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Evaluation of Allelopathic Potential of *Oxalis europea* on Weed and Rice Growth

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

During the *aman* season (June–November) of 2019, an experiment was carried out at the Agronomy Field Laboratory of Bangladesh Agricultural University, Bangladesh, to examine the allelopathic potential of amrul shak (*Oxalis europea*) residues on weed management and crop performance of T. *aman* rice. Three cultivars, Binadhan-7, BR11, and BRRI dhan49, were used in the trial, together with five various amrul shak residues: no crop residues, 0.5 t ha^{-1}, 1.0 t ha^{-1}, 1.5 t ha^{-1}, and 1.5 t ha^{-1} + farmers' practice (one hand weeding). The relationships between variety, amrul shak residues, and weed population, dry weight, and percent inhibitions were shown to be highly significant. For every weed species, the treatment with no agricultural residues had the largest weed population and dry weight (T_1). Amrul Shak residues 1.5 t ha^{-1} + Farmers' practice (one-hand weeding) had the lowest dry weight and weed population of all the weed species (T_5). The application of amrul shak residues @ 1.5 t ha^{-1} + Farmers' practice (one hand weeding) resulted in the highest percent inhibition of 78.63, 81.42, 77.87, and 78.75 in Shama (*Echinochloa crusgalli*), Panikachu (*Monochoria vaginalis*), Chesra (*Scirpus juncoides*), and Susni shak (*Marsilea quadrifolia*), respectively. The study's findings suggest that the residues of amrul shak have the ability to inhibit the growth of weeds. For the purpose of producing T. *aman* rice, amrul shak residues therefore present a promising supply of effective weed control tools.

Keywords: Allelopathy; amrul shak; weed management; growth performance; T. Aman rice.

1. INTRODUCTION

The majority of people in various parts of the world eat rice (*Oryza sativa* L.), which is the primary food crop in Asia. With almost half of the world's population consuming it, rice is the most essential food. Ensuring enough inexpensive rice is available for everyone in Asia, where 90% of the world's rice is consumed. Rice is also becoming a more important staple food in Latin America and Africa [1]. There are two cultivated and twenty-one wild species of genus *Oryza*. Geographic and agronomic conditions of Bangladesh are favorable for rice cultivation. The genus Oryza has twenty-one wild species and two cultivated species. Bangladesh's agronomic and geographic characteristics are ideal for rice farming.

Bangladesh uses 1, 14, 17183 hectares of cropped land for rice production, yielding 36.60 million tons of rice annually [2]. In Bangladesh, rice can be divided into three categories: *aus*, *aman*, and *boro*, depending on the season it is grown. *Aman* is vital in Bangladesh because, while having the highest average production of any crop, it is still unable to meet the country's needs. A total of 55, 59, 964 hectares are expected to be planted to mangroves in the 2020–2021 fiscal year, an increase of 0.87% over the previous year. Comparing the total estimated *aman* production of the Financial Year 2020–2021 to that of the Financial Year 2019–20, which is 1.65% higher, is 1,44,37763 metric tons [2]. However, the amount of land used for agriculture is decreasing daily. When comparing the average rice output to other rice-producing nations like China, India, Indonesia, and so forth, the low yield is a result of excessive weed infestation, traditional native varieties, and inadequate crop management [3]. The most important issues contributing to the low rice production are among these causes of heavy weed infestation. Therefore, to increase crop residues of rice production, it is essential to combine contemporary technology with traditional farming knowledge [4].

It is possible to achieve allelopathic activity in a variety of higher plants and plant organs through laboratory-based bioassay procedures. Allelochemicals were first tested in the lab on how seeds germinate and how seedlings grow [5]. Plant residues that release a higher percentage of allelochemicals into the soil can help suppress weeds more effectively [6]. By preventing weed growth (via physical barriers, allelopathy, and light interception), crop residues can indirectly lower the amount of weed seeds produced. Due to their strong linear relationship, smaller weed plants yield fewer weed seeds [7].

Through the release of allelochemicals from living plants and/or the breakdown of phytotoxic residues, crop allelopathy suppresses weeds [8-9]. Crop residues have the potential to inhibit weed development because they produce allelochemicals when they break down [10]. The dynamics of weeds are impacted by the incorporation of soil or the surface application of allelopathic crop residues, which reduces or delays seed germination and establishment. Additionally, the suppression of individual plant growth leads to a general decrease in the density and strength of the weed community [11]. Various phytotoxins that negatively impact other plants are produced in the soil as a result of the breakdown of allelopathic crop leftovers [12].

Researchers are focusing more on employing various agricultural residues to inhibit plant growth in order to combat weed infestation at the moment [13]. Crop wastes are not a waste, but rather an amazing natural resource. One such strategy is to use the allelopathic capabilities of various weed species to manage weeds in the field. Controlling weeds through allelopathy is one of the strategies for reducing herbicide dependency and for environmentally friendly sustainable weed management [14]. Many studies have proven that weed plants have allelopathic properties, which have potential to suppress weed growth and development [15-16]. Thus, more weed studies are important for finding weed species that have allelopathic potential to control weed under field conditions.

Oxalis europea family oxalidaceae with about 800 species and is widely distributed in tropical, sub-tropical and temperate zones [17]. The weed prefers dry and moist soil but cannot grow in shade [18]. A preliminary laboratory screening of the *O. europea* on allelopathy has been found, but before going to farmers' fields it is needed to make field trial first. Therefore, with all of these factors in consideration, the current study was conducted to achieve the following goals: to assess the allelopathic action of *O. europea* under field conditions and to assess the efficiency of *O. europea* residues in inhibiting the growth of weeds.

2. MATERIALS AND METHODS

2.1 Experiment Site and Soil

At an elevation of 18 meters above sea level, the experimental field was situated at 24°75' N latitude and 90°50' E longitude. It belonged to the non-calcareous dark grey floodplain soil under the Sonatola series of the Old Brahmaputra Floodplain, which is part of the Agro-ecological region of the Old Brahmaputra Floodplain ("AEZ-9) [19]. In addition to having little organic matter and little fertility, the soil at the experiment site was essentially neutral in reaction. The Sonatola series of dark grey, non-calcareous floodplain soil beneath the Old Brahmaputra Alluvial Tract is what the soil of the experimental area is derived from. With a silt loam texture, the terrain type was medium high. Table 1 describes the chemical and physical features of the soil in the trial field.

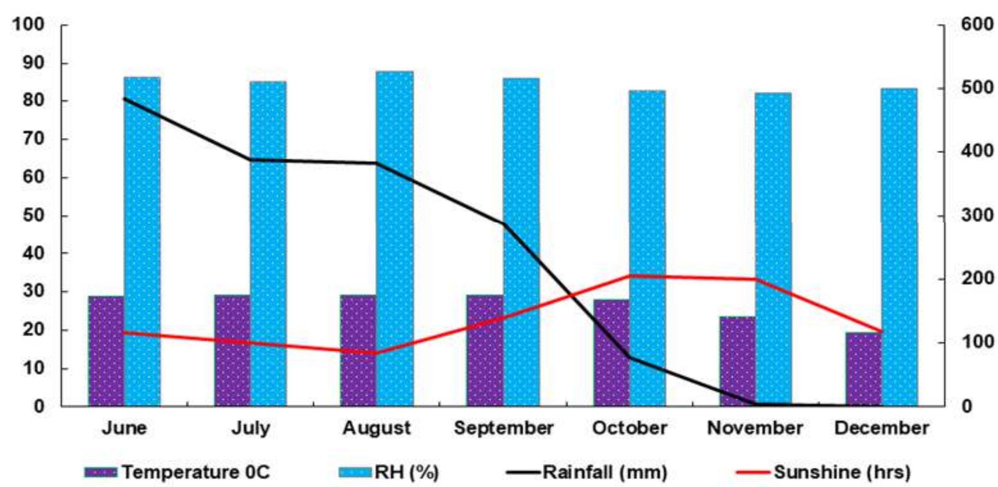

Fig. 1. The study site's monthly average air temperature, relative humidity, rainfall, and sunlight hours were distributed from June to December of 2019

Table 1. Physical and chemical properties of the experimental field

Physical							Chemical					
Porosity (%)	**Sand (%)**	**Silt**	**Clay (%)**	**Bulk density (g/cc)**	**Particle density**	**Textured**	**N (%)**	**P (ppm)**	**Po (me)**	**S (ppm)**	**pH**	**OM (%)**
44.7	21.75	66.60	11.65	1.42	2.57	Silt loam	0.101	27	0.12	22.7	6.8	1.30

Source: Department of Soil Science, Bangladesh Agricultural University, Mymensingh.
Here, N= Nitrogen, P= Phosphorus, Po= Potassium, OM= Organic matter

2.2 Climate

The area has a tropical climate, marked by high temperatures and abundant rainfall from April to September during the Kharif season, and somewhat low temperatures and little rainfall from October to March during the Rabi season. Fig. 1 shows the meteorological conditions for the experiment, including the monthly average air temperature (0C), air pressure (mbs), wind speed (kmph), relative humidity (%), rainfall (mm), and sunshine (hour day-1).

2.3 Experimental Design and Treatments

Three separate replications and a randomized complete block design (RCBD) were used to set construct the experiment. There were 45 plots in total, which is 5 × 3 × 3. The size of each plot was 10 m2 (4 m × 2.5 m). There were two components to the experimental treatment. They are listed in the following order: Amrul Shak Residues (5) is factor A. T_1 = Control, T_2 = 0.5 t ha^{-1}, T_3 = 1.0 t ha^{-1}, T_4 = 1.5 t ha^{-1}, and T_5 = 1.5 t ha^{-1}+ Farmers' method of pulling weeds by hand. Rice Varieties (3) is Factor B. V_1 = Binadhan-7, V_2 = BR11, and V_3 = BRRI dhan49.

2.4 Crop Husbandry

Amrul shak residue was used in this study. This weed was collected from different area of Agronomy Field Laboratory, BAU. The weed residues were collected and then dried in the shade on the BAU Agronomy Field Laboratory's covered threshing floor. A sickle was then used to trim the investigated weed leftovers as tiny as possible. We obtained the test cultivars' seeds from Bangladesh Agricultural University in Mymensingh's Agronomy Field Laboratory. Using the specific gravity method, viable seeds from the gathered cultivars were chosen. For twenty-four hours, seeds were submerged in water in a bucket. Following that, these were removed from the water and densely packed in gunny bags. Within 48 hours, the seeds began to grow and were ready to be sown. A plot of land was chosen so that seedlings could be raised there. The ground was first leveled using a ladder and then puddled nicely using a country plough. On June 26, 2019, the sprouting seeds were evenly sown in a nursery bed that had been prepared. The healthy seedlings in the nursery bed were raised with the necessary attention. When needed, weeds were pulled out of the nursery bed. On July 25, 2019, the land was cleared with a tractor. Tractors were used to prepare the field completely, and then ladders were used. During the land preparation process, weeds and stubbles were eliminated from the field. The field layout was completed the next day once the land was fully ready on July 26, 2019. The following fertilizers were applied to the experimental plots: urea, zinc sulphate, gypsum, muriate of potash, and triple superphosphate at rates of 200, 115, 125, 100, and 12 kg ha^{-1}, respectively. Before finishing the land preparation, the entire amount of fertilizer aside from urea was applied. At 15, 30, and 45-days following transplantation (DAT), urea was top dressed in three installments. The prepared amrul shak residues were applied in the prepared field before transplanting at the rate of 0 t ha^{-1}, 0.5 t ha^{-1}, 1.0 t ha^{-1}, and 1.5 t ha^{-1} as per experimental specification. The prepared amrul shak residues were then thoroughly mixed with a spade into the corresponding plots. One day before to removing the seedlings, water was sprayed onto the nursery bed. On July 28, 2019, thirty-two-day-old seedlings were carefully removed from the nursery bed. The seedlings that had been uprooted were moved right away to the main field. To be transplanted, healthy seedlings of comparable sizes were chosen. On July 28, 2019, seedlings were planted in the prepared puddle field at a rate of three seedlings per hill, with a hill distance of 15 cm and a row spacing of 25 cm, respectively.

2.5 Data Collection at Different Growth Stages

2.5.1 Growth data of rice

2.5.1.1 Plant height and dry weight of rice

In this study, plant height and dry weight at 20, 40, and 60-days following transplanting were measured. Plant height is calculated from the top of the highest leaf to the plant's collar zone. The sample was measured for plant height, dried in the sun, and then placed in an electric oven set to 80°C for 72 hours while enclosed in a brown paper bag. An electric balance was used to determine the rice plant's dry weight, which was then expressed in g $hill^{-1}$.

2.5.2 Weed data

2.5.2.1 Weed population

The 0.25 m x 0.25 m quadrate approach, as reported by Cruz et al. [20], was utilized to gather data on the population of weeds from every plot of rice plants. There was a corresponding count of weeds in the quadrate.

2.5.2.2 Weed dry weight

Following the weed density count, each quadrate's weeds were pulled up, cleaned, divided into species, and dried for 72 hours at 80°C in an electric oven before being placed back in the sun. With the use of an electric balance, the dry weight of each species was determined and reported in g/25 cm^{-2}.

2.5.2.3 Percent inhibition

The following formula was used to figure out the percentage of weed inhibition:

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

2.6 Statistical Analysis

Data collected for various factors were properly gathered, collated, and then statistical analysis was performed. The MSTAT-C software package was utilized to assist in doing the analysis of variance. The mean differences among the treatments were evaluated by Duncan's Multiple Range Test (DMRT) as referred to as out by Gomez and Gomez [21].

3. RESULTS AND DISCUSSION

3.1 Infested Weed Species in the Experimental Field

Infesting the experimental field were four weed species from four families. Table 2 lists the weed's family, scientific name, morphological type, life cycle, and local name in the experimental plot. The weeds that were present in the experimental plots were *Marsilea quadrifolia*, *Echinochloa crusgalli*, *Monochoria vaginalis*, and *Scripus juncoides*. There were two broadleaf, one sedge, and one grass type morphological species among the weeds. The experimental plot had two types of weeds that were perennial and two that were annual.

3.2 Weed Population, Dry Weight and Percent Inhibition

3.2.1 Effect of variety

Variety had a substantial impact on the percentage inhibition of shama, panikachu, and chesra dry weight, and weed population (Table 3). It appears that BR11 had the lowest weed population (3.37) and Binadhan-7 variety had the greatest weed population (4.23) in shama. The maximum dry weight of weeds (5.94 g) was discovered in Binadhan-7, followed by BR11 (5.92 g) and BRRI dhan49 (5.53 g) with the lowest dry weight. The percent inhibition of weed was found to be highest (47.44%) in Binadhan-7, lowest (43.53%) in BR11, and highest (46.08%) in BRRI dhan49. Results demonstrate that while Binadhan-7 supports a larger dry weight and weed population, it also exhibits the highest percent inhibition, indicating excellent competitive power even in the presence of more weeds. With the lowest weed dry weight and the lightest inhibition, BRRI dhan49 demonstrated superior weed suppression. BR11, on the other hand, had the least amount of inhibition and the lowest number of weeds, suggesting a lower effectiveness of weed management [22]. Rahman et al. [23] discovered a similar finding. According to the findings in panikachu, Binadhan-7 had the highest weed population (4.87), whereas BRRI dhan49 had the lowest (4.29). BR11 had the driest weight of the weed (6.74 g), whereas BRRI dhan49 had the lowest (5.54 g). The percentage of weed inhibition in BRRI dhan49 was 49.44 percent, while in BR11, it was 0.97 percent (Table 3). Based on its lowest weed population, dry weight, and highest percent inhibition, which all indicate strong weed control, the results indicate that BRRI dhan49 is the most effective variety to reduce panikachu. With its maximum weed population and moderate dry weight, Binadhan-7 demonstrated less competitive control. With a decreased weed population, BR11 showed the lowest inhibition and the highest dry weight, indicating a limited suppression of panikachu [24]. When we come to chesra, Binadhan-7 had the largest weed population (4.61), while BRRI dhan49 had the lowest (3.14%). BR11 had the highest weed dry weight (5.44 g), whereas BRRI dhan49 had the lowest (4.65 g). In BRRI dhan49, the percent inhibition of weed was highest (53.66%), while in BR11, it was lowest (47.75%) (Table 3). The findings show that BRRI dhan49 exhibits the strongest weed suppression, with the lowest weed population, dry weight, and highest percent inhibition, making it the most effective weed control for chesra. In spite of decreased weed populations, BR11 displayed the largest dry weight and the lowest inhibition, suggesting inadequate suppression. Binadhan-7, on the other hand, had the highest weed population and less control [25]. The dry weight and the percentage of susni shak inhibition were strongly impacted by variety, however the weed population was not severely impacted. Whereas Binadhan-7 had the lowest weed population (3.31), BR11 had the greatest weed population (3.49). For weed dry weight, Binadhan-7 had the highest value (5.88g), while BRRI dhan49 had the lowest (5.03g). Binadhan-7 (44.06%) had the lowest percent inhibition of weed, whereas BR11 had the greatest percentage (49.32%) (Table 3). While there were no significant differences in the Susni Shak weed population between types, Binadhan-7 had the greatest weed dry weight and lowest percent inhibition, suggesting that even with less weeds, the weed suppression was lower. The lowest dry weight was displayed by BRRI dhan49, indicating improved control effectiveness. It's interesting to note that BR11 had the highest percent inhibition and the highest weed population, indicating a higher ability to restrict weed growth than the other types. Mou et al. [26] discovered a similar outcome.

Table 2. Infesting weed species found growing in the experimental plots of rice

SL. No.	Local name	Scientific name	Family	Morphological type	Life cycle
1	Shama	*Echinochloa crusgalli*	Gramineae	Grass	Annual
2	Panikachu	*Monochoria vaginalis*	Pontederiaceae	Broadleaf	Perennial
3	Chesra	*Scirpus juncoides*	Cyperaceae	Sedge	Perennial
4	Susni shak	*Marsilea quadrifolia*	Marsileaaceae	Broadleaf	Annual

Table 3. Effect of variety on weed population, dry weight and percent inhibition of shama (*Echinochloa crusgali*), panikachu (*Monochoria vaginalis*), chesra (*Scirpus juncoides*) andf Susni shak *(Marsilea quadrifolia*)

Variety	Weed population (no/25 cm2)	Dry weight (g/25 cm2)	% inhibition
***Echinochloa crusgalli* (Shama)**			
Binadhan-7	4.23a	5.94a	47.44a
BR11	3.37b	5.92a	43.53c
BRRI dhan49	3.60b	5.53b	46.08b
LSD $_{(0.05)}$	0.25	0.11	0.93
Level of significance	**	**	**
CV (%)	9.00	2.54	2.73
Panikachu (*Monochoria vaginalis*)			
Binadhan-7	4.87a	6.70a	46.04b
BR11	4.45b	6.74a	45.11b
BRRI dhan49	4.29b	5.54b	49.44a
LSD $_{(0.05)}$	0.41	0.13	1.01
Level of significance	**	**	**
CV (%)	12.26	2.93	2.88
Chesra (*Scirpus juncoides*)			
Binadhan-7	4.61a	5.40a	48.78b
BR11	4.07b	5.44a	47.75b
BRRI dhan49	3.14c	4.65b	53.66a
LSD $_{(0.05)}$	0.39	0.13	1.35
Level of significance	**	**	**
CV (%)	13.53	3.63	3.60
Susni shak (*Marsilea quadrifolia*)			
Binadhan-7	3.31	5.88a	44.06b
BR11	3.49	5.61b	49.32a
BRRI dhan49	3.34	5.03c	48.25a
LSD $_{(0.05)}$	0.29	0.26	4.14
Level of significance	NS	**	**
CV (%)	11.80	6.36	11.82

*In a column, values having similar letter do not differ significantly whereas values with dissimilar letter differ significantly as per DMRT. ** = Significant at 1% level of probability, NS= non-significant*

3.2.2 Effect of amrul shak residues

Amrul shak residues had a substantial impact on the weed population, dry weight, and percent inhibition of shama, panikachu, chesra, and susni shak. The treatment with no crop residue applied, the control treatment, had the highest weed population (5.59), while the treatment with 1.5 t ha^{-1}+ farmers' practice (one-hand weeding) had the lowest weed population. T_1 treatment had the largest weed dry weight (10.68 g), whereas T_5 treatment had the lowest weed dry weight (2.28 g). The dry weight of the marijuana was simply reversed in the percent inhibition trend. Where dry weight was smaller, the % inhibition was higher. When it came to shama weed, T_5 had the maximum inhibition (78.63%), while T_1, the control plot, had the lowest inhibition (Table 4). The results clearly demonstrate that the application of amrul shak residues substantially decreased the number of weeds and dry weight, resulting in the highest percent inhibition of Shama. This was especially true when combined with 1.5 t ha^{-1} and farmers' practices (T_5). This shows that removing Shama weed by hand and applying residues is a very successful method of control. Uddin and Pyon [27] and Won et al. [28] have reported similar results, demonstrating the substantial efficacy of various crop residues in weed control. In panikachu, T_1 had the largest weed population (6.16) due to little crop residue, while T_5 had the lowest weed population (1.5 t ha^{-1} + farmers' practice (one-hand weeding)). T_5 [1.5 t ha^{-1}+ Farmers' practice (one hand weeding)] had the lowest weed dry weight, while T_1 [no crop residue] had the greatest weed dry weight (11.89 g). The largest percentage of weed inhibition (81.42%) was seen in T_5 (1.5 t ha^{-1}+ Farmers' practice (one hand weeding)], while T_1 (No crop residue treatment) had the lowest percentage. The combination of 1.5 t ha^{-1} crop residue and one-hand weeding (T_5) was shown to be the most successful in suppressing weeds, as evidenced by the lowest weed population, the highest percent inhibition, and the dry weight. Conversely, the weed population, dry weight, and inhibition were all highest in the control treatment (T_1) without crop residue, indicating inadequate weed control. This emphasizes how crucial it is to combine human weeding with crop leftovers for efficient weed control [29]. The weed population in chesra was 5.48 times higher in T_1 (no crop residue) than it was in T_5 (1.5 t ha^{-1} + farmers' practice (one hand weeding)). The T_1 treatment (no crop residue) had the greatest weed dry weight (10.33 g), followed by the T_2 treatment (0.5 t ha^{-1}) with the second-highest weed dry weight (6.01 g), and the T_5 treatment (1.5 t ha^{-1} + farmers' practice (one hand weeding treatment)) with the lowest weed dry weight (Table 4). The T_5 treatment (1.5 t ha^{-1}+ farmers' practice) showed the highest percent inhibition (77.87%), while the T_1 treatment (no crop residue) showed the lowest percent inhibition (Table 4). The best results for weed control were obtained by combining 1.5 t ha^{-1} of crop residue with one hand weeding (T_5), which resulted in the lowest weed population, dry weight, and highest percent inhibition. The largest weed population and dry weight, on the other hand, were found in the control treatment (T_1) without crop residue, indicating poor weed suppression [30]. The maximum weed population (5.04) in the susni shak was discovered in T_1 (no crop residues), while T_5 [1.5 t ha^{-1}+ Farmers' practice (one hand weeding treatment)] had the lowest weed population. T_5 [1.5 t ha^{-1}+ Farmers' practice (one hand weeding treatment)] had the lowest dry weight of weeds, while T_1 (no crop residues) had the highest dry weight (10.76 g). In T_5 [1.5 t ha^{-1}+ Farmers' practice (one hand weeding treatment)] treatment, the percent inhibition of weed was highest (78.75%), followed by T_4 (1.5 t ha^{-1} treatment) (65.74%), and the lowest percentage was found in T_1 (No crop residue) treatment (Table 4). In terms of weed population, dry weight, and percent inhibition, the most successful method of weed management was achieved by applying 1.5 t ha^{-1} of crop residues and weeding by hand (T_5). On the other hand, poor weed control was evident in the case of T_1, where there were no crop residues and the largest weed population and dry weight [31].

3.2.3 Effect of interaction between variety and amrul shak residues

Weed population, dry weight, and percent inhibition were found to be significantly impacted by the interaction between crop residue and variety. The weed population with the highest value (6.09) was discovered in V_3T_1 (BRRI dhan49 × No crop residues), while V_1T_1 (Binadhan-7 × No crop residues) had the second-highest weed population (5.78). In V_3T_5 [BRRI dhan49 × 1.5 t ha^{-1}+ Farmers' practice (one hand weeding)], the lowest weed population (1.93) was discovered (Table 5). V_1T_1 (Binadhan-7 × No crop residues) had the highest weed dry weight (11.30 g), while V_3T_5 [BRRI dhan49 × 1.5 t ha^{-1}+ Farmers' practice (one hand weeding)] had the lowest weed dry weight (1.76 g). Table 5 shows that V_3T_5 [BRRI dhan49 × 1.5 t

Table 4. Effect of amrul shak residues on weed population, dry weight and percent inhibition of shama (*Echinochloa crusgali*), panikachu (*Monochoria vaginalis*), chesra (*Scirpus juncoides*) andf Susni shak *(Marsilea quadrifolia*)

Treatments	Weed population (no/25 cm2)	Dry weight (g/25 cm2)	% inhibition
Shama (*Echinochloa crusgalli*)			
T_1	5.59a	10.68a	0.000e
T_2	4.27b	7.12b	33.31d
T_3	3.66c	5.24c	50.77c
T_4	3.00d	3.64d	65.72b
T_5	2.15e	2.28e	78.63a
LSD $_{(0.05)}$	0.32	0.14	1.20
Level of significance	**	**	**
CV (%)	9.00	2.54	2.73
Panikachu (*Monochoria vaginalis*)			
T_1	6.16a	11.89a	0.000e
T_2	5.40b	7.34b	38.40d
T_3	5.15b	6.07c	49.14c
T_4	3.47c	4.12d	65.38b
T_5	2.51d	2.22e	81.42a
LSD $_{(0.05)}$	0.54	0.17	1.30
Level of significance	**	**	**
CV (%)	12.26	2.93	2.88
Chesra *(Scirpus juncoides*)			
T_1	5.48a	10.33a	0.000e
T_2	4.50b	6.01b	41.82d
T_3	3.58c	4.00c	61.28c
T_4	3.23cd	3.17d	69.35b
T_5	2.92d	2.29e	77.87a
LSD $_{(0.05)}$	0.51	0.18	1.74
Level of significance	**	**	**
CV (%)	13.53	3.63	3.60
Susni shak *(Marsilea quadrifolia*)			
T_1	5.04a	10.76a	0.000e
T_2	3.80b	5.95b	39.17d
T_3	3.46b	5.01c	52.41c
T_4	2.54c	3.60d	65.74b
T_5	2.06d	2.23e	78.75a
LSD $_{(0.05)}$	0.38	0.33	5.38
Level of significance	**	**	**
CV (%)	11.80	6.36	11.82

*In a column, values having similar letter do not differ significantly whereas values with dissimilar letter differ significantly as per DMRT. ** = Significant at 1% level of probability. Here, T_1= No crop residue, T_2 = 0.5 t ha^{-1}, T_3 =1.0 t ha^{-1}, T_4 = 1.5 t ha^{-1}, T_5 = 1.5 t ha^{-1}+ Farmers' practice (one hand weeding)*

ha^{-1}+ Farmers' practice (one hand weeding)] had the highest percent inhibition of weed (82.85%), while V_1T_1 (Binadhan-7 × No crop residue), V_2T_1 (BR11 × No crop residue), and V_3T_1 (BRRI dhan49 × No crop residues) had the lowest percentages. On weed population, dry weight, and percent inhibition of panikachu, it was discovered that there was a substantial interaction between variety and amrul shak residues. V_1T_1 (Binadhan-7 × no crop residue) with the greatest panikachu weed population (6.49), followed by V_2T_1 (BR11 × no crop residue) with the second-highest weed population (6.04), and V_3T_5 (BRRI dhan49 × 1.5 t ha^{-1}+ Farmers' practice (one hand weeding)) with the lowest. intervention (Table 6). Table 6 shows that the weed dry weight in V_1T_1 (Binadhan-7 × no crop residue) was 12.42 g, while the weed dry weight in V_3T_5 [BRRI dhan49 × 1.5 t ha^{-1}+ Farmers' practice (one hand weeding)] was the lowest. In V_3T_5 [BRRI dhan49 × 1.5 t ha^{-1}+ Farmers' practice (one hand weeding)], the percent inhibition of weed was highest (85.25%). Lastly, the treatments V_1T_1 (Binadhan-7 × no crop residue), V_2T_1 (BR11 × no crop residue), and V_3T_1 (BRRI dhan49 × no crop residue) showed the lowest one (Table 6). Chesra weed population, dry weight, and percent inhibition were shown to be significantly impacted by the interaction between variety and amrul shak residue. As shown in Table 7, the chesra weed population (5.83) was largest in V_2T_1 (BR11 × no crop residue) and lowest in V_3T_5 (BRRI dhan49 × 1.5 t ha^{-1}+ Farmers' practice (one hand weeding)). With regard to weed dry weight, V_1T_1 (Binadhan-7× no crop residue) had the highest value (10.55 g), whereas V_3T_5 had the lowest (1.73 g). The maximum percentage of weed inhibition (82.70%) was found in V_3T_5 treatment (BRRI dhan49 ×1.5 t ha^{-1}+ farmers' practice), whereas the lowest percentage was found in V_1T_1 treatment (Binadhan-7 × no crop residue) (Table 7). Significant effects on weed population, dry weight, and percent inhibition of susni shak were seen while varying the amount of amrul shak residue. In V_2T_1 (BR11 × no crop residue), the greatest weed population (5.50) was observed; this was followed by V_3T_1 (BRRI dhan49 × no crop residue), and V_3T_5 [BRRI dhan49 × 1.5 t ha^{-1}+ Farmers' practice (one hand weeding)] had the lowest one (Table 8). V_2T_1 (BR11 × no crop residue) had the highest weed dry weight (11.10 g), while the V_3T_5 treatment combination had the lowest weed dry weight (Table 8). In V_2T_5 (BR11 × 1.5 t ha^{-1}+ Farmers' practice (one hand weeding)], the maximum percent inhibition of weed was detected (79.76%), whereas the lowest percentage was found in V_1T_1 (Binadhan-7 × no crop residue) treatment (Table 8).

Table 5. Combined effect of variety and amrul shak residues on Shama (*Echinochloa crusgalli*)

Treatment combination	Shama (*Echinochloa crusgalli*)		
	Weed population (no/25 cm2)	**Dry weight (g/25 cm2)**	**% inhibition**
V_1T_1	5.78a	11.30a	0.000j
V_1T_2	4.94b	7.45c	34.07h
V_1T_3	4.56b	5.11e	54.72f
V_1T_4	3.36d	3.37g	70.15d
V_1T_5	2.52fg	2.45h	78.26b
V_2T_1	4.91b	10.49b	0.000j
V_2T_2	3.95c	7.34c	30.03i
V_2T_3	3.14de	5.32e	49.26g
V_2T_4	2.88def	3.82f	63.60e
V_2T_5	1.99gh	2.64h	74.77c
V_3T_1	6.09a	10.26b	0.000j
V_3T_2	3.93c	6.58d	35.82h
V_3T_3	3.27de	5.29e	48.33g
V_3T_4	2.77ef	3.75f	63.41e
V_3T_5	1.93h	1.76i	82.85a
$LSD_{(0.05)}$	0.56	0.24	2.08
Level of Significance	**	**	**
CV%	9.00	2.54	2.73

V_1= Binadhan-7, V_2= BR11, V_3= BRRI dhan49, others details are same as shown in Table 4

Table 6. Combined effect of variety and amrul shak residues on Panikachu (*Monochoria vaginalis)*

Treatment combination	Panikachu (*Monochoria vaginalis)*		
	Weed population (no/25 cm2)	**Dry weight (g/25 cm2)**	**% inhibition**
V_1T_1	6.49a	12.42a	0.000h
V_1T_2	5.32bc	7.43d	40.15f
V_1T_3	5.64ab	6.53e	47.41e
V_1T_4	4.00de	4.48g	63.91c
V_1T_5	2.93fg	2.64j	78.74b
V_2T_1	6.04ab	12.29a	0.000h
V_2T_2	5.64ab	8.21c	33.17g
V_2T_3	5.26bc	6.62e	46.08e
V_2T_4	2.98fg	4.16h	66.07c
V_2T_5	2.34g	2.42j	80.25b
V_3T_1	5.96ab	10.97b	0.000h
V_3T_2	5.26bc	6.37e	41.87f
V_3T_3	4.54cd	5.05f	53.92d
V_3T_4	3.44ef	3.71i	66.15c
V_3T_5	2.25g	1.61k	85.25a
LSD $_{(0.05)}$	0.93	0.31	2.25
Level of significance	**	**	**
CV (%)	12.26	2.93	2.88

Others details are same as shown in Table 4 & Table 5

Table 7. Combined effect of variety and amrul shak residues on chesra (*Scirpus juncoides)*

Treatment combination	Chesra (*Scirpus juncoides*)		
	Weed population (no/25 cm2)	**Dry weight (g/25 cm2)**	**% inhibition**
V_1T_1	5.61a	10.55a	0.000h
V_1T_2	5.33ab	6.33c	39.88g
V_1T_3	4.56bcd	4.29e	59.30e
V_1T_4	3.98cde	3.32f	68.47c
V_1T_5	3.60ef	2.50g	76.25b
V_2T_1	5.83a	10.41a	0.000h
V_2T_2	4.65bc	6.41c	38.45g
V_2T_3	3.71def	4.20e	59.66e
V_2T_4	3.31efg	3.54f	65.97cd
V_2T_5	2.88fgh	2.64g	74.66b
V_3T_1	5.00ab	10.03b	0.000h
V_3T_2	3.52ef	5.30d	47.15f
V_3T_3	2.49gh	3.52f	64.88d
V_3T_4	2.40h	2.65g	73.60b
V_3T_5	2.29h	1.73h	82.70a
LSD $_{(0.05)}$	0.89	0.31	3.02
Levelof significance	**	**	**
CV (%)	13.53	3.63	3.60

Others details are same as shown in Table 4 & Table 5

Table 8. Combined effect of variety and amrul shak residues on Susni shak *(Marsilea quadrifolia)*

Treatment combination	Susni shak (*Marsilea quadrifolia*)		
	Weed population (no/25 cm2)	Dry weight (g/25 cm2)	% inhibition
V_1T_1	4.50bc	11.03a	0.000f
V_1T_2	3.45de	6.64c	27.14e
V_1T_3	3.57de	5.59de	49.28cd
V_1T_4	2.76fg	3.77h	65.76b
V_1T_5	2.27gh	2.41i	78.14a
V_2T_1	5.50a	11.10a	0.000f
V_2T_2	4.04cd	5.93d	46.27cd
V_2T_3	3.36ef	4.98fg	55.06c
V_2T_4	2.51gh	3.80h	65.54b
V_2T_5	2.06h	2.23i	79.76a
V_3T_1	5.11ab	10.15b	0.000f
V_3T_2	3.92cde	5.28ef	44.08d
V_3T_3	3.45de	4.46g	52.89cd
V_3T_4	2.36gh	3.22h	65.93b
V_3T_5	1.85h	2.05i	78.36a
LSD $_{(0.05)}$	0.66	0.58	9.33
Level of significance	**	**	**
CV (%)	11.80	6.36	11.82

Others details are same as shown in Table 4 & Table 5

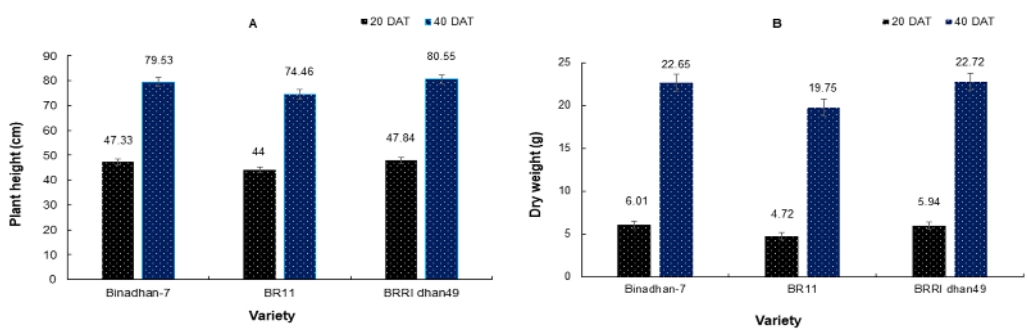

Fig. 2. Effect of variety on plant height and dry weight

3.3 Growth of Rice at Different Days after Transplanting (DAT)

3.3.1 Effect of variety

In this investigation, plant height was measured at 20 and 40 DAT. At 20 DAT, variety had a substantial impact on plant height. The tallest plant (47.84 cm at 20 DAT and 80.55 cm at 40 DAT) was generated by the variety BRRI dhan49. The shortest plant, measured at 44.00 cm at 20 DAT and 74.46 cm at 40 DAT, was shown by BR11 (Fig. 2A). Islam et al. [32] also reported similar results, identifying substantial genetic diversity in plant height between the types. Variability affected dry weight at every sampling day in a substantial way. The varieties with the highest dry weights were Binadhan-7 (6.01 g) at 20 DAT and BRRI dhan49 (22.72 g) at 40 DAT. The lowest dry weights were 4.72 g and 19.75 g, respectively, from the cultivar BR11 at 20 and 40 DAT (Fig. 2B). While BR11 consistently provided the lowest dry weight, indicating better weed suppression across both sampling times, the data show that BRRI dhan49 had the greatest weed dry weight at 40 DAT, suggesting higher weed competition over time [33].

3.3.2 Effect of amrul shak residues

Amrul shak residues at all sampling days in this investigation had a substantial impact on plant height and dry weight. The T_3 (1.0 t ha^{-1}) treatment at 20 and 40 DAT produced plants with the largest heights, 49.00 cm and 85.00 cm, respectively. In T_2 (0.5 t ha^{-1}) at 20 DAT, the shortest plant height measured 42.22 cm, while in T_4 (1.5 t ha^{-1}) at 40 DAT, the highest plant height was 70.83 cm (Fig. 3A). Yoseftabar [34] observed that varying agricultural wastes led to a considerable rise in plant height. The maximum dry weight was 6.72 g in T_3 (1.0 t ha^{-1}) at 20 DAT, and 29.26 g in T_5 at 40 DAT. T_5 [1.5 t ha^{-1}+ Farmers' practice (one hand weeding)] produced the lowest dry weight of 4.47 g at 20 DAT, while T_1 (No crop residue) produced the lowest dry weight of 14.93 g at 40 DAT (Fig. 3B). As a result of the incorporation of crop wastes and hand weeding, despite initial lower dry weight, T_5 demonstrated considerable growth at 40 DAT, despite displaying good weed control with the lowest dry weight at 20 DAT [35].

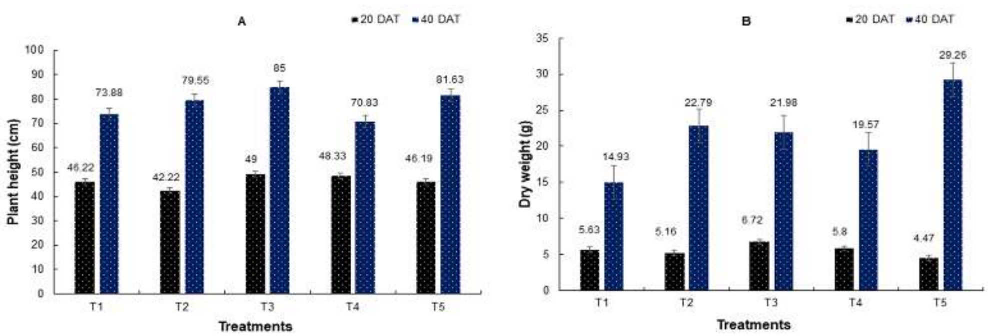

Fig. 3. Effect of amrul shak residues on plant height and dry weight

Others details are same as shown in Table 4

Table 9. Combined effect of variety and amrul shak residues on plant height at different growth stages

Treatment combination	Plant height (cm)	
	20 DAT	**40 DAT**
V_1T_1	49.33ab	67.33
V_1T_2	41.66cd	72.66
V_1T_3	47.66abc	81.66
V_1T_4	43.33bcd	86.00
V_1T_5	38.66d	68.33
V_2T_1	44.66bcd	84.33
V_2T_2	48.33ab	89.33
V_2T_3	46.33abc	80.66
V_2T_4	52.33a	85.00
V_2T_5	48.66ab	69.66
V_3T_1	49.66ab	75.33
V_3T_2	46.66abc	67.51
V_3T_3	47.00abc	85.33
V_3T_4	43.66bcd	75.33
V_3T_5	47.92ab	84.24
LSD $_{(0.05)}$	7.32	25.84
Level of significance	**	NS
CV (%)	8.38	17.55

*In a column, values having similar letter do not differ significantly whereas values with dissimilar letter differ significantly as per DMRT. ** = Significant at 1% level of probability, NS = Not significant. Here, V_1=Binadhan-7, V_2=BR11, V_3= BRRI dhan49, T_1=No crop residue, T_2 = 0.5 t ha^{-1}, T_3 =1.0 t ha^{-1}, T_4 =1.5 t ha^{-1}, T_5 = 1.5 t ha^{-1}+ Farmers' practice (one hand weeding). DAT = Days after transplanting*

Table 10. Combined effect of variety and amrul shak residues on dry weight of rice plant at different days after transplanting (DAT)

Treatment combination	Dry weight (g)	
	20 DAT	40 DAT
V_1T_1	6.11abcd	12.65fg
V_1T_2	4.35de	11.85g
V_1T_3	6.45abc	20.30de
V_1T_4	6.13abcd	20.13de
V_1T_5	4.22de	22.84cde
V_2T_1	5.15bcde	25.41bcd
V_2T_2	7.89a	30.00ab
V_2T_3	4.56cde	16.84efg
V_2T_4	7.71a	19.09def
V_2T_5	5.16bcde	23.57bcd
V_3T_1	6.93ab	19.31de
V_3T_2	5.30bcde	15.82efg
V_3T_3	4.76cde	26.88bc
V_3T_4	3.55e	27.92abc
V_3T_5	5.11bcde	32.98a
LSD $_{(0.05)}$	2.23	7.30
Level of significant	**	**
CV (%)	21.25	17.86

Others details are same as shown in Table 4 & Table 5

3.3.3 Effect of interaction between variety and amrul shak residues

At 40 DAT, the relationship between variety and amrul shak residue did not change significantly. In terms of numbers, the tallest plants measured 52.33 cm in V_2T_4 (BR11× 1.5 t ha^{-1}) at 20 DAT and 89.33 cm in V_2T_2 (BR11× 0.5 t ha^{-1}) at 40 DAT. The treatments with the lowest plant height (V_1T_5 [Binadhan-7× 1.5 t ha^{-1}+ Farmers' practice (one hand weeding)] at 20 DAT and V_1T_1 (Binadhan-7× No crop residue) at 40 DAT were found to have the lowest plant height (67.33 cm) (Table 9). At every sampling day, there was a substantial interaction between the variety and the amrul shak residues. At 20 days after treatment, V_2T_2 (BR11× 0.5 t ha^{-1}) had the highest dry weight (7.89 g), while V_3T_4 (BRRI dhan49 × 1.5 t ha^{-1}) had the lowest dry weight (3.55 g). Furthermore, at 40 days after treatment, V_3T_5 [(BRRI dhan49 ×1.5 t ha^{-1}+ Farmers' practice (one hand weeding)] had the highest dry weight (32.98), while V_1T_2 (Binadhan-7× 0.5 t ha^{-1}) had the lowest dry weight (11.85 g) (Table10).

4. CONCLUSION

The variety BRRI dhan49 that was treated with T5 (1.5 t ha^{-1}+) and the farmers' method of "one-hand weeding" yielded the best results, as shown above. Using amrul shak residues before transplanting decreases weed development, according to the current study's findings. This will reduce the need for synthetic pesticides, which helps protect ecosystems, people's health, and slows the spread of herbicide-resistant weeds. In light of the foregoing, it should come as no surprise that weed residues from amrul shak hold considerable promise as an approach to weed control. As a result, modern agricultural research suggests that amrul shak residues could provide a means of weed management for future crop development.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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