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Research Article

EFFECT OF FREE-FLOATING PLANTS ON WEED EMERGENCE, GROWTH, AND YIELD OF TRANSPLANTED AMAN RICE VARIETIES

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ABSTRACT

At Sher-e-Bangla Agricultural University's agronomy field in Dhaka, Bangladesh, a study was carried out from July to December 2019 to determine the suppressing capacity of floating weeds in T. aman rice (*Oryza sativa* L.). The experiment consisted of two factors, namely, rice varieties (three), including Tulshimala, BR11(Mukta), and Bangladesh Rice Research Institute (BRRI) hybrid dhan6, and weed management (five), including weedy check (control), integrated weed management (IWM) (Pretilachlor 6% + pyrazosulfuron 0.15% and one hand weeding), spreading of *Pistia stratiotes*, *Lemna minor,* and *Salvinia molesta* in 0.5 m^2 area in a split-plot design with three replications. The ranking of the relative rate of spreading over the experiment was *L. minor* > *S. molesta* > *P. stratiotes*. A total of six weed species representing five families were found from the transplanting to the later stage of rice growth, where the occurrence of weed infestation related to rice variety and crop growth. BRRI hybrid dhan6 significantly suppressed weeds in related plots. Although weed biomass was significantly reduced, the morphological and biomass characteristics of T. *aman* rice varieties got disadvantages when grown with *P. stratiotes* and *S. molesta*. Cultivation of BRRI hybrid dhan6 and weed control through IWM gave the highest grain yield (5.92 t ha^{-1}). However, the spreading of *L. minor* facilitated optimal weed control, and good yields were harvested without significant differences, irrespective of varieties. Therefore, competitive weed variety should be considered along with the spreading of *L. minor* to reduce herbicide loads in the environment and to the evolution of cross-resistant weed populations.

Keywords: Free-floating plants, Weed growth, Weed control, Rice yield.

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INTRODUCTION

The agrarian country Bangladesh is enriched with plenty of water and suitable climatic conditions for rice production. The annual rice production in Bangladesh is 35.30 million metric tons from 11.80 million acres of land (BBS, 2022). Among the three rice ecotypes in Bangladesh, *aus* (summer), *aman* (rainy season), and *boro* (winter), *aman* rice occupies the highest area coverage (Magzter, 2021). The total area coverage by *aman* rice for the financial year 2020-21 has been estimated at 5625907 hectares compared to 5559964 hectares for the financial year 2019–20, which is 0.87 % higher (BBS, 2022). Variety is a genetic factor that contributes greatly to producing a crop's yield components (Masum *et al*., 2010). The particular rice variety impacts how rice plants thrive in various agro-climatic situations (Alam *et al*., 2012). The high-yielding varieties feature larger panicles than conventional types, which results in an average increase in rice grain of 7.27% (Bhuiyan *et al*., 2011). Bangladesh Rice Research Institute (BRRI) (2008) reported that modern transplant *aman* rice varieties produced grain yields up to 6.5 t ha^{-1}. Therefore, varietal performance is an important factor in improving crop production. Due to weeds, agricultural systems are much less profitable for farmers (Ahmed *et al*., 2014). Weeds compete with crop plants for light, nutrients, water, and space. Bangladesh's weather and edaphic conditions are ideal for weed development (Ahmed *et al*., 2014). Without proper weed management, this might result in considerable yield losses. Without weed removal, transplanted rice exhibited yield losses from weeds that ranged from 15% to 40% (Rashid *et al*., 2012; Ahmed *et al*., 2014). However, the extent of yield loss is influenced by both the weed flora and the infestation level. Farmers invest a lot of money and time into minimizing their impact, but they frequently fail.

Weed control expenses and farm income can be directly impacted by the types of weed management techniques used. Herbicide-based weed control is gaining popularity since it can reduce expenses by avoiding expensive labor (Islam *et al*., 2017). Herbicide use has surged 37-fold in Bangladesh during the past three decades. Although herbicides can successfully control rice weeds, relying solely on chemical control methods harms the environment and the economy (Kumar *et al*., 2017). The former includes unfavorable effects on creatures other than the target and the evolution of herbicide resistance in weeds. The latter entails extra expenditures for using chemical management measures to combat any new weed species that may emerge due to changes in weed flora (Hossain *et al*., 2020; Heap, 2021). These factors permit integrated approaches to managing weeds while reducing the environmental hazards associated with herbicides and the high costs associated with manual weeding (Chauhan *et al*., 2015). Estimates indicate that farmers spend about US$100 to 300 ha^{-1}, about 10–20% of the total production cost for controlling weeds in rice fields (Islam *et al*., 2017). Hence, integrated weed management (IWM) could reduce weed control costs, reduce the yield gap, and increase yield and profits from rice production. IWM can be defined as integrating more than one approach involving cultural, physical, biological, and chemical methods (Harker and Donovan, 2013). Systematically and comprehensively maximizing control techniques consists of chemical and nonchemical procedures to keep weed populations below a predetermined threshold level (Wilkerson *et al*., 2002). Herbicides are used as a last resort in IWM. However, when necessary, they should be used in an integrated management strategy, such as the rotation of herbicides with various modes of action (MOAs), the mixing of herbicides with various MOAs and best application techniques, or the use of soil-active pre-emergence and post-emergence herbicides (Harker and Donovan, 2013; Kumar *et al*., 2017). Different pre-mix and tank-mix combinations are being tried to control mixed weeds in one go (Yadav *et al*., 2018), reducing the total volume of herbicide and easing and economizing its application. Some herbicides were reported to have controlled weeds and increased the yield of the different rice varieties.

Small, floating aquatic plants are often a conspicuous component of aquatic systems (Hillman, 1961). It can be either competitive with rice fields or suppressive of weeds without accumulated nutrients from the field. The ability of *Azolla* to suppress other weeds has been mentioned in Philippino literature studies since 1927 (Moody and Janiya, 1992). Weed growth is suppressed when *Azolla* forms a thick, virtually light-proof mat. There are probably two mechanisms for this suppression, the most effective being the light-starvation of young weed seedlings by the sunlight blockage (Lumpkin and Plucknett, 1980). The other mechanism is the physical resistance to weed seedling emergence created by a heavy, interlocking *Azolla* mat, which does not affect rice growth (Pons, 1987). Bangun and Syam (1988) showed that an *Azolla* cover could significantly reduce weed infestation without harming the rice yield. Several studies have reported the suppressive effect of *Azolla* on rice weed species, such as *Utricularia flexuosa* Vanl, *Echinochloa crus-galli* (L.) Beauv., *Sagittaria* spp., *Cyperus difformis* L. and *Polygonum* sp. (Nguyen 1930; Ngo 1973; Talley *et al*., 1977). *Pistia stratiotes* is a perennial aquatic macrophyte widely distributed worldwide and can remove several heavy metals from water, including Arsenic (Farnese *et al*., 2013). Aquatic floating plant-like duckweed (*Lemna minor*) is mainly used for phytoremediation and nutrient recovery from wastewater and animal feedstock and the production of biofuels due to its high growth rate, high biomass yield, excellent nutrient uptake ability, and tolerance to high nutrient levels (Cheng *et al*., 2002; Mohedano *et al*., 2012). In transplanted rice, *S. molesta* was found to cause a 12.5% yield loss due to a reduction in panicle-bearing tillers (Azmi, 1988). Excessive growth of the free-floating plant harms the growth and development of the standing crop. Dense mats of the free-floating plant harm wetland rice ecosystems because these conditions lead to anoxic conditions, significantly diminishing plant diversity (Andreasen *et al*., 2018). Invasions by introduced exotic species are partly responsible for increased floating plant dominance (Alhadari *et al*., 2023). However, eutrophication is likely to have also boosted the spread of free-floating plants. Research on the combined effect of T. *aman* varieties and weed control (through herbicides and free-floating plants) is limited. Given the foregoing information, the present study assessed the competitive impacts of free-floating plants on the weed control, growth, and yield of the rice varieties chosen for the study.

METHODS

Study area

The experiment was conducted at the Agronomy field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar Agargaon, Dhaka, 1207, which is geographically situated at 23°77' N latitude and 90°33' E longitude at an altitude of 8.6 m above sea level. The experimental field belongs to the Agro-ecological zone (AEZ) of "The Modhupur Tract", AEZ-28. This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract, leaving small hillocks of red soils as "islands" surrounded by the floodplain. The experiment was conducted from July to December 2019 during the transplanting *aman* (rainy) season. The temperature during the cropping period ranged between 19.1°C and 32.6°C, the humidity 47–81% with 10.5–11.0 h day length, and the highest 114 mm rainfall was recorded.

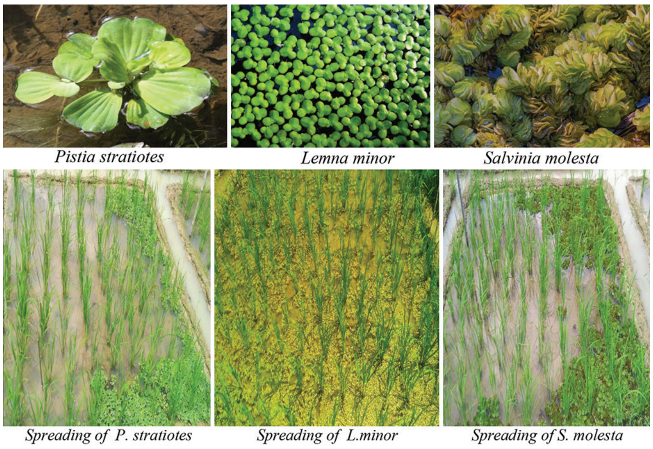
Soil analysis

Soil samples from 0 to 15 cm depths were collected from the experimental field. The analytical data of the soil sample collected from the experimental area were analyzed in the Soil Resources Development Institute, Soil Testing Laboratory, Khamarbari, Dhaka. The soil of the experimental site was silty clay loam (sand 26%, silt 45%, and clay 29%) with pH 5.8, ECE-25–28, C 0.45%, N 0.12%, HPO_4^{2-} 0.40 mg g^{-1} soil, K^+ 0.70 mg g^{-1} soil, Ca^{2+} 4.77 mg g^{-1} soil, Mg^2+ 0.78 mg g^{-1} soil, SO_4^{2-} 1.40 mg g^{-1} soil, Fe^3+ 0.65 mg g^{-1} soil, Mn^{2+} 0.40 mg g^{-1} soil, Zn^2+ 0.48 mg g^{-1} soil, Na^{2+} 1.00 mg g^{-1} soil, Cu^{2+} 0.40 mg g^{-1} soil and Al^{2+} 0.80 mg g^{-1} soil, organic matter 0.78%).

Plant materials

BR11 (Mukta) and BRRI hybrid dhan6 were collected from BRRI, Joydebpur, Gazipur, and Tulsimala were collected from Sherpur, Bangladesh. A local variety, namely, Tulshimala (average yield 3–4 t ha^{-1}), a modern inbred variety BR11(Mukta) (average yield 6.5 t ha^{-1}), and a hybrid variety BRRI hybrid dhan6 were being used as test crops for this experiment. Healthy and disease-free seeds were selected following standard techniques. Seeds were immersed in water in a bucket for 24 h. These were then taken out of the water and kept in gunny bags. The seeds started sprouting after 48 h and were suitable for sowing in 72 h.

The selected *P. stratiotes, L. minor, and Salvinia molesta* floating freshwater aquatic plants, well-known invasive species in the tropics and subtropics, were collected from within the farmers' field of Gazipur district of Bangladesh.



Fertilizer management

Plant nutrients (viz. nitrogen, phosphorus, potash, sulfur, and zinc) for rice were given through urea, triple super phosphate, muriate of potash, gypsum, and zinc sulfate @ 150, 100, 70, 60, and 10 kg ha^{-1}, respectively. Urea was applied in three equal splits. The first dose of urea was applied 21 days after transplanting (DAT). The second dose of urea was added as top dressing at 45 days (active vegetative stage) after transplanting, and the third dose was applied at 60 days (panicle initiation stage) after transplanting as recommended by BRRI (2008).

Experimental treatments and design

The experiment consisted of two factors, namely, varieties, that is, Tulshimala, BR11 (Mukta), and BRRI hybrid dhan6, and weed control, that is, weedy check (Control), IWM (Pretilachlor 6% + pyrazosulfuron 0.15% @ 9.88 kg ha^{-1} + one hand weeding), *P. stratiotes* (spreading 0.5 m^{-2}), *L. minor* (spreading 0.5 m^{-2}), and *S. molesta* (spreading 0.5 m^{-2}). Before cultivation, the field was plowed into a split-plot design with three replications. In the main plot, there was herbicide treatment, and in the subplot, there were various treatments. There were 15 treatment combinations and 45 unit plots. The unit plot size was 5.4 m^2 (2.7 m × 2 m). The blocks and unit plots were separated by 1.0 m and 0.50 m spacing, respectively.

Assessment and interpretation of variability in weed growth and weed control

Relative rate of spread (RRS)

RRS was computed using the following Dickinson and Miller (1998) formula using the % cover in each floating weed 45 days after the experiment's start:

RRS = ((final cover - initial cover)/initial cover)/total # days

Relative weed density in weedy check plot

Relative weed density in the weedy check plot was estimated at 30 and 60 DAT. The relative weed density was worked out per the formula Mishra gave (1968).

$$\text{Relative weed density}(\%) = \frac{\text{Number of individuals of same species}}{\text{Number of individuals of all species}} \times 100$$

Weed control efficiency (WCE)

WCE was measured using the following formula given by Mani *et al.* (1973).

$$WCE = \frac{Weed\ population\ in\ control - weed\ population\ in\ treated\ plot}{Weed\ population\ in\ control} \times 100$$

Weed control index (WCI)

WCI was measured using the following formula given by Mishra and Tosh (1979).

$$WCI = \frac{Weed\ dry\ weight\ in\ control - weed\ dry\ weight\ in\ treated\ plot}{Weed\ dry\ weight\ in\ control} \times 100$$

Crop growth rate (CGR) (mg cm^{-2} day^{-1})

The CGR was worked out between 60 and 90 DAT with the help of the following formula given by Watson (1958).

$CGR = \frac{W2 - W1}{P(t2 - t1)}$ mg cm^{-2} day^{-1}, Where, P = ground area (cm^{-2}), W_1 = dry weight per unit area at t_1, W_2 = dry weight per unit area at t_2, t_1 = time of first sampling, and t_2 = time of second sampling.

Relative growth rate (mg g^{-1} day^{-1})

The mean relative growth rate was calculated from measurements of dry weight at the time intervals (Between 60 and 90 DAT) with the help of the following equation suggested by Beadle (1985).

$\text{Relative growth rate} = \frac{Ln(W2) - Ln(W1)}{(t2 - t1)}$, Where, Ln = natural log values, W_1 = dry weight per unit area at t_1, W_2 = dry weight per unit area at t_2, t_1 = time of first sampling, and t_2 = time of second sampling

Net assimilation rate (NAR) (mg cm^{-2} day^{-1})

The NAR was calculated from the following equation given by Gregory (1926).

$\text{NAR} = \frac{(W2 - W1)(\text{LnLA2} - \text{LnLA1})}{(t2 - t1)(\text{LnLA2} - \text{LnLA1})}$ mg cm-^{2} day^{-1}, Where, LA_1 = leaf area of the first sampling, LA_2 = leaf area of the second sampling, W_1 = dry weight per unit area at t_1, W_2 = dry weight per unit area at t_2, t_1 = time of first sampling, t_2 = time of second sampling, and Ln = natural log values.

Statistical analysis

Statistical analysis was carried out according to standard procedure using the analysis of variance technique with the help of a computer program named Statistix 10 data analysis software. The mean differences were adjusted at a 5% of probability level.

RESULTS

RRS

From transplanting to 45 days, each species exhibited a different pattern of change in the mean cover through time (Fig. 1). The ranking of RRS over the experiment was *L. minor >S. molesta > P. stratiotes*. The mean cover of *Lemna minor* increased rapidly and had the highest cover throughout the experiment.

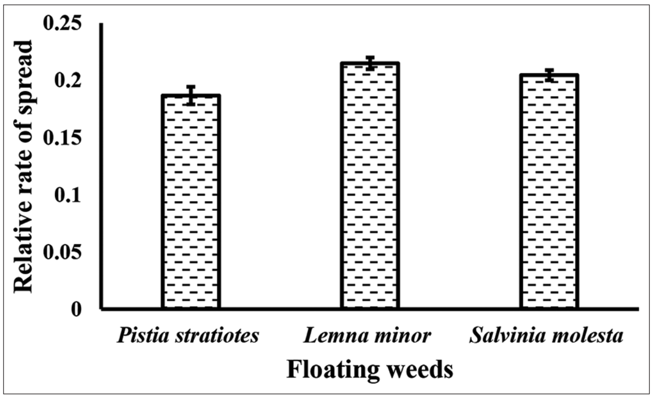


Fig. 1: Relative rate of spread of floating weeds in T. *aman* rice varieties. Bars represent ±SD values obtained from three biological replications

Weed flora of *T. aman* rice

Six weed species belonging to five families were found to infest the experimental rice field. These are given in Table 1. Among the infested weeds, *E. crus-galli* and *Leptochloa chinensis* were grasses from the Poaceae family, and *Fimbristylis miliacea* was sedge from the Cyperacea family. The rest were broadleaf weeds, that is, *Enhydra fluctuans* from Asteraceae, *Sagittaria guayanensis* from *Alismataceae*, and *Ludwigia octovalvis* from the Onagraceae family. However, all weeds were not found in the same variety of raised plots. Among the infested weeds, *L. chinensis* was not found in BRRI hybriddhan6 raised plots, *F. miliacea* was not found in Tulshimala and BRRI hybriddhan6 raised plots, and *L. octovalvis* was not found in BR11, and BRRI hybriddhan6 raised plots. *E. crus-galli*, *E. fluctuans,* and *S. guayanensis* were found throughout the experimental period, whereas *L. chinensis*, *F. miliacea*, and *L. octovalvis* were found at the later stage of crop growth.

Weed density m^{-2}

Results revealed that maximum weed density m-2 (26.99 and 11.11 at 30 and 60 DAT, respectively) was recorded in weedy check plot while IWM treated plot was recorded minimum weed density m^{-2} (0 and 0, respectively) at 30 and 60 DAT, respectively. A significant effect on weed density m^{-2} was found in different varieties at 30 DAT and 60 DAT (Fig. 2a). Among the different rice varieties, the maximum weed density m^{-2} (17.71 and 7.20 at 30 and 60 DAT) was observed in the Tulshimala rice variety. In contrast, the minimum weed density m^{-2} (11.86 and 4.66 at 30 and 60 DAT) was observed in BRRI hybrid dhan6 rice variety cultivation. The number of weeds lower in the high-yielding rice variety might be due to the vigorous growth of the variety helping to reduce the weed population and hence lower in number. Different weed control treatments significantly affect weed density m^{-2} on T. aman rice (Fig. 2b).

The combined effect of variety and weed control treatments significantly affected weed density m^{-2} at 30 and 60 DAT (Table 2). Experiment results revealed that the weedy check plot and Tulshimala rice cultivation recorded maximum weeds density m^{-2} (28.88 and 11.88) at 30 and 60 DAT. While application of mixed herbicide Pretilachlor 6% + pyrazosulfuron 0.15% WP 9.88 kg ha^{-1} mix herbicide and one hand weeding along with BRRI hybrid, dhan6 rice cultivation gave minimum weeds density m^{-2} (0.0 and 0.0, respectively) at 30 and 60 DAT, respectively.

Weed dry weight m^{-2} (g)

Rice varieties play an important role in controlling weeds to some extent levels, which ultimately impacts dry weight accumulation by different weeds in the field. Rice variety showed significant variation in respect of weed dry weight m^{-2} at 30 and 60 DAT (Fig. 3a). Results showed that among different rice varieties, the maximum weed dry weight m^{-2} (5.23 and 2.56, respectively, at 30 and 60 DAT, respectively) was observed

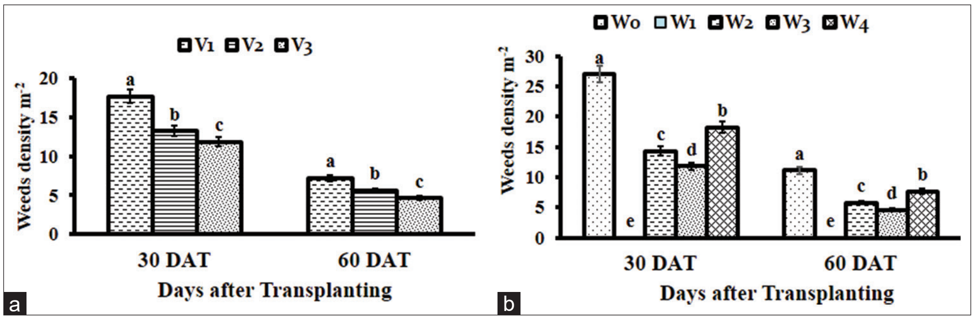


Fig. 2: Effect of rice varieties (a) and weed control treatments (b) on weed density m^{-2} of T. *aman* rice on different days after transplanting. Bars represent ±SD values obtained from three biological replications. Here, V_1: Tulshimala, V_2: BR11, and V_3: BRRI hybrid dhan6; W_0: Weedy check (Control), W_1: Integrated weed management, W_2: *Pistia stratiotes*, W_3: *Lemna minor* and W_4: *Salvinia molesta*

Table 1: List of infesting weeds in the experimental field of T. *aman* rice at Sher-e-Bangla Agricultural University, Bangladesh

S. No.	Name	Type	Family	Infested variety	Occurrence
1.	*Echinochloa crus-galli*	Grass	Poaceae	V_1, V_2, and V_3	Throughout the season
2.	*Leptochloa chinensis*	Grass	Poaceae	V_1, V_2	At the maximum vegetative stage
3	*Fimbristylis miliacea*	Sedge	Cyperaceae	V_2	At the maximum vegetative stage
4	*Enhydra fluctuans*	Broadleaf	Asteraceae	V_1, V_2, and V_3	Throughout the season
5	*Sagittaria guayanensis*	Broadleaf	Alismataceae	V_1, V_2, and V_3	Throughout the season
6	*Ludwigia octovalvis*	Broadleaf	Onagraceae	V_1	At the maximum vegetative stage

Here, V_1: Tulshimala, V_2: BR11 and V_3: BRRI hybrid dhan6

Table 2: Combined effect of variety and weed control treatment on weeds density and dry matter weight (g) m^{-2} of T. *aman* rice

Treatment combinations	Weeds density m^{-2}		Weeds dry matter weight (g) m^{-2}	
	30 DAT	60 DAT	30 DAT	60 DAT
V_1W_0	28.88_{a}	11.88_{a}	10.34_{a}	4.83_{a}
V_1W_1	0.00_{i}	0.00_{i}	0.00_{g}	0.00_{j}
V_1W_2	19.22_{d}	7.33_{d}	5.56_{c}	2.67_{d}
V_1W_3	16.55_{e}	6.22_{e}	4.56_{d}	2.17_{e}
V_1W_4	23.88_{c}	10.55_{c}	5.67_{c}	3.13_{bc}
V_2W_0	26.55_{b}	11.22_{b}	8.74_{b}	3.32_{b}
V_2W_1	0.00_{i}	0.00_{i}	0.00_{g}	0.00_{j}
V_2W_2	13.22_{f}	5.55_{f}	4.67_{d}	1.67_{fg}
V_2W_3	10.22_{g}	4.22_{g}	3.23_{e}	1.26_{hi}
V_2W_4	16.22_{e}	7.22_{d}	4.46_{d}	1.89_{f}
V_3W_0	25.55_{b}	10.22_{c}	8.73_{b}	2.91_{cd}
V_3W_1	0.00_{i}	0.00_{i}	0.00_{g}	0.00_{j}
V_3W_2	10.55_{g}	4.55_{g}	3.23_{e}	1.48_{gh}
V_3W_3	8.67_{h}	3.33_{h}	2.19_{f}	1.02_{i}
V_3W_4	14.55_{f}	5.22_{f}	3.42_{e}	1.52_{g}
$LSD_{(0.05)}$	1.42	0.43	0.47	0.24
CV(%)	5.89	4.34	6.38	7.80

In a column means having similar letter (s) are statistically similar, and those having dissimilar letter (s) differ significantly at a 0.05 level of probability. V_1: Tulshimala, V_2: BR11, V_3: BRRI hybrid dhan6, W_0: Weedy check (Control), W_1: Integrated weed management, W_2: *Pistia stratiotes*, W_3: *Lemna minor*, W_4: *Salvinia molesta*

in Tulshimala rice. At the same time, the minimum weed dry weight m^{-2} (3.51 and 1.49 g, respectively, at 30 and 60 DAT, respectively) was observed in the BRRI Hybrid dhan6 rice variety treatment. Weed dry weight m^{-2} was significantly influenced due to the application of different weed control treatments at 30 and 60 DAT (Fig. 3b). Results showed that the maximum weed dry weight m^{-2} (9.27 and 3.69 g, respectively) at 30 and 60 DAT was recorded in the weedy check plot. At the same time, the application of IWM recorded minimum weed dry weight m^{-2} (0.0 and 0.0 g, respectively) at 30 and 60 DAT, respectively.

Experiment results revealed that the weedy check plot and Tulshimala rice cultivation recorded the maximum weeds dry weight m^{-2} (10.34 and 4.83 g) at 30 and 60 DAT. In contrast, the application of IWM and BRRI hybrid dhan6 rice variety cultivation recorded the minimum weeds dry weight m^{-2} (0.00 and 0.00, respectively) at 30 and 60 DAT, respectively. The combined effect of variety and weed control significantly affected the weed's dry weight m^{-2} at 30 and 60 DAT (Table 2).

WCE (%)

Rice variety significantly affects on WCE of T. *aman* rice at 30 and 60 DAT (Fig. 4a). Due to different rice varieties treatment, the WCE ranged from 38.69 to 53.57% over the weedy check plot. Experiment results revealed that the cultivation of the BRRI Hybrid dhan6 rice variety recorded the maximum WCE (53.57 and 54.37%, respectively) at 30 and 60 DAT, respectively, while the cultivation of Tulshimala rice variety recorded minimum WCE (38.69 and 53.57%, respectively) at 30 and 60 DAT, respectively. The application of different weed control treatments significantly affects the WCE of T. *aman* rice at 30 and 60 DAT (Fig. 4b). Due to weed control treatment application, WCE ranged from 31.83 to 100% over the weedy check. Experiment results revealed that the highest WCE was observed in IWM compared to other treatments. However, all the weed control treatments suppressed weeds, but the magnitude of suppression was higher in IWM-treated plots, and it was (100%, and 100 %, respectively) at 30 and 60 DAT, respectively. The minimum WCE (0.0 and 0.0 %, respectively) at 30 and 60 DAT, respectively, was observed in the weedy check.

The combined effect of variety and weed control significantly affected weed control efficiency at 30 and 60 DAT (Table 3). Due to the combined effect of variety and weed control, the weed control efficiency ranged from 17.42 to 100% over the weedy check plot. Experiment results revealed that the application of IWM along with the Tulshimala rice variety recorded the maximum weed control efficiency (100 and 100%, respectively) at 30 and 60 DAT, respectively, which was statistically similar to the application of IWM along with the BR11 rice variety (100 and 100 %, respectively), application of IWM along with BRRI hybrid dhan6 rice variety (100 and 100 %, respectively). The minimum weed control efficiency (0.0 and 0.0 %, respectively) at 30 and 60 DAT, respectively, was recorded in the weedy check along with the Tulshimala rice variety, which was statistically similar to the weedy check along with BR11 rice variety cultivation (0.0, and 0.0 %, respectively) and weedy check plot along with BRRI hybrid dhan6 rice variety (0.0 and 0.0 %, respectively) at 30 and 60 DAT, respectively.

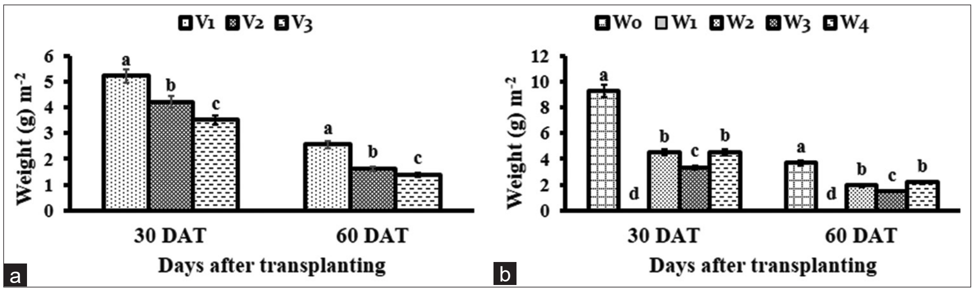


Fig. 3: Effect of rice varieties (a) and weed control treatments (b) on weed dry weight m^{-2} of T. *aman* rice on different days after transplanting. Bars represent ±SD values obtained from three biological replications. Here, V_1: Tulshimala, V_2: BR11, and V_3: BRRI hybrid dhan6; W_0: Weedy check (Control), W_1: Integrated weed management, W_2: *Pistia stratiotes*, W_3: *Lemna minor* and W_4: *Salvinia molesta*

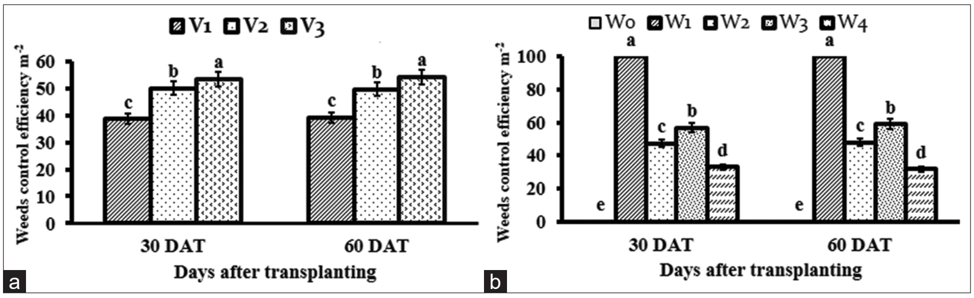


Fig. 4: Effect of rice varieties (a) and weed control treatments (b) on weed control efficiency m^{-2} of T. *aman* rice on different days after transplanting. Bars represent ±SD values obtained from three biological replications. Here, V_1: Tulshimala, V_2: BR11, and V_3: BRRI hybrid dhan6; W_0: Weedy check (Control), W_1: Integrated weed management, W_2: *Pistia stratiotes*, W_3: *Lemna minor* and W_4: *Salvinia molesta*

Table 3: Combined effect of variety and weed control on the crop growth rate, relative crop growth rate, net assimilation rate, and yield of T. *aman* rice

Treatment Combinations	Crop growth rate	Relative crop growth rate	Net assimilation rate	Yield (t ha^{-1})
V_1W_0	1.08±0.07$_{i}$	20.51±0.19$_{h}$	0.62±0.003$_{g}$	2.91±0.29$_{i}$
V_1W_1	1.56±0.12$_{g}$	23.00±0.38$_{f}$	0.69±0.005$_{f}$	3.91±0.33$_{e\text{-}h}$
V_1W_2	1.36±0.06$_{h}$	22.69±0.18$_{fg}$	0.66±0.003$_{fg}$	3.49±0.17$_{g\text{-}i}$
V_1W_3	1.53±0.06$_{g}$	22.88±0.21$_{fg}$	0.68±0.005$_{fg}$	3.76±0.24$_{f\text{-}h}$
V_1W_4	1.29±0.2$_{h}$	21.15±1.12$_{gh}$	0.70±0.01$_{f}$	3.35±0.64$_{hi}$
V_2W_0	1.54±0.1$_{g}$	23.28±0.66$_{f}$	0.67±0.02$_{fg}$	4.18±0.29$_{c\text{-}f}$
V_2W_1	2.29±0.17$_{b}$	31.89±1.3$_{b}$	1.02±0.03$_{b}$	4.68±0.32$_{bc}$
V_2W_2	2.08±0.08$_{d}$	28.09±0.62$_{d}$	0.93±0.02$_{cd}$	4.56±0.18$_{cd}$
V_2W_3	2.19±0.09$_{c}$	25.17±0.71$_{e}$	1.10±0.03$_{a}$	5.19±0.24$_{b}$
V_2W_4	2.19±0.11$_{bc}$	30.85±1$_{bc}$	0.86±0.01$_{e}$	4.39±0.26$_{c\text{-}e}$
V_3W_0	1.96±0.18$_{e}$	26.01±0.7$_{e}$	0.87±0.013$_{de}$	4.57±0.7$_{cd}$
V_3W_1	2.98±0.29$_{a}$	35.29±1.38$_{a}$	1.13±0.02$_{a}$	5.92±0.78$_{a}$
V_3W_2	1.73±0.15$_{f}$	27.90±0.67$_{d}$	0.89±0.01$_{c\text{-}e}$	3.86±0.43$_{e\text{-}h}$
V_3W_3	2.21±0.16$_{bc}$	29.70±0.75$_{cd}$	0.94±0.02$_{c}$	4.65±0.57$_{bc}$
V_3W_4	1.73±0.19$_{f}$	25.82±1.12$_{e}$	0.84±0.01$_{e}$	4.04±0.64$_{d\text{-}g}$
SE	0.05	0.89	0.02	0.58
CV(%)	3.42	4.17	4.35	8.06

Here, V_1: Tulshimala, V_2: BR11, and V_3: BRRI hybrid dhan6, W_0: Weedy check (Control), W_1: Integrated weed management, W_2: *Pistia stratiotes*, W_3: *Lemna minor* and W_4: *Salvinia molesta*

WCI (%)

Rice variety significantly affects WCI at 30 and 60 DAT (Fig. 5a). Due to different rice varieties treatment, the WCI ranged from 49.27 to 59.77% over the weedy check plot. Experiment results revealed that BRRI Hybrid dhan6 rice variety cultivation recorded the maximum WCI of 59.77 % at 30 DAT and 52.37 % at 60 DAT, statistically similar to the BR11 rice variety (51.04%). In comparison, the cultivation of the Tulshimala rice variety cultivation recorded a minimum WCI of 49.27% at 30 DAT, which was statistically similar to the BR11 rice variety, and at 60 DAT, 46.95 % WCI was found in the Tulshimala rice variety. Application of different weed control treatments significantly effects on WCI of T. *aman* rice at 30 and 60 DAT (Fig. 5b). Due to herbicide application, the WCI ranged from 33.14 to 100% over the weedy check plot. The experiment result revealed a higher WCI in plots receiving IWM compared to other treated plots. However, all the weed control treatments suppressed weeds. Still, the magnitude of suppression was higher in IWM, and it was 100 % both at 30 and 60 DAT, while the minimum WCI (0.0 and 0.0%, respectively) at 30 and 60 DAT, respectively, was in recorded in weedy check.

The combined effect of variety and weed control significantly affected the WCI at 30 and 60 DAT (Table 3). Due to the combined effect of variety and weed control, the WCI ranged from 17.42 to 100 % over the weedy check plot. Experiment results revealed that the application of IWM along with Tulshimala rice variety cultivation recorded the maximum weed control efficiency (100 and 100%) at 30 and 60 DAT, which was statistically similar to the application of IWM along with BR-11 rice variety (100 and 100%, respectively), application of IWM along with BRRI hybrid dhan6 rice variety (100 and 100%, respectively) while the minimum WCI (0.0 and 0.0 %) at 30 and 60 DAT was recorded in the weedy check plot along with Tulshimala rice cultivation which was statistically similar with weedy check plot along with BR11 rice variety cultivation (0.0 and 0.0%, respectively) and weedy check along with BRRI hybrid dhan6 rice variety cultivation (0.0 and 0.0%, respectively) cultivation at 30 and 60 DAT, respectively.

Crop growth performance

The CGR, relative CGR, and NAR of T. *aman* rice were significantly varied due to the different rice varieties and weed control treatments (Fig. 6). Experimental results had shown that the highest CGR (2.12 mg cm^{-2} day^{-1}) was recorded in the BRRI hybrid dhan6 (V_3) rice variety, while the lowest CGR (1.36 mg cm^{-2} day^{-1}) was recorded in Tulshimala (V_1) rice variety. Weed control through IWM (W_1) recorded the highest CGR (2.28 mg cm^{-2} day^{-1}), whereas the lowest CGR (1.53 mg cm^{-2} day^{-1}) was recorded in the weedy check plot (W_0). Therefore, cultivation of the BRRI hybriddhan6 variety and weed control through IWM (V_3W_1) recorded the highest CGR (2.98 mg cm^{-2} day^{-1}), whereas cultivation of the Tulshimala variety and weed check plot (V_1W_0) recorded the lowest CGR (1.08 mg cm^{-2} day^{-1}). The experimental result showed that

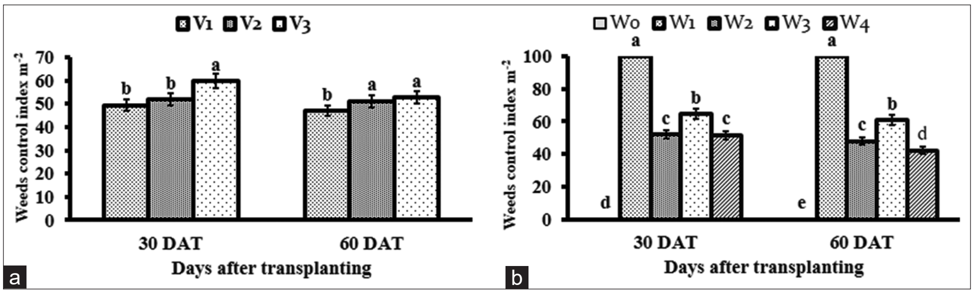


Fig. 5: Effect of rice varieties (a) and weed control treatments (b) on weed control index m^{-2} of T. *aman* rice on different days after transplanting. Bars represent ±SD values obtained from three biological replications. Here, V_1: Tulshimala, V_2: BR11, and V_3: BRRI hybrid dhan6; W_0: Weedy check (Control), W_1: Integrated weed management, W_2: *Pistia stratiotes*, W_3: *Lemna minor,* and W_4: *Salvinia molesta*

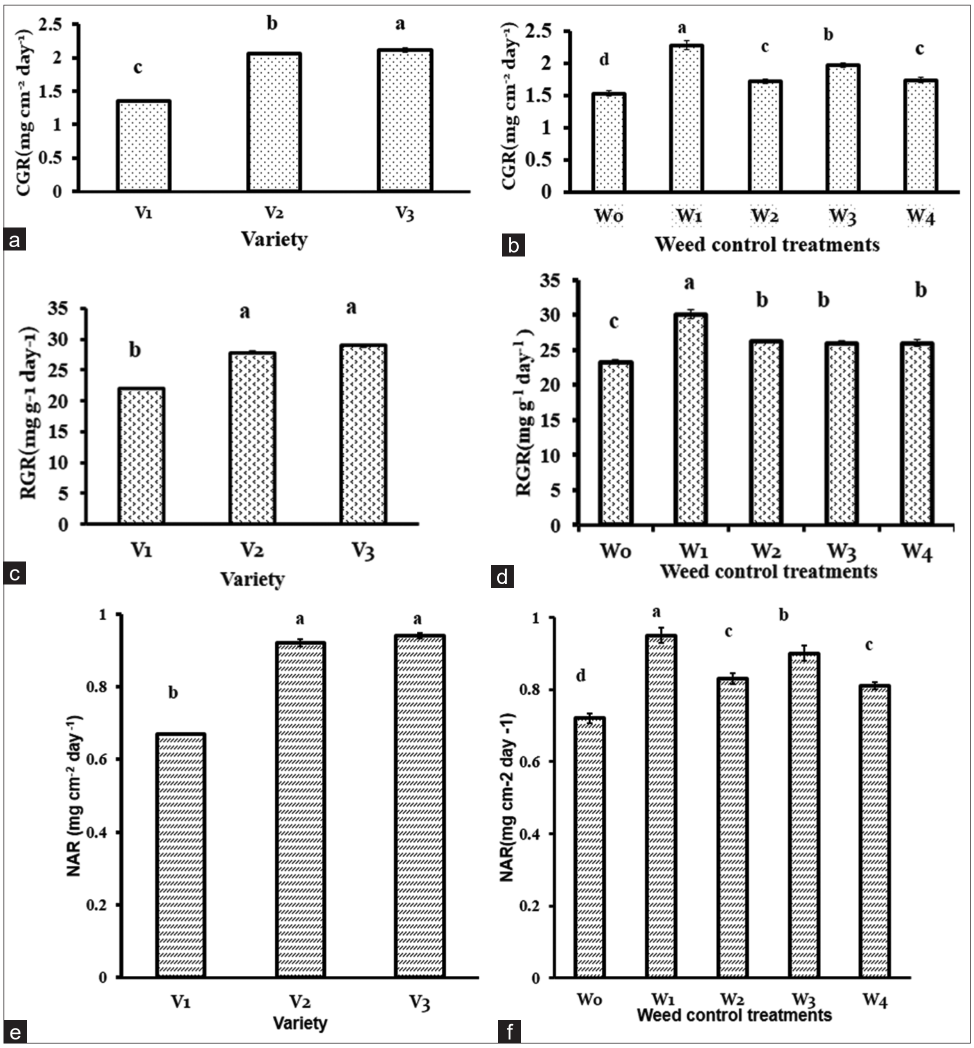


Fig. 6: Effect of variety and weed control treatments on the crop growth rate (a and b, respectively), relative crop growth rate (c and d, respectively), and net assimilation rate (e and f, respectively) of T. *aman r*ice. Here, V_1: Tulshimala, V_2: BR11, and V_3: BRRI hybrid dhan6; W_0: Weedy check (Control), W_1: Integrated weed management, W_2: *Pistia stratiotes*, W_3: *Lemna minor,* and W_4: *Salvinia molesta*

the highest relative CGR (28.94 mg g^{-1} day^{-1}) was recorded in the BRRI hybrid dhan6 (V_3) rice variety which was statistically similar to BR11 (V_2) rice variety recorded relative CGR (27.85 mg g^{-1} day^{-1}). The lowest relative CGR (22.05 mg g^{-1} day^{-1}) was recorded in Tulshimala (V_1) rice variety. Weed control through IWM (W_1) recorded the highest relative CGR (30.06 mg g^{-1} day^{-1}), whereas the lowest CGR (23.27 mg g^{-1} day^{-1}) was recorded in the weedy check plot (W_0). Therefore, the BRRI hybriddhan6 variety's cultivation and weed control through IWM (V3W1) recorded the highest relative CGR (35.29 mg g^{-1} day^{-1}). In comparison, cultivation of the Tulshimala variety along with weed check plot (V_1W_0) recorded the lowest relative CGR (20.51 mg g^{-1} day^{-1}), which was statistically similar to V_1W_4 (21.15 mg g^{-1} day^{-1}) treatment combination. The highest NAR (0.94 mg cm^{-2} day^{-1}) was recorded in the BRRI hybrid dhan6 (V_3) rice variety which was statistically similar to BR11 (V_2) rice variety recorded NAR (0.92 mg cm^{-2} day^{-1}). The lowest NAR (0.67 mg cm^{-2} day^{-1}) was recorded in Tulshimala (V_1) rice variety. Weed control through IWM (W_1) recorded the highest NAR (0.95 mg cm^{-2} day^{-1}), whereas the lowest NAR (0.72 mg cm^{-2} day^{-1}) was recorded in the weedy check plot (W_0).

Therefore, cultivation of the BRRI dhan6 variety along with weed control through IWM (V_3W_1) recorded the highest NAR (1.13 mg cm^{-2} day^{-1}), which was statistically similar to V_3W_1 (1.10 mg cm^{-2} day^{-1}). In contrast, cultivation of the Tulshimala variety along with weed check plot (V_1W_0) recorded the lowest NAR (0.62 mg cm^{-2} day^{-1}), which was statistically similar to V_1W_{2} (0.66 mg cm^{-2} day^{-1}), V_2W_{0} (0.67 mg cm^{-2} day^{-1}) and V_1W_3 (0.68 mg cm^{-2} day^{-1}) treatment combination.

Yield performance

Rice varieties, weed control treatments, and their combinations significantly influenced the grain yield of T. *aman* rice (Fig. 7). Experiment results showed that among different rice varieties, cultivation of the BRRI dhan6 (V_3) variety recorded the highest grain yield (4.61 t ha^{-1}), which was statistically similar to the (4.60 t ha^{-1}) BR11 (V_2) variety. While cultivation of the Tulshimala variety (V_1) recorded the lowest grain yield (3.48 t ha^{-1}) compared to other varieties of cultivation. Weed control through IWM (W_1) recorded the highest grain yield (4.84 t ha^{-1}), which was statistically similar to W_3 (*L. minor*) treatment and recorded grain yield (4.84 t ha^{-1}). The lowest grain yield (3.89 t ha^{1}) was recorded in the weedy check (W_0). Whereas the lowest grain yield (2.91 t ha^{-1}) was recorded in the cultivation of Tulshimala along with a weedy check plot (V_1W_0 treatment combination), which was statistically similar to V_1W_4 (3.35 t ha^{-1}) and V_1W_2 (3.35 t ha^{-1}) treatment combination. It was clear from the experimental data that cultivation of BRRI dhan6, along with weed control through IWM (V_3W_1), recorded the highest grain yield (5.92 t ha^{-1}) comparable to other treatment combinations.

DISCUSSION

Infestation and competition by weeds are impacted by all production techniques, whether directly or indirectly, used to grow the crop. The same procedures that promote crop growth also favor weed emergence. However, studies have demonstrated that some agronomic methods can be changed, which would impact crop growth as opposed to weed development. Crop rotation, summer tillage, stale seedbed preparation, weed competitive crop cultivars, green manuring, mixed/intercropping, intercultural operations, etc., are some of the tried-and-true techniques that are included. Such procedures frequently need for little or no additional cost. The present study aimed to determine if floating weeds may minimize weed growth in transplanted *aman* rice production. Three floating plants *viz. L. minor*, *P. stratiotes*, and *S. molesta* were spread to suppress the weed growth in rice. This difference in outcome from the experiment can be attributed to *L. minor*'s and *S. molesta*'s increase in growth and *P. stratiotes*'s relatively slow growth with the cogrowth of rice, irrespective of varieties. Dickinson and Miller (1998) observed that *S. minima*'s had relatively slow growth than *L. minor*. Paiman *et al*. (2020) found several types of weeds in rice (i.e., grassy, sedges, and broad leaf), and the occurrence of weed infestation related to rice variety and crop growth. The number of weeds lower in the high-yielding rice variety might be due to the vigorous growth of the variety helping to reduce the weed population and hence lower in number. Afrin *et al*. (2015) also found similar results which supported the present finding and reported that the number of weeds, or the weed population, depends on the soil, environment, varieties, and other factors. As a result, variations in the weed population occurred. Gibson *et al.* (2001) reported that competitive rice cultivars, namely, hybrids, usually have better vigor than inbreeds and effectively suppress the infestation of weed populations or density. The application of Pretilachlor 6% + pyrazosulfuron 0.15% WP 9.88 kg ha^{-1} mix herbicide might have prevented the germination of susceptible weed species and reduced the growth of germinated weeds by inhibiting the process of photosynthesis comparable to other weed control treatments. The result obtained from the present study was similar to the findings of Mahbub and Bhuiyan (2018) also reported that the mixture of herbicides gave 80% control of annual and perennial weeds comparable to individual application of herbicides. Rekha *et al.* (2003) and Reddy *et al.* (2000) also found similar results and reported that the weed density was highest in the weed check condition. Weed density was decreased under different weed management treatments. Herbicidal treatment considerably reduced weed density in agricultural fields compared to a weedy check because herbicides damage weed seeds as they germinate over a longer period, emptying weed seed reserves in the soil. Sohel *et al*. (2020) reported that the competitive ability of different rice varieties significantly reduces the weed population in the field, ultimately impacting the total dry matter accumulation by weeds in the m^{-2} area. The result found in this experiment agreed with Chauhan and Johnson (2011), who reported that the highly competitive varieties would be rapid canopy closure so that shade under the canopy would suppress the growth of weeds, which ultimately reduces the dry matter accumulation by weeds. The differences in the dry matter accumulation by different weeds m^{-2} were due to the application of different weed control treatments altering the physiological and morphological activities of the weeds. As a result, dry matter accumulation by different weeds m^{-2} was reduced compared to non-treated ones. Afrin *et al.* (2015) reported that different rice varieties significantly influence weed control efficiency. The differences in weed control efficiency were due to variation in weed density in the experimental plots, which was attended to through different weed control treatments. Different weed control treatments deteriorate the physiological and morphological features of weed and thus reduce weed density and increase weed control efficiency. Different rice varieties may have a higher competitive ability which helps to suppress the weeds population and reduce resource utilization, thus increasing the WCI by decreasing weeds biomass production. Chauhan and Johnson

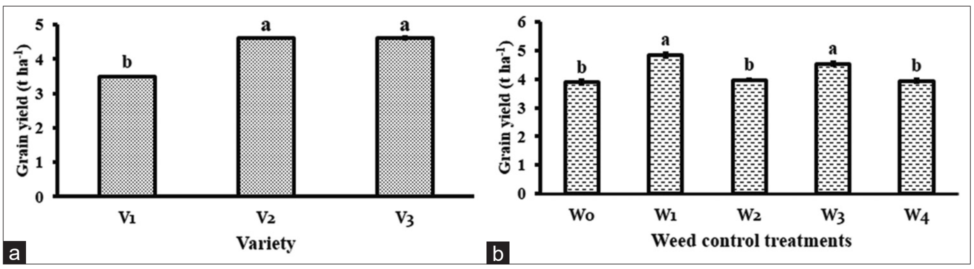


Fig. 7: Effect of variety (a) and weed control treatments (b) on grain yield of *aman* rice

(2011) and Masum *et al.* (2019) also observed similar results and reported that the WCI could be attributed to less weed biomass due to the highly competitive variety's ability to suppress weeds. The changes in WCI were brought about by various herbicidal effects on weeds that aid in changing their physiological and morphological characteristics, reduce solar energy absorption, reduce the accumulation of dry matter, and eventually lower weed density in crop fields. The result obtained from the present study was similar to the findings of Suryakala *et al.* (2019), who reported that the WCI ranged from 78.66-92.32% with various herbicide combinations. Priya and Kubsad (2013) also reported higher weed control efficiency and lower weed index in herbicide treatments than weedy check due to lower weed dry weight, higher weed control efficiency, and lower weed index due to effective control of complex weed flora. The CGR is the product of the leaf area index and NAR values. A higher CGR in modern varieties than in aromatic varieties may be due to the higher leaf area index. Toshiyuki *et al.* (2006) reported that the genotypic difference in grain yield was most closely related to CGR. Lodhi (2016) reported that different weed control treatments increased CGR s comparable to the weedy check. Amin *et al.* (2002) reported that rice varieties' relative CGR s differ. Olayinka and Etejere (2015) reported that all the weed control treatments had higher RGR than the weedy check. The differences in grain yield among different rice varieties were due to the differences in genetic makeup, which influences filled grains per panicle and 1000-seed weight collectively contributed to yield differences among varieties. Dutta *et al.* (2002) reported that the genotypes which produced the highest net assimilate rate also showed higher grain yield in rice. The crop that received weed-free treatment recorded the highest growth and yield attributes resulting in higher grain yield. IWM through the application of pretilachlor 6% + pyrazosulfuron 0.15% reduced weed's population, and weed's dry weight caused significantly restricted growth of weed and lesser competition for light, moisture, and space by weeds as compared to the rest of the weed control treatments. On the other hand, including duckweed (*L. minor*) in rice agroecosystems has reduced nitrogen loss and increased the availability of nutrients to the crop, influencing rice's grain yield.

CONCLUSION

Based on the above results of the present experiment, it was found that the mean cover of *L. minor* increased rapidly and had the highest cover throughout the experiment, followed by *S. molesta* and *P. stratiotes*. Different types of weeds are found in rice (i.e., grassy, sedges, and broadleaf), and weed infestation is related to rice variety and crop growth. BRRI hybrid dhan6 rice variety significantly suppressed weed density. IWM successfully controlled all weeds and gave the highest weed control efficiency and WCI. Therefore, cultivation of BRRI hybrid dhan6 and weed control through IWM gave the highest grain yield (5.92 t ha^{-1}) and the highest economic return comparable to other treatment combinations. However, the spreading of *L. minor* also increases grain yield and net return irrespective of varieties. The experimental results also suggest that morphological and biomass characteristics of T. *aman* rice varieties get disadvantages when grown with *P. stratiotes* and *S. molesta*. However, more research should be done to reach a specific conclusion and recommendation, especially the phytoremediation by *P. stratiotes* and *S. molesta* over different AEZ in Bangladesh.

CONFLICTS OF INTEREST

No conflicts of interest have been declared.

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