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Allelopathic effects of *Marsilea crenata* Presl. extracts and residues on weeds suppression & rice yield (*Oryza sativa* L.)

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ABSTRACT

Biotic weed management is increasingly needed in sustainable rice production. Plant-based extracts and residues offer environmentally friendly alternatives to decrease neighbouring plant growth. This study examined the inhibitory effects of *Marsilea crenata* Presl.extracts and residues on weed growth and rice (*Oryza sativa* L.) yield in pot and field settings. The pot employed *M. crenata* extracts at 0 % (control), 25 %, 50 %, 75 % and 100 %, whereas the field experiment used residues (0, 1.0, 2.0 and 3.0 t ha^{-1} including farmer practices (2-hand weedings) and three rice varieties (BRRI dhan28, BRRI dhan29 and BRRI dhan60). Rice cultivars, *M. crenata* extracts and residue treatments significantly influenced weed dynamics. Higher extract concentrations of *M. crenata* reduced weeds biomass in pots, while in field study, residue application of *M. crenata* at 3 t ha^{-1} reduced weeds density. This highest residue level also maximized rice tillers $hill^{-1}$, 1000-grain weight and grain yields. These findings suggested that *M. crenata* residues effectively suppressed the weeds growth and increased rice yield, offering a promising bio-based strategy for sustainable weeds management.

Keywords: Allelopathy, extracts, field study, *Marsilea crenata*, Pot culture, Residues, Rice yield, Sustainable agriculture, Weed suppression

INTRODUCTION

Rice (*Oryza sativa* L.) crop feeds more than half of the world's population, however, its production is severely threatened by weeds infestation, particularly direct-seeded rice (28). In Bangladesh, rice is cultivated throughout year in 3-separate seasons: *Boro*, *Aus* and *Aman,* among these*, Boro* rice is main crop (41.94 %) (22). The rice crop yield is reduced by many factors, but weeds are the main one, as these compete with rice plants for growth resources such as space, nutrients, air, water and light, thereby reduces crop yield (9,20). In Bangladesh, transplanted *Aman* rice, modern *Boro* rice and *Aus* rice grain yield was reduced by 30-40 %, 22-36 % and 70-80 %, respectively by weeds infestation (29).

Herbicides are used to control weeds but harmful to nature, their residues in plants or soil enters into the food chain and pose a threat to both people and livestock. The indiscriminate use of herbicides has lead to development of weeds resistance to herbicides (14,16). A safe and cost-effective way to reduce inputs for weed management, has drawn the attention of researchers (17). Researchers are paying close attention to crop cultivars' self-weeding or inhibitory (allelopathic) behaviour (21). The use of inhibitory behaviour of crop and/or allelopathic crop is a viable alternative to the use of chemical herbicides. Crop allelopathy controls weed by releasing inhibitory chemicals from living plants and from plant residues (5,19). Allelopathy is a biological phenomenon, in which plants release secondary metabolites (allelochemicals), that influences the growth of neighbouring plants

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(17). *Marsilea crenata* Presl. (Marsileaceae fern) is found throughout Southeast Asia (Figure 1) in rice fields and is known for its allelopathic properties (15).

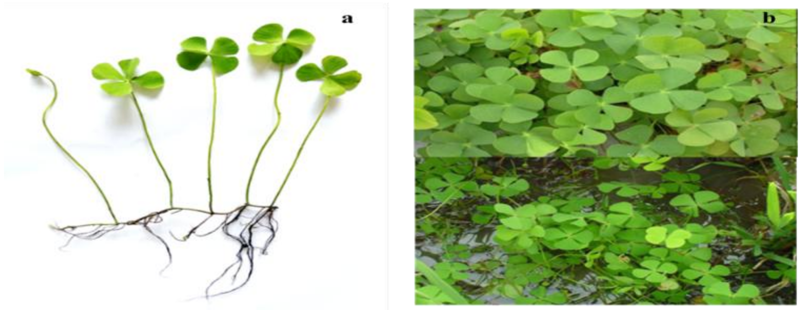

Figure 1. a. Field photograph of individual *Marsilea crenata* Presl., b. field photograph of *Marsilea crenata* Presl. in low lying rice field (photo courtesy M.S. Islam)

This aquatic tiny fern plant *Marsilea crenata* looks like clover, with leaves floating in deep water, or standing upright in shallow water (Figure 1). It possesses many biological properties. Islam *et al*. (15) discovered its allelopathic capabilities in petri dish bioassay. This study aimed to evaluate the allelopathic effects of *M. crenata* leaf extracts and residues on weed suppression and rice yield under controlled pot and field conditions.

MATERIALS AND METHODS

I. Experiment Site

The experimental field was located in Old Brahmaputra flood Plain (AEZ-9) at 24°25′ N latitude and 90°50′ E longitude, 18 m above sea level (8). The soil was silty loam, infertile, low organic matter content and dark grey in colour (Table 1). The climate is tropical, high temperatures and heavy rainfall during summer (April to September) and scanty rainfall during winter (October to March). The climatic conditions were: mean air temperature (23.43 °C), relative humidity (3.8 %), rainfall (80.7 mm) and sunshine (196.24 h day^{-1}) during the experimental period.

Table 1. Soil Physico- chemical properties of the experimental field

Physical properties								Chemical properties					
Porosity (%)	Particle size	Bulk density (g/cc)	Sand (%)	Silt (%)	Clay (%)	Colour	Texture	N (%)	P (ppm)	S (ppm)	Po (me %)	OM (%)	pH
44.7	2.57	1.42	21.75	66.60	11.65	Dark grey	Silt loam	0.10	27	22.7	0.12	1.30	6.5

The study was conducted in Department of Agronomy, Bangladesh Agricultural University, Mymensingh, during the *Boro* season of 2021-2022 (November -May) The study consisted of two experiments: (i). Pot experiment using leaf extracts of *Marsilea crenata* and (i). Field experiment using *M. crenata* plant residues.

II. Plant Materials

Leaves and stems of *M. crenata* were collected at the vegetative stage from the crop field of Agronomy Field Laboratory, Bangladesh Agricultural University during July-August 2020.

III. Pot Experiment

Natural paddy soil up to 30 cm depth was collected between 6-27 November 2021 from Agronomy Field Laboratory. The collected soil was dried under sun. After drying, equal amount of soil was put in 15 pots (Height 30 cm, Width 28.5; Capacity: 12L) and saturated with water for 7-days. After putting natural paddy soil in the pot, we measured the saturated water required for each pot, which was 9 L. Well-dried *M. crenata* leaves were cut with a fodder cutter (1-2 cm pieces). At room temperature, chaffed crop residues were soaked in 1:20 (w/v) water for 48 h. A coarse mesh filter removed plant residue from the water extract 48 h after soaking. The extract collected was considered 100 % concentration. Dilutions were then made to get the concentrations of 75 %, 50 %, 25 %. Water was used as control (0 %). The extracts were applied to pots until the soil was saturated. Treatments were replicated thrice in Completely Randomized Design (CRD). Weeds population was recorded at 7 (6 November, 21), 14 (13 November, 21), 21 (20 November, 21) and 28 (27 November, 21) days after extract treatment. At 28 days after treatment, all weeds were counted uprooted, washed, separated species-wise and dried in the sun and then in an electric oven at 80 °C for 72 h. The dry weight was determined for each species.

IV. Field Experiment

A split-plot design was used, with 3-rice cultivars (BRRI dhan28, BRRI dhan29 and BRRI dhan60) as the main plot and 4- rates of *M. crenata* residue application (0, 1.0, 2.0, 3.0 t ha^{-1}) and farmers' practice of 2-hand weedings as the subplots. Each sub-plot size was 2.5 m x 2.0 m. Treatments were replicated thrice in Randomized Complete Block Design. The residues of *M. crenata* were dried in shade and applied in field 7-days before rice transplanting and thoroughly incorporated into plots as per treatments.

V. Crop Husbandry

The field was tractor-ploughed on January 2, 2021. After cleaning and removing weeds and stubble, the land was puddled well. Urea, triple super phosphate, muriate of potash, gypsum and zinc sulphate were applied at 240 (N-110.4 kg ha^{-1}), 100 (P-21.12 kg ha^{-1}), 120 (K-59.76 kg ha^{-1}), 110 (S-19.8 kg ha^{-1}) and 10 (Zn-3.6 kg ha^{-1}) kg ha^{-1}, respectively. All fertilizers except urea were applied during land preparation. Urea was top-dressed at 15, 30 and 45 days after transplanting. On January 9, 2021, 3-rice seedlings $hill^{-1}$ were transplanted in 25 cm apart rows and 15 cm hill distances. The field was flood irrigated to maintain a constant level of standing water up to 6 cm in early stage to enhance tillering and 10-12 cm at later stage to discourage late tillering. Finally, the field was drained 15 days before harvest. The growing season had 8 irrigations. Rice cultivars ripened at different intervals, the variety 'BRRI dhan28' was harvested on April 23, 'BRRI dhan60' on April 29 and 'BRRI dhan29' variety on May 7, 2021. Each plot was individually harvested and thrashed. The grains were dried to 14 % moisture content.

VI. Sampling and Measurement

Each rice plot weeds population was counted using a 0.25 m × 0.25 m quadrat (27). Weeds in each quadrat were counted at 25 and 50 days after transplanting (DAT). The weeds were dried, washed, segregated species-wise and the dry weight of each weed specie was determined.

VII. Statistical Analysis

Weed parameters, yield and yield-contributing attributes were statistically analysed. The "Analysis of Variance" was used to analyze the data in MSTAT-C. The mean difference between treatments was tested for significance using Duncan's Multiple Range Test (DMRT) (11). Principal component analysis and correlation matrix were done with R.

RESULTS AND DISCUSSION

WEEDS DYNAMICS

I. Pot culture

In pot experiment, 7-weed species (*Eleusine indica* L., *Cyperus rotundus* L., *Cynodon dactylon* L., *Eclipta alba* L., *Echinochloa crusgalli* L., *Polygonum hydropiper* L., *Echinochloa colonum* L.) from 4-families were recorded (Table 2). The most dominant weeds were: *Echinochloa crus-galli*, *Cyperus iria* and *Fimbristylis miliacea. M. crenata* extracts suppressed weed species at 25 %, 50 %, 75 % and 100 % concentrations, the *Echinochloa colonum* and *Cynodon dactylon* proved most sensitive as they were killed even at the 25 % concentration. However, *Eleusine indica, Cyperus rotundus* and *Eclipta alba* were very tolerant and were unaffected even at 100 % concentration (Figure 2 and Table 2).

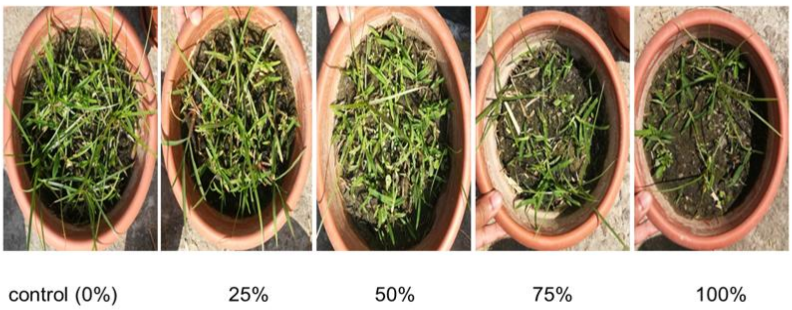

Figure 2. Weeds population at different extract concentrations of *M. crenata* residues in Pot culture

Table 2. Effects of of *M. crenata* extract concentrations on weed species in Pot culture

Weed spp	Family	Weed spp at various *M. crenata* extract conc (%)			
		25.0 %	50.0 %	75 %	100 %
Eleusine indica (L.)	Gramineae	Present	Present	Present	Present
Cyperus rotundus (L.)	Cyperaceae	Present	Present	Present	Present
Cynodon dactylon (L.)	Gramineae	-	-	-	-
Eclipta alba (L.)	Compositae	Present	Present	Present	Present
Echinochloa crusgalli (L.)	Gramineae	Present			
Polygonum hydropiper (L.)	Polygonaceae	Present	Present	-	-
Echinochloa colonum (L.)	Gramineae	-	-	-	-

Weeds population and dry weight of weed species were significantly affected by various extract concentrations of *M. crenata*. Weeds were most abundant in 0 % (control) and least abundant at 100 % (Table 3). While the 100 % concentration had the lowest dry weight at 28 days after treatment and the control (0 % conc) had the maximum weed dry weight of 1.75 g/pot (Table 3). In population, the highest inhibition (66.4 %) was observed at 28 days with 100 % extract concentration, while in dry weight, the highest inhibition (70.9 %) was recorded at 28 days with 100 % extract concentration (Figure 3).

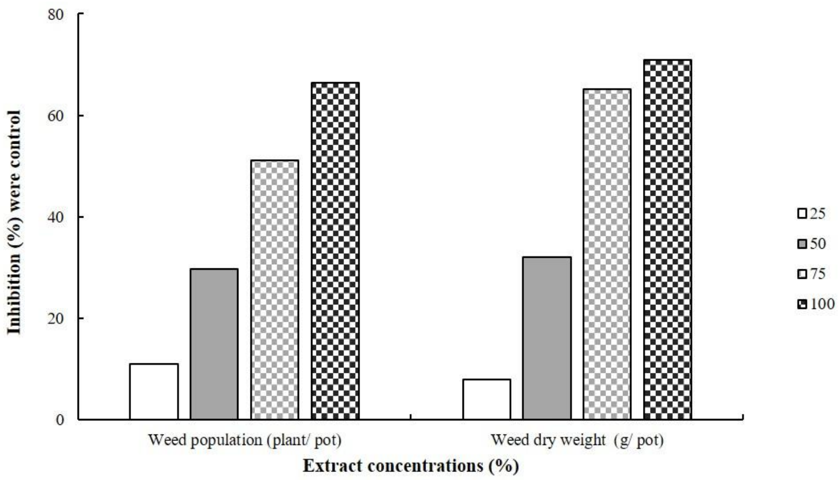

Figure 3. Inhibitory effects of *M. crenata* extract concentrations on weeds population and dry weight at 28 days in pots.

We examined the inhibitory effects of *M. crenata* extracts in pot culture on rice crop weed species composition. The inhibitory impact of the residue extract was concentration dependent, an increase in extract concentration was associated with a decrease in weed species richness. weed density and weed dry weight. Others, like Islam *et al*. (12), Islam *et al.* (13), Kato-Noguchi *et al*. (18), have documented that inhibitory effects of plant extracts depended on concentration. Similarly, Islam *et al*. (15) found that aqueous methanol extracts from *M. crenata* reduced the seedling growth of several crops and weeds.

Table 3. Effects of *M. crenata* extract concs on weed population and weed dry weight in Pot culture

Extract Conc (%)	Weed population (plant/ pot)				Weed DW at 28 days (g/ pot)
	7 days	14 days	21 days	28 days	
Control (0)	81.40a	97.30a	108.46a	117.50a	1.75a
25	58.25b	71.68b	97.44b	104.59b	1.61a
50	53.27c	58.35c	69.29c	82.60c	1.19b
75	42.41d	45.59d	51.60d	57.43d	0.61c
100	30.40e	32.55e	37.48e	39.51e	0.51c
Level of Significance	**	**	**	**	*

Data in a column that have the same letter or letters and those that do not differ considerably from one another are similar. *: Significant at the 5 % probability level, **: Significant at the 1 % probability level.

II. Field Study

Four weed species (*Scirpus juncoides, Echinochloa crusgalli, Cyperus difformis* and *Monochoria vaginalis*) were recorded in the experimental plots. Three main rice weeds (*Echinochloa crusgalli, Cyperus difformis* and *Scirpus juncoides*) were also identified in rice fields at Bangladesh Agricultural University (3). These weed species were also reported in previous studies (24). *M. crenata* residues impacted the weeds population and biomass. The nil-residues (control) treatment had the highest weed population of *Monochoria vaginalis*, *Echinochloa crusgali*, *Cyperus difformis* and *Scirpus juncoides* (Table 4).

Table 4. Effects of *M. crenata* residues rates on weed density and dry weight at 50 days in Field study.

M. crenata residue (t/ha)	*Monochoria vaginalis*		*Echinochloa crusgali*		*Cyperus difformis*		*Scirpus juncoides*	
	Density (plants/m^2)	DW (g/m^2)	Density (plants/m^2)	DW (g/m^2)	Density (plants/m^2)	DW (g/m^2)	Density (plants/m^2)	DW (g/m^2)
0	13.00a	13.09a	9.86a	7.57a	17.37a	11.42a	14.55a	11.95a
1	9.85b	10.64b	9.23a	5.55b	14.14b	9.90b	14.05a	10.90b
2	8.55b	7.40c	6.29b	3.93c	10.12c	8.48c	9.96b	8.06c
3	5.53c	4.54e	5.28b	1.58e	7.52d	5.47e	6.73c	5.55d
Hand weeding	6.36c	5.76d	6.31b	2.26d	10.20c	6.51d	9.59b	7.63c
$LSD_{0.05}$	1.46	0.72	1.48	0.18	1.89	0.62	1.75	0.66

Figs in a column with the same letter or letters and those without differentiating greatly differ from each other. 0: Nil-residues, 1: *M. crenata* residues at 1.0 t ha^{-1}, 2: *M. crenata* residues at 2.0 t ha^{-1}, 3: *M. crenata* residues at 3.0 t ha^{-1}.

The weeds population was lowest in *M. crenata* residues at 3 t ha^{-1} for *Monochoria vaginalis*, *Echinochloa crusgali*, *Cyperus difformis* and *Scirpus juncoides* (Table 4). The dry weight of weeds was lowest in *M. crenata* residues 3 t ha^{-1} and the highest in nil-residues treatment for all weed species (Table 4). In case of density inhibition, the maximum reductions were 57.5 %, 46.8 %, 56.7 % and 53.7 % for *M. vaginalis*, *E. crusgalli*, *C. difformis*, and *S. juncoides*, respectively, with *M. crenata* residues at 3.0 t ha^{-1}. Similarly, inhibition in dry weight, were maximum in 65.3 %, 79.1 %, 52.1 % and 53.6 % for *M. vaginalis*, *E. crusgalli*, *C. difformis*, and *S. juncoides*, respectively, at same residue level (3.0 t ha^{-1}) (Figs 4 and 5).

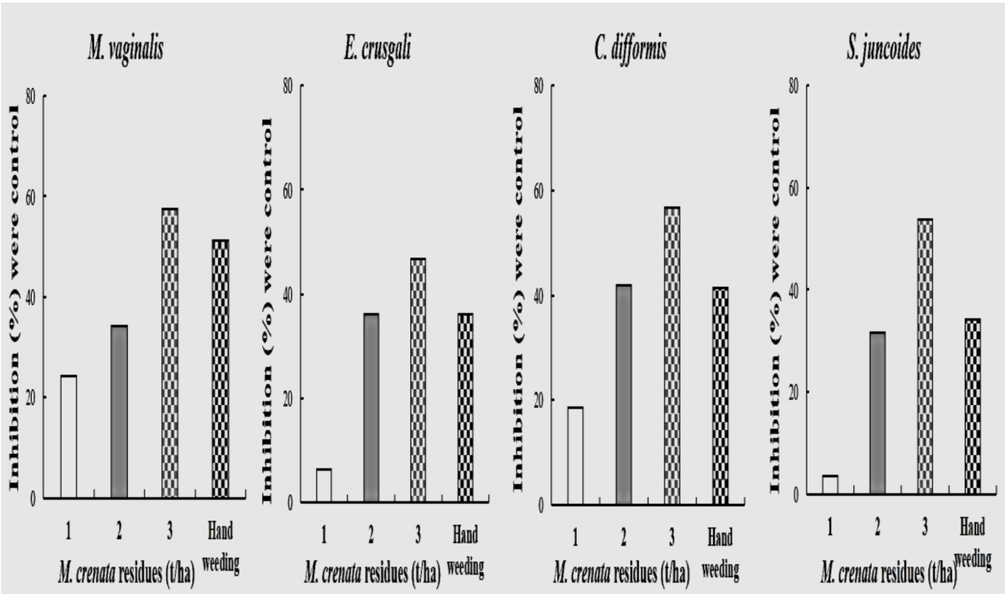

Figure 4. Inhibitory effects of *M. crenata* residues on 4 weeds density at 50 days after treatment in field study. 1: *M. crenata* residues at 1.0 t ha^{-1}, 2: *M. crenata* residues at 2.0 t ha^{-1}, 3: *M. crenata* residues at 3.0 t ha^{-1}.

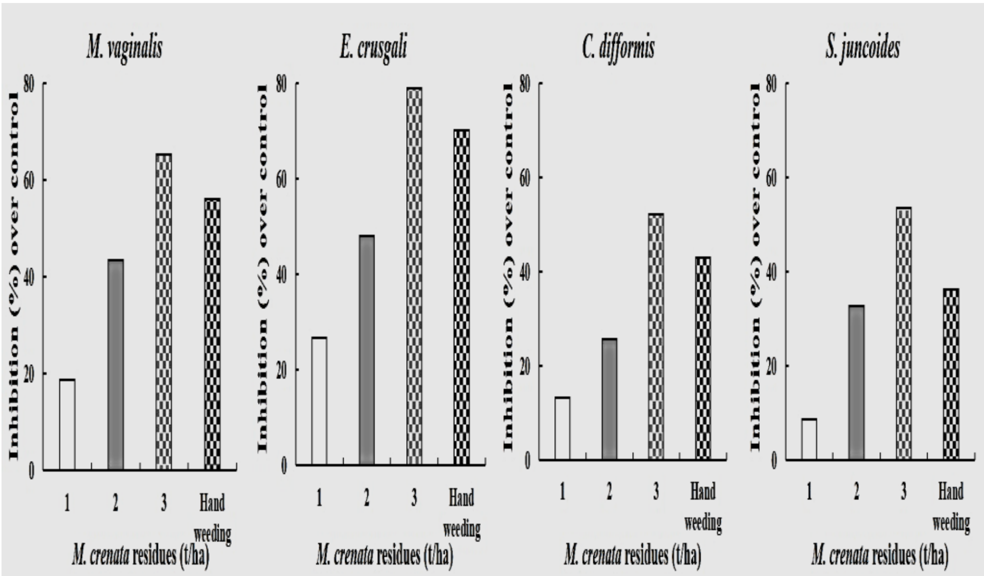

Figure 5. Inhibitory effects of *M. crenata* residues on 4 weeds dry weight 50 days after treatment in field study. 1: *M. crenata* residues at 1.0 t ha^{-1}, 2: *M. crenata* residues at 2.0 t ha^{-1}, 3: *M. crenata* residues at 3.0 t ha^{-1}.

MARSILEA CRENATA RESIDUES

I. Interactions rice variety x *Marsilea crenata* residues

The weed population and dry weight were significantly impacted by the interactions between variety and *M. crenata* residues. BRRI dhan28 × No crop residues (control) had the highest weeds population for *Monochoria vaginalis* (13.56 plants/m^2), *Echinochloa crusgali* (10.49 plants/m^2), *Cyperus difformis* (18.81 plants/m^2) and *Scirpus juncoides* (18.54 plants/m^2) (Table 5).

Table 5. Interactions between rice variety and *M. crenata* residues on weed population and dry weight at 50 days in field study

Variety x *M. crenata* residue (t/ha)	*Monochoria vaginalis*		*Echinochloa crusgali*		*Cyperus difformis*		*Scirpus juncoides*	
	Density (plants/m^2)	DW (g/m^2)	Density (plants/ m^2)	DW (g/m^2)	Density (plants/m^2)	DW (g/m^2)	Density (plants/ m^2)	DW (g/m^2)
	Rice variety Dhan28							
dhan28 x 0	13.56	13.58	10.49	7.62a	18.81	11.09	18.54	12.71
dhan28 x 1	9.07 (-33.1%)	10.97 (-9.2%)	9.14 (-2.9%)	5.37d (-9.5%)	16.99 (-9.7%)	9.88 (-0.9%)	15.34 (-7.3%)	11.64 (-8.4%)
dhan28 x 2	9.15 (-32.5%)	7.58 (-4.2%)	8.02 (-3.5%)	3.96f (-48%)	12.96 (-31.1%)	7.97 (-8.1%)	10.3 (-4.4%)	8.9 (-30%)
dhan28 x 3	5.57 (-58.9%)	4.58 (-6.3%)	6.95 (-3.7%)	1.55k (-9.7%)	9.67 (-48.6%)	5.38 (-1.5%)	8.74 (-2.9%)	5.89 (-3.7%)
dhan28 x Hand weeding	7.45 (-45.1%)	6.06 (-5.4%)	8.04 (-3.4%)	2.57h (-6.3%)	11.82 (-27.2%)	6.38 (-.5%)	13.05 (-9.6%)	7.28 (-2.7%)
	Rice variety Dhan29							
dhan29 x 0	12.52	12.26	8.68	7.20b	15.03	11.02	13.58	11.28
dhan29 x 1	10.88 (-13.1%)	9.96 (-8.8%)	8.38 (-3.5%)	5.37d (-5.4%)	11.26 (-25.1%)	8.79 (-0.2%)	12.48 (-8.1%)	10.26 (-9%)
dhan29 x 2	7.87 (-37.1%)	6.27 (-8.9%)	4.28 (-0.7%)	3.40g (-2.8%)	8.5 (-43.4%)	7.96 (-7.8%)	9.52 (-9.9%)	7.24 (-5.8%)
dhan29 x 3	4.62 (-63.1%)	3.58 (-0.8%)	3.36 (-1.3%)	1.44k (-80%)	6.26 (-58.3%)	4.54 (-8.9%)	5.66 (-8.3%)	4.87 (-6.8%)
dhan29 x Hand weeding	5.06 (-59.6%)	4.62 (-2.3%)	4.87 (-3.9%)	1.96ij (-2.8%)	10.65 (-29.1%)	5.83 (-7.1%)	7.62 (-3.9%)	6.91 (-8.7%)
	Rice variety Dhan60							
dhan60 x 0	12.91	13.43	10.41	7.88a	18.29	12.15	13.24	11.87
dhan60 x 1	9.6 (-25.6%)	10.99 (-8.2%)	10.19 (-2.1%)	5.93c (-4.7%)	14.18 (-22.5%)	11.04 (-9.1%)	12.63 (-4.6%)	10.79 (-9.1%)
dhan60 x 2	8.65 (-33%)	8.36 (-7.8%)	6.58 (-6.8%)	4.43e (-3.8%)	8.9 (-51.3%)	9.51 (-1.7%)	10.06 (-24%)	8.05 (-2.2%)
dhan60 x 3	6.4 (-50.4%)	5.47 (-9.3%)	5.52 (-47%)	1.74jk (-80%)	6.64 (-63.7%)	6.49 (-6.6%)	5.78 (-6.3%)	5.89 (-0.4%)
dhan60 x Hand weeding	6.57 (-49.1%)	6.62 (-0.7%)	6.03 (-2.1%)	2.25i (-1.4%)	8.15 (-55.4%)	7.33 (-9.7%)	8.1 (-8.8%)	8.71 (-6.6%)
$LSD_{0.05}$	2.53	1.24	2.55	0.32	3.28	1.07	3.03	1.15

Figs in a column with the same letter or letters and those without differ slightly, whereas figs with different letters differ much. 0: Nil-residues, 1: *M. crenata* residues at 1.0 t ha^{-1}, 2: *M. crenata* residues at 2.0 t ha^{-1}, 3: *M. crenata* residues at 3.0 t ha^{-1}.

The combination of BRRI dhan29 × *M. crenata* residues 3.0 t ha^{-1} had the lowest weed population for *Monochoria vaginalis* (4.62 plants/m^2), *Echinochloa crusgali* (3.36 plants/m^2), *Cyperus difformis* (6.26 plants/m^2) and *Scirpus juncoides* (5.66 plants/m^2). However, the weed dry weight was maximum in BRRI dhan28 × No crop residues for *Monochoria vaginalis* (13.58 g/m^2) and *Scirpus juncoides* (12.71 g/m^2), whereas the BRRI dhan60 × No crop residues had the maximum weed dry weight reduction in *Echinochloa* *crusgali* (7.88 g/m^2) and *Cyperus difformis* (12.15 g/m^2). However, the dry weight of weeds was lowest in BRRI dhan29 × *M. crenata* residues at 3 t ha^{-1} for all weed species. In terms of weeds density inhibition, the highest reductions of 63.1 %, 63.3 %, 58.1 % and 58.3 % were observed in *M. vaginalis*, *E. crusgalli*, *C. difformis* and *S. juncoides* weeds, respectively, with BRRI dhan29 × *M. crenata* residues at 3.0 t ha^{-1} and BRRI dhan60 ×*M. crenata* residues at 3.0 t ha^{-1}. The dry weight inhibition was maximum 70.8 %, 80.0 %, 58.9 % and 56.8 % in *M. vaginalis*, *E. crusgalli*, *C. difformis* and *S. juncoides*, respectively, with BRRI dhan60 × *M. crenata* residues at 3.0 t ha^{-1} (Table 5).

For each variety, each residue and their combinations used in the experiment, there were differences in weeds population and weed dry weight. This substantial impact on the weed dynamics by the varieties and residues was reported by Arefin *et al.* (4), who found that BRRI dhan29 had lower weed density than BRRI dhan28 and Ferdousi *et al.* (10) also discovered that interactions between rice cultivars and wheat residue treatments considerably affected the weeds density. Weed dry weight was affected by interactions between cultivars and allelopathic residues (2), who also corroborated the present findings. Not only these residues applications significantly reduced weed populations, but also reduced the weeds dry weight. Residue may act as mulch materials, which exert shade or allelopathic effects on weeds and reduce their density and dry weight (7,25,26,30).

II. Effects of *M. crenata* residues on rice

M. crenata residue at 3 t/ha consistently resulted in taller rice plant, higher number of effective tillers hill^{-1}, higher 1000-grains weight, grain yield and harvest index than nil-residue (control) (Table 6). The treatment of *M. crenata* residue at 3 t/ha resulted in the tallest rice plants (83.80 cm), whereas, the nil-residue treatment had the shortest plants (76.30 cm). In terms of effective tillers hill^{-1}, *M. crenata* residue at 3 t/ha produced the maximum numbers (6.66), while the hand weeding treatment produced the lowest (5.83). Test weight, with the No crop residues (control) treatment had the lightest grains (22.36 g), while the *M. crenata* residue at 3 t/ha produced heaviest grains (22.83 g). *M. crenata* residues had considerable impact on grain yield. The treatment of *M. crenata* residue at 3 t/ha yielded the highest grain yield (5.55 t/ha), followed by hand weeding (5.09 t/ha) and the Nil-residues (control) treatment (4.25 t ha^{-1}) *M. crenata* residues did not affect number of non-effective tillers hill^{-1}, the length of panicle and the number of filled grains panicle^{-1} (Table 6).

Table 6. Effects of *M. crenata* residues on yield and yield components of rice.

Residues (t/ha)	Plant height (cm)	Number of effective tillers hill^{-1}	Panicle length (cm)	No. of filled grain	1000-grain weight	Grain yield (t ha^{-1})	Harvest index (%)
0	76.30c	5.88bc	19.23	117.93	22.36c	4.25e	47.86bc
1	82.58a	6.33ab	20.01	119.63	22.51bc	4.75d	47.64d
2	81.88ab	6.36a	19.95	120.41	22.67ab	4.92c	47.89b
3	83.80a	6.66a	20.07	122.22	22.83a	5.55a	48.70a
Hand weeding	77.72bc	5.83c	19.29	120.09	22.50bc	5.09b	47.69cd
LSD $_{(0.05)}$	4.66	0.45	0.99	4.72	0.17	0.08	0.20

Figs in a column with the same letter or letters and those without differentiating greatly differ from each other, 0: Nil-residues, 1: *M. crenata* residues at 1.0 t ha^{-1}, 2: *M. crenata* residues at 2.0 t ha^{-1}, 3: *M. crenata* residues at 3.0 t ha^{-1}.

M. crenata residue applied at 1 t/ha and 3 t/ha significantly increased plant height than control, whereas 2 t/ha and hand weeding showed no statistical difference (Figure 6). The number of effective tillers per hill were significantly enhanced at both 2 t/ha and 3 t/ha residue levels. For 1000-grain weight, the 3 t/ha treatment, produced 2.1 % increase over the control. In contrast, residue levels at 1 t/ha, 2 t/ha and hand weeding did not differ significantly from the control. Grain yield was increased markedly by 30.9 % with 3 t/ha residue treatment compared with the control. This suggested consistent positive influence of higher residue application on yield (Figure 6). Overall, residue application, particularly at 3 t/ha, enhanced growth, yield components and grain yield, showed the most substantial improvement (Figure 6).

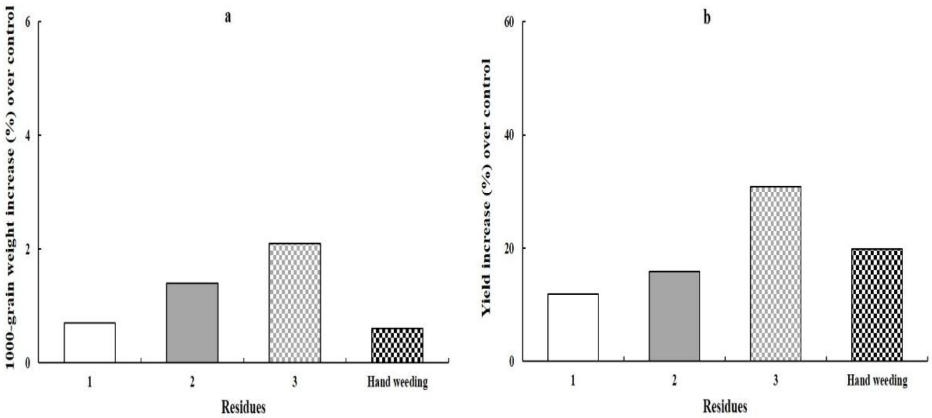

Figure 6. Effects of *M. crenata* residues on (a) 1000- grain weight and (b) grain yield (t/ ha) of rice. 1: *M. crenata* residues at 1.0 t ha^{-1}, 2: *M. crenata* residues at 2.0 t ha^{-1}, 3: *M. crenata* residues at 3.0 t ha^{-1}.

M. crenata residues applied at 3.0 t ha^{-1} increased rice growth and yield components (plant height, number of effective tillers and grain yield plant). Reduced weeds pressure was probably the single primary factor responsible for these improvements rather than separate effects. The lowest weed density and weed dry weight were found in *M. crenata* residue at 3 t/ha, whereas, the nil-residue (control) treatment had the highest weed infestation, indicating that the presence of residues greatly hindered weed emergence and growth (1,9,23,31). By decreasing the weeds competition, residue-treated plots provided rice plants with improved access to growth resources (light, water, nutrients and space) essential for optimal crop development. This is consistent with findings by De Datta (6) and Khanh *et al.* (19), who reported that effective weed management directly enhances the rice productivity. Moreover, increased organic matter from decomposed residues may have improved soil structure and nutrients availability, further supporting crop growth.

Although some yield components, like 1000-grains weight, did not show statistically significant differences, the cumulative benefits of reduced weed interference explained the overall superior performance of *M. crenata* residue at 3 t/ha treatment. Therefore, it is reasonable to conclude that the improved growth and reproductive performance of rice in residue-treated plots were largely due to suppressed weed populations and enhanced resource availability, underscoring the dual role of *M. crenata* residues in both weed control and yield enhancement.

CONCLUSIONS

M. crenata extracts and residue treatments had significant impacts on the weed population, dry weight, rice yield and yield contributing characteristics. Seven weeds from four families were recorded in the pot experiment, whereas four weed species from three families were recorded in the field. In the pot experiment, when the *M. crenata* extract concentration was increased, the number of weed species and their dry weight decreased but the weed species *Eleusine indica*, *Cyperus rotundus* and *Eclipta alba* were less affected by the extracts, indicating that these weeds were not sensitive to the extracts. In field study, adding 3 t ha^{-1} *crenata* residues maximized tillers $hill^{-1}$, 1000-grain weight and grain yields. The study suggested that *M. crenata* residues could be used to suppress weeds and sustainably increased rice yields.

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ETHICAL APPROVAL

The authors declare that the study was carried out following scientific ethics and conduct. However, this study did not involve any use of animals; hence, no ethical approval was obtained from the concerned committee.

COMPETING INTEREST

The authors announce that they have no conflict of interest.

DECLARATION

We declare that all authors of this manuscript have made substantial contributions. We have not excluded any author that substantially contributed to this manuscript. We have followed the ethical norms established by our respective institutions.

AUTHORS CONTRIBUTION

M.S. Islam: Conceptualization, Methodology, Writing-original draft; M.L. Mia: Data curation, Formal analysis, Writing-original draft; M.R. Islam: Methodology, Investigation, Writing-original draft; M.G. Kibria: Methodology; Data curation; A.K. Hasan: Writing - review and critical editing, Supervision; M.A. Salam: Writing - review and critical editing, Supervision.

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