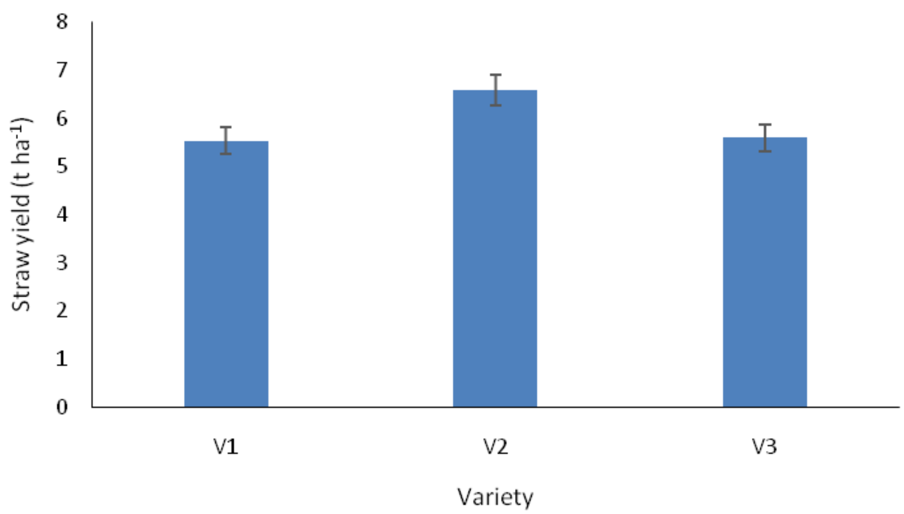

Figure 2. Effect of variety on SY of transplanted aman rice
Here, V_1 = BRRI dhan49, V_2 = BRRI dhan87 and V_3 = Binadhan – 7

Effect of AEL crop residues with herbicide on GY and SY

The application of the AEL crop residues influenced GY and SY. The highest GY (5.83t ha^{-1}) was recorded in Weed free (T_7) condition. The lowest GY (2.65 t ha^{-1}) was found in Control (T_1) treatment (Figure 3). SY was significantly influenced, with the highest SY (6.38 t ha^{-1}) obtained in the Weed free (T_7) condition. The lowest SY (4.36 t ha^{-1}), was noted in Control (T_1) treatment (Figure 4). This trend supports the conclusions made by Sarker et al. (2022), who observed that crop residues might influence crop performance quite widely. Ahmed et al. (2018) also established that the aqueous extract of sorghum crop residues influence yield and yield-contributing characters. Significant agronomic benefits were observed in both Boro rice and wheat systems. In the rice experiment, the highest grain yield (GY) of 6.08 t ha^{-1} was recorded in the three-times hand weeding treatment, closely followed by treatments involving hot water extract of lentil and grass pea (ELG), while the lowest yield (3.56 t ha^{-1}) occurred in the no-extract control treatment (Rahman et al., 2024). The improvements extended to straw yield (SY) and biological yield (BY), with three-times hand weeding resulting in the highest SY (7.67 t ha^{-1}) and BY (13.67 t ha^{-1}), affirming the yield-enhancing effect of effective weed suppression.

Similarly, in the wheat trial, the application of recommended dose of herbicide (RDH) and its combination with AES at a 1:20 ratio produced significantly higher GY (4.59 and 4.48 t ha^{-1}, respectively), as opposed to the lowest GY (3.9 t ha^{-1}) in the no-weeding treatment. A similar trend was observed in SY, where RDH alone yielded 6.57 t ha^{-1}, indicating that AES can complement chemical herbicides in maintaining competitive yields (Tonni et al., 2024). The statistical significance in yield responses across treatments emphasizes the biological efficacy of extract-based strategies.

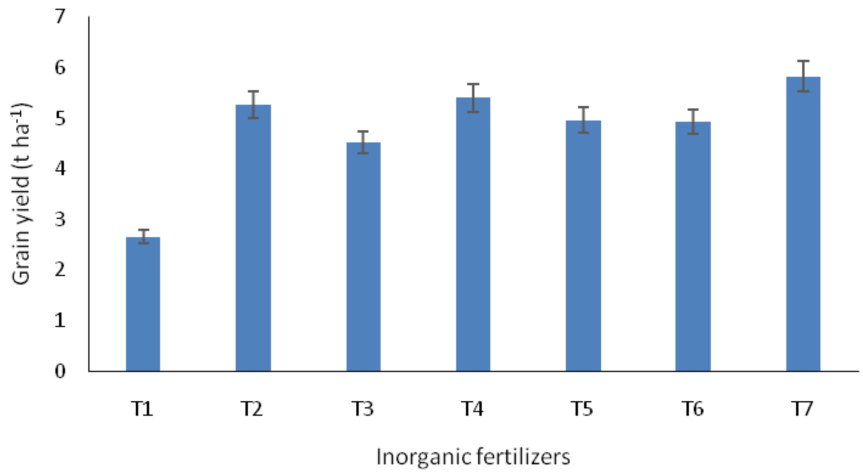

Figure 3. Effects of AEL with herbicide on GY of transplanted aman rice

Here, T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = lentil crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + lentil crop residues, T_5 = Pre-emergence (70% recommended dose) + lentil crop residues, T_6 = Pre-emergence (60% recommended dose) + lentil crop residues and T_7 = Weed free

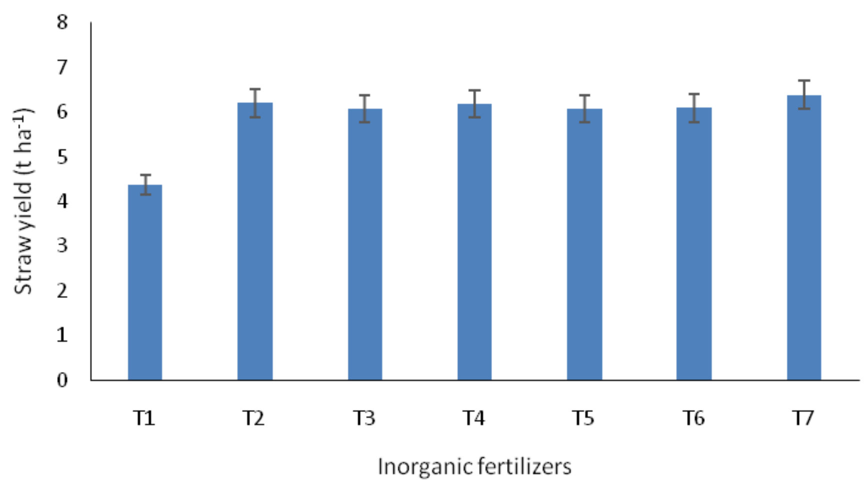

Figure 4. Effects of AEL with herbicide on SY of transplanted aman rice

Here, T_1 = Control, T_2 = Recommended dose of herbicide at pre-emergence, T_3 = lentil crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + lentil crop residues, T_5 = Pre-emergence (70% recommended dose) + lentil crop residues, T_6 = Pre-emergence (60% recommended dose) + lentil crop residues and T_7 = Weed free

Interaction effect between variety and AEL crop residues with herbicides on GY and SY

Variety and AEL crop residue affecting GY and SY were found to have a significant interaction effect. The highest GY (6.47t ha^{-1}) was produced by BRRI dhan87 with Weed free condition, and the lowest GY (2.46 t ha^{-1}) was produced by BRRI dhan49 and control treatment (Figure 5). The highest SY (7.10 t ha^{-1}) was obtained in BRRI dhan87 with Weed free condition. The lowest SY (3.80 t ha^{-1}) was recorded in BRRI dhan49 and control treatment (Figure 6). Similar conclusions were made by Sarker et al. (2022) regarding the combination of variety and aqueous crop residue extracts effectively enhanced yield. Afroz et al. (2018) also noted the significant impact of marsh pepper and buckwheat crop residue extracts on yield and related traits of *T. aman* rice. The interaction between varieties and management treatments had a statistically significant effect on yield attributes. Notably, BAUdhan3 in combination with three times hand weeding recorded the highest GY (6.91 and 6.80 t ha^{-1}), as well as the highest SY (8.13 and 8.23 t ha^{-1}) and BY (15.04 and 15.30 t ha^{-1}) in the studies by Zinnat et al. (2024) and Alam et al. (2024), respectively. In contrast, BRRI dhan28 without extract application resulted in the lowest yield performance across all parameters, with GY as low as 2.79–2.90 t ha^{-1}**,** and correspondingly low SY and BY.

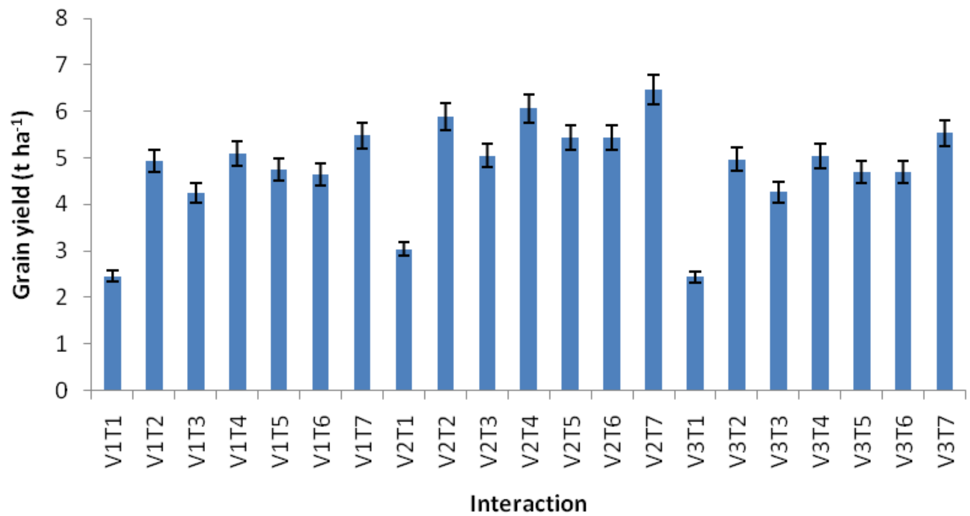

Figure 5. Interaction effect of variety and AEL crop residue and herbicide on the GY of transplanted aman rice

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 = lentil crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + lentil crop residues, T_5 = Pre-emergence (70% recommended dose) + lentil crop residues, T_6 = Pre-emergence (60% recommended dose) + lentil crop residues and T_7 = Weed free

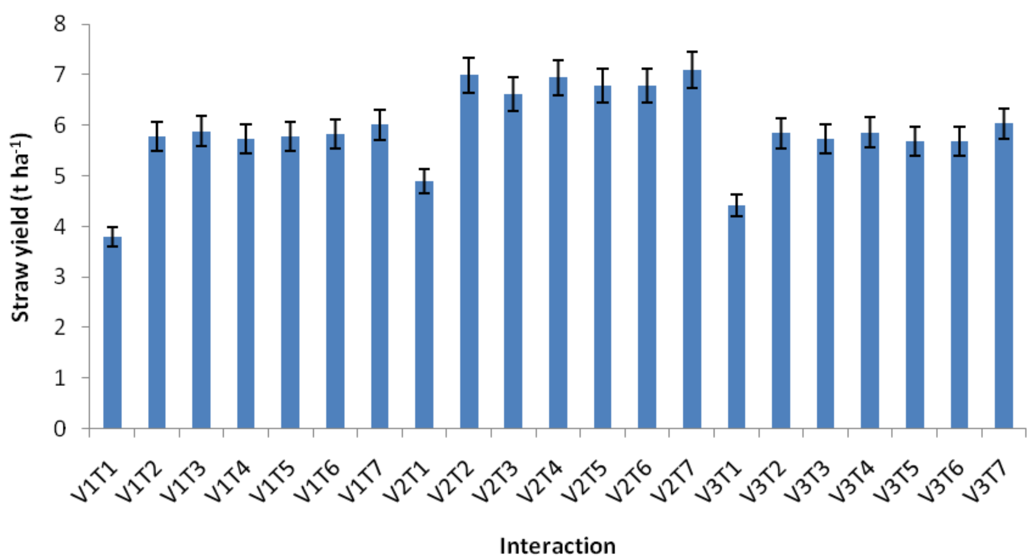

Figure 6. Interaction effect of variety and AEL crop residue and herbicide on the SY of transplanted aman rice

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 = lentil crop residues extracts, T_4 = Pre-emergence (80% recommended dose) + lentil crop residues, T_5 = Pre-emergence (70% recommended dose) + lentil crop residues, T_6 = Pre-emergence (60% recommended dose) + lentil crop residues and T_7 = Weed free

Conclusion

The study demonstrated that BRRI dhan87 outperformed other varieties in terms of yield-contributing characters and overall yield. For optimal cultivation of T. *aman* rice, a weed-free condition maintained 10 days after transplanting proved most effective. The results also indicated that the application of crop residue extracts, particularly the aqueous extract of AEL, significantly promoted yield-contributing traits and overall yield, while effectively suppressing weed growth due to its herbicidal properties. These findings suggested that AEL residue extract holds substantial potential as a natural WC method, enhancing yield while minimizing weed interference in *T. aman* rice cultivation.

Authors contribution

MOR and MRU developed the concept and designed the experiments. MOR, RAR and MYAKR collected the data and wrote the manuscript. MTA evaluated the result, analyzed data statistically and contributed to writing the manuscript. UKS, NKT, MRU, and MHOR contributed to revising manuscript critically for important intellectual content. All authors read the article and approved the final version to be published.

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Competing interests

The authors have declared that no competing interests exist.

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