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Preliminary Reports on Comparative Weed Competitiveness of Bangladeshi Monsoon and Winter Rice Varieties under Puddled Transplanted Conditions

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Abstract: Weed-competitive rice cultivars, a viable tool for integrated weed management of rice-field weeds, may greatly reduce the weed pressure and excessive dependence on herbicide in controlling weeds. Based on this premise, field experiments were conducted in 2018 and 2019 during the monsoon and winter rice-growing seasons at the Agronomy Field Laboratory of Bangladesh Agricultural University, Bangladesh, to evaluate the weed competitiveness of the selected rice varieties. A total of 42 monsoon and 28 winter rice varieties from Bangladesh were evaluated under "weedy" and "weed-free" conditions in the puddled transplanted system of cultivation. The field experiments were designed with three replications in a randomized complete block design. The results revealed that weed competition greatly reduces the yield of rice, and relative yield loss was 15–68% and 20–50% in monsoon and winter season rice, respectively. The lowest relative yield losses were recorded in monsoon rice from the variety BU dhan 1 (18%) and from the winter rice BRRI hybrid dhan5 (23.7%), which exhibited high weed tolerance. The weed competitive index (WCI) greatly varied among the varieties in both seasons and the monsoon season, ranging from 0.4 to 2.8, and the highest value was recorded from the hybrid variety Dhani Gold followed by BU dhan 1. In winter season rice, the WCI varied 0.25 to 2.4 and the highest value was recorded from the variety BRRI hybrid dhan3, followed by hybrid variety Heera 6. In monsoon rice, hybrid Dhani Gold was the most productive, but BU dhan 1 was the most weed competitive variety. Among the winter-grown varieties, the hybrid Heera 6 was the most productive, and the most weed competitive. Our research confirmed a high degree of variability in weed competitiveness among the 70 Bangladeshi rice varieties tested.

Keywords: weed suppressive ability; rice varieties; relative yield loss; puddled transplanted system

1. Introduction

In rice production, among the major pests, weeds rank first in terms of crop losses and cost involvement for their management [1,2]. The average yield losses due to weed infestation in rice may vary from 40 to 60% and in some cases go up to 94–96% depending on the type of weeds, infestation level, establishment methods, and weed management practices [3–5]. In Bangladesh, yield reduction may vary 68–100%, 16–48%, 22–36% in direct-seeded pre-monsoon (mostly rainfed), transplanted monsoon (mostly rainfed puddled), and transplanted winter rice (irrigated puddled), respectively, due to weeds [6–8].

Chemical weed control is the only feasible way to manage weeds because of the acute labor crisis in the peak period especially during planting, weeding, and harvesting stages [9]. The labor crisis in agriculture is becoming worse in the country due to labor's increased involvement in nonagriculture sectors for higher wages. This shift of labor from agriculture to nonagriculture plus high wages has thus left labor-intensive agriculture at risk. It is estimated that the labor share in Bangladesh agriculture decreased from 70% in 1991 to 39% in 2019 with an increase in the use of herbicides from 99 Mt/kL in 1991 to 6997 Mt/kL in 2018 [10,11]. Low-cost involvement in herbicidal weed management and shortage of labor during the peak period of weed control encourages farmers to use herbicide in the crop fields [1]. Continuous and excessive use of herbicides for a long time causes several negative effects on the surrounding wildlife and farmers' health [12–15]. For example, the long-term effect of Agent Orange (mixture of 2,4-D and 2,4,5-T) used in the Vietnam Wars, and the Seveso tragedy of Italy in 1976 during production of 2,4,5-T are very well known in world history [12]. To date, traces of dioxin present in those herbicides cause birth defects, reduced birth weight, fetal death, cancer, and cardiovascular diseases, etc. [16,17]. Saka [18] examined the toxicity of Simetryn, Mefenacet, and Thiobencarb, commonly used herbicides in the rice fields of Japan, and found these herbicides, especially Thiobencarb, are toxic to *Silurana tropicalis* (tadpoles). Liu et al. [19], on the other hand, evaluated the toxicity of Butachlor (the most commonly used herbicide in the rice fields of Taiwan and Southeast Asia) observed no effect on the growth of *Fejervarya limnocharis* (alpine cricket frog) but observed a negative action on their survival, development, and time of metamorphosis. Similarly, the genotoxic and mutagenic effect of Atrazine on *Oreochromis niloticus* (Nile tilapia) [20] is well known. Sometimes, herbicides have indirect effects on the phytophagous beneficial insects through destruction of their habitat or reduction of the nutritional value of their host plants [21–23]. Herbicides also have lethal and sublethal effects on ladybird beetles [24], green lacewings [25], earthworms [26], parasitic wasps, and honeybees [27] when they come into direct contact with herbicides either topically or through ingesting treated food materials. Furthermore, application of the same herbicide frequently over the years may produce herbicide-resistant weeds [28–34]. Since the late 1950s (the first case was identified) to date, a total of 521 unique cases of herbicide-resistant weeds has been reported in 94 crops of 71 countries, and 263 species compromising the efficacy of 167 herbicides or 23 out of 26 known herbicide sites of action [35].

Competitive crop variety development is one of the major alternatives to combat these issues. Weed tolerance (WT) and weed suppressive ability (WSA) are the two major components of weed competitiveness. WT refers to the competency of sustaining potential yields under weed infestation while WSA refers to the ability of a cultivar to lessen weed growth through competition [36]. Numerous articles have documented the variability among cultivars in their ability to compete with weeds [33–37]. However, Zhao et al. [38] stated that WSA of a low yielding variety will not always guarantee high yield under weedy conditions. Hence, it is important to develop high yield potential and strong WSA variety to sustain yield under weedy conditions.

Many researchers from the rice growing countries also address these issues, seeing the high susceptibility of rice to weeds [39,40]. However, information related to the weed competitiveness of Bangladeshi rice varieties especially under the puddled transplanted system is scant. However, the rice establishment methods influence the weed composition and abundance [35,37,41]. For example, dry direct-seeded systems of rice cultivation allow more weeds than puddled transplanted systems [39,41,42]. Except for our previous work on weed competitiveness of Bangladeshi winter rice varieties under dry direct-seeded conditions [35,37], there has been no other research conducted so far to screen the weed competitive ability of monsoon and winter season rice varieties in Bangladesh.

Considering the huge pool of Bangladeshi rice varieties, this study was conducted to evaluate the magnitude of variability in weed competitive ability and yield among selected high-yielding varieties of rice grown under puddled transplanted conditions, and to identify potential, high yielding weed competitive rice varieties.

2. Materials and Methods

2.1. Experimental Site

The experiments were carried out at the Agronomy Field Laboratory of Bangladesh Agricultural University (24°75′ N latitude and 90°50′ E longitude) from July 2018 (July to December, monsoon season rice) to June 2019 (January to June, winter season rice). The soil in the area belongs to the Sonatola soil series of noncalcareous dark gray floodplain soil in the Old Brahmaputra floodplain agroecological zone (AEZ-9) [43]. The soil is silty loam and almost neutral in reaction (pH 6.8). The organic matter content (0.93%) and general fertility level (0.13% total N, and exchangeable P, K, and S are 16.3, 0.28 and 13.9 ppm, respectively) of the experimental field is low. The monthly average air temperature (°C), RH (%), and monthly total rainfall (mm) during the experimental period recorded are shown in Figure 1.

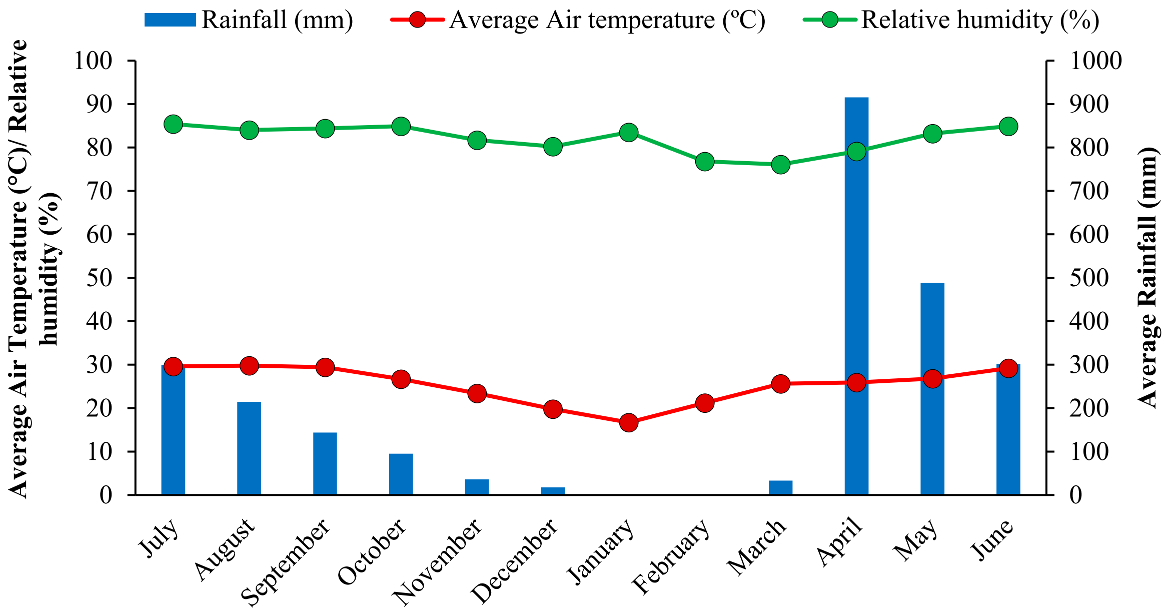

Figure 1. Monthly average air temperature (°C), relative humidity (%), and monthly total rainfall (mm) of the Bangladesh Agricultural University weather station from July 2018 to June 2019 (during the experimental period).

2.2. Treatments and Design of the Experiments

Two factorial experiments were carried out where, in both cases, factor A comprised two weeding regimes, viz., a) season-long "weed free" and b) season-long "weedy" condition. On the other hand, factor B consisted of the selected rice varieties in Bangladesh from BRRI, BINA, private seed companies, and traditional local varieties. A total of 42 varieties were selected for monsoon-grown rice (Experiment 1) and 28 varieties for winter-grown rice (Experiment 2). Characteristics (varietal identity, growth duration, and plant height) of the selected varieties are presented in Tables 1 and 2. Both experiments were laid out in a randomized complete block design with three replications. The unit plot size was 5.0 m^2 (2 m × 2.5 m). In addition, three plots without rice were maintained to study the growth, diversity, and abundance of weeds under the field experimental settings. The weed-free plots were maintained by manual hand weeding 2–4 times immediately after the emergence of weeds.

Table 1. Brief description of the monsoon grown rice varieties used in the experiments to evaluate their weed competitiveness (experimental period: July to December 2018).

Rice Varieties	Growth Duration (days)	Plant Height (cm)	Rice Varieties	Growth Duration (days)	Plant Height (cm)
BR10	150	115	BRRI dhan57	105	115
BR11	145	115	BRRI dhan62	100	102
BR22	150	125	BRRI dhan66	115	120
BR25	135	138	BRRI dhan70	130	125
BRRI dhan30	145	120	BRRI dhan71	115	108
BRRI dhan31	140	115	BRRI dhan72	125	116
BRRI dhan32	130	120	BRRI dhan75	115	110
BRRI dhan33	118	100	BRRI dhan76	163	140
BRRI dhan34	135	117	BRRI dhan77	155	140
BRRI dhan37	140	125	BRRI dhan78	135	118
BRRI dhan38	140	125	BRRI dhan79	135	112
BRRI dhan39	122	108	BRRI dhan80	130	120
BRRI dhan40	145	110	BU dhan 1	120	100
BRRI dhan41	148	115	BU hybrid dhan 1	-	100
BRRI dhan44	145	130	Binadhan-7	120	112
BRRI dhan46	150	105	Binadhan-11	135	100
BRRI dhan49	135	100	Binadhan-13	142	131
BRRI dhan51	142	90	Binasail	140	117
BRRI dhan52	140	116	Agrodhan-12	145	110
BRRI dhan54	135	115	Dhani Gold	110	100
BRRI dhan56	110	115	Naizersail	150	

Note: average growth duration and plant height of the varieties.

Table 2. Brief description of the winter grown rice varieties used in the experiment to evaluate their weed competitiveness (experimental period: January to June 2019).

Rice Varieties	Growth Duration (days)	Plant Height (cm)	Rice Varieties	Growth Duration (days)	Plant Height (cm)
BR3	170	95	BRRI dhan67	145	100
BR14	160	120	BRRI dhan68	149	97
BR16	165	90	BRRI dhan69	153	105
BR24	105	105	BRRI dhan74	147	95
BRRI dhan28	140	90	BRRI dhan81	143	100
BRRI dhan29	160	95	BRRI dhan84	141	96
BRRI dhan36	140	90	BRRI dhan86	140	95
BRRI dhan47	145	105	SL 8	149	109
BRRI dhan50	155	82	BRRI hybrid dhan3	145	110
BRRI dhan55	145	100	BRRI hybrid dhan5	145	110
BRRI dhan58	150	100	Tejgold	155	100
BRRI dhan61	150	96	Heera 2	145	100
BRRI dhan63	146	86	Heera 6	151	128
BRRI dhan64	152	110	Tia	128	115

Note: average growth duration and plant height of the varieties.

2.3. Crop Husbandry

Quality rice seeds of each variety were collected from several institutions, (1) Bangladesh Rice Research Institute (BRRI), (2) Bangladesh Institute of Nuclear Agriculture, (3) Bangabandhu Sheikh Mujibur Rahman Agricultural University, (4) Agronomy Department of Bangladesh Agricultural University, (5) Petrochem Agro Industries Limited, and (6) Bayer Crop Science Limited. The germinated seeds of each variety were sown in the wet nursery bed. Irrigation was gently supplied to the bed and when needed (only in the case of winter rice). Nursery bed soil was fertile enough to provide nutritional support to the rice seedlings for the short period. Although no chemical fertilizer was applied, nursery beds were supplied with organic manures during preparation to ease seedling uprooting.

Thirty-day old (monsoon-grown rice) and forty-five-day old (winter-grown rice) seedlings were transplanted in the puddled land on 15 July 2018 (monsoon-grown rice) and 24 January 2019 (winter-grown rice) at 25 cm × 15 cm spacing with 3 seedlings hill^{-1}. The experimental plots were fertilized with the BRRI recommended dose of fertilizer, i.e., 220, 120, 75, 60, and 10 kg ha^{-1} as urea (nitrogen, N), triple superphosphate (TSP), muriate of potash (MoP), gypsum, and zinc sulfate, respectively. All but urea fertilizers were applied as basal; whereas, urea was applied in three equal splits at 15, 30, and 45 days after transplanting (DAT). The monsoon-grown rice was rainfed; thus, no irrigation was provided. However, in the case of the winter-grown rice, flood irrigation was given to maintain a constant water level up to 6 cm in the early stages to boost tillering, and 10–12 cm in the later stage to prevent late tillering. Finally, the field was drained 15 days ahead of harvest. No remarkable insect or pathogen infestation was identified in either experiment; hence, no crop protection measures were taken for controlling insects and pathogens.

2.4. Data Recording

2.4.1. Weed Data

At 45 DAT, a quadrat (0.5 m × 0.5 m) was placed randomly in three different places of each season-long weedy plot for collecting weed samples. Weeds were clipped at ground level, identified, and counted by species, and dried in an oven at 70 °C until the weight became constant. Weed density and biomass were expressed as number per square meter and gram per square meter, respectively. The summed dominance ratio (SDR) was computed to identify the dominant weed species using the following equations [44]:

$$\text{SDR of a weed species} = \frac{\text{Relative density} + \text{Relative weed biomass}}{2} \tag{1}$$

where

$$\text{Relative density } (\%) = \frac{\text{Density of a given weed species}}{\text{Total weed density}} \times 100 \tag{2}$$

$$\text{Relative weed biomass } (\%) = \frac{\text{Biomass of a given weed species}}{\text{Total weed biomass}} \times 100 \tag{3}$$

The relative contribution of broadleaved, grasses, and sedges to the weed vegetation in terms of relative density and biomass were also calculated.

2.4.2. Crop Data

The whole plot was harvested manually when 90% of the seeds became golden yellow. The harvested crop was bundled separately as per treatment, properly tagged, and brought to the threshing floor. The crop was threshed by a pedal thresher. The grains were cleaned by winnower and sun-dried to 14% moisture content. The straw was also sun-dried. At the end, grain and straw yield plot^{-1} were recorded and converted to t ha^{-1}. The relative yield loss (%RYL) due to weed competition was also calculated as follows:

$$\text{RYL } (\%) = \frac{\text{Weed free yield} - \text{Season long weedy yield}}{\text{Weed free yield}} \times 100 \tag{4}$$

2.5. Weed Competitive Index

The weed competitive index (WCI) of the varieties was calculated to find the most weed competitive cultivar using the following formula [40]:

$$WCI = \left[\frac{\frac{GYw}{GYm}}{\frac{WBw}{WBm}}\right] \tag{5}$$

where GYw is the yield of the individual cultivar under weedy condition, GYm is the mean yield of all cultivars under weedy conditions, WBw is the weed biomass of individual cultivar under weedy condition, and *WBm* is the mean weed biomass of all cultivars under weedy condition.

2.6. Statistical Analysis

Collected data were checked for homogeneity and normality and then statistically analyzed using "R Statistics" software. Two season data were analyzed separately due to different growing seasons and variety. The grain yield data were analyzed using a two-way ANOVA (weeding regimes and varieties) and for weed data one-way ANOVA (varieties). SE was used to observe the data dispersion from the mean.

3. Results

3.1. Floristic Composition of Weeds

In monsoon season rice, seven weed species belonging to five different families were identified in weedy plots, and among them three were grasses, three were broadleaves, and one was sedge (Table 3). The most dominant weed species encountered in the monsoon grown rice field was *Echinochloa crus-galli* (SDR 29.97) and the least dominant one was *Marsilea quadrifolia* (4.93). Grass weeds contributed 77% of the total biomass and 47% of total density compared to broadleaves (20% and 40%, respectively) and sedge (3% and 13%, respectively) (Figures 2a and 3a).

Table 3. Predominant weed species and their relative density (RD), relative biomass (RB), and summed dominance ratio (SDR) in untreated weedy plots (average value) of the experimental field.

Sl. No.	Scientific Name	Family Name	Type	Relative Density (%)	Relative Biomass (%)	SDR
		Monsoon season				
1	*Echinochloa crus-galli* (L.) P. Beauv	Gramineae	Grass	10.53	49.42	29.97
2	*Digitaria sangunalis* L.	Gramineae	Grass	13.16	25.56	19.36
3	*Pistia stratiotes L.*	Araceae	Broadleaf	23.68	9.06	16.37
4	*Panicum repens* L.	Gramineae	Grass	23.68	1.88	12.78
5	*Monochoria vaginalis* (Burn. F.) C. Presl.	Pontederiaceae	Broadleaf	7.89	9.42	8.66
6	*Cyperus difformis* L.	Cyperaceae	Sedge	13.16	2.69	7.92
7	*Marsilea quadrifolia L.*	Marsileaceae	Broadleaf	7.89	1.97	4.93
		Winter season				
1	*Echinochloa crus-galli* (L.) P. Beauv	Gramineae	Grass	17.9	30.7	24.3
2	*Pistia stratiotes*	Araceae	Broadleaf	16.7	24.8	20.8
3	*Marsilea quadrifolia*	Marsileaceae	Broadleaf	19.2	16.9	18.1
4	*Digitaria ischaemum* L.	Gramineae	Grass	14.7	13.8	14.3
5	*Monochoria vaginalis* (Burn. F.) C. Presl.	Pontederiaceae	Broadleaf	10.3	12.2	11.2
6	*Panicum repens* L.	Gramineae	Grass	17.9	1.1	9.5
7	*Cyperus difformis* L.	Cyperaceae	Sedge	3.2	0.6	1.9

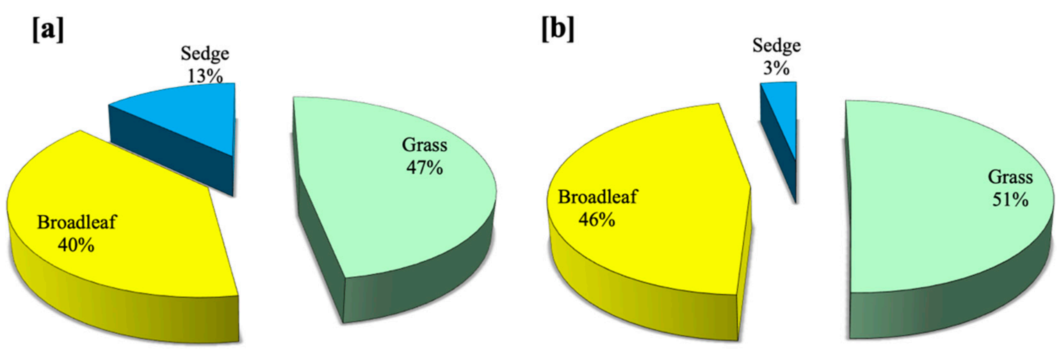

Figure 2. Relative weed density of different weed groups (grass, broadleaf, and sedge) in (**a**) monsoon and (**b**) winter seasons.

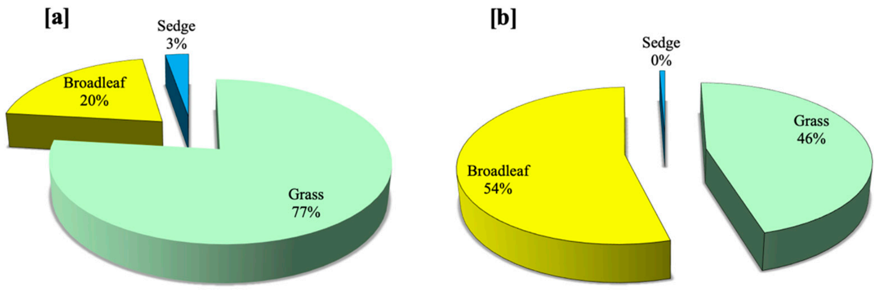

Figure 3. Relative weed biomass of different weed groups in (**a**) monsoon and (**b**) winter seasons.

Seven weed species observed in monsoon season rice were also found in weedy plots of winter grown rice (Table 3). However, their level of dominance in winter grown rice differed from monsoon grown rice. Weed species *Echinochloa crus-galli* (SDR 24.3) remained the most dominant in winter grown rice while *Cyperus difformis* (1.9) was the least dominant. In winter grown rice, broadleaf weeds contributed 54% of the total biomass and 46% of total density compared to grasses (46% and 51%, respectively) and sedge (0.6% and 3%, respectively) (Figures 2b and 3b).

3.2. Grain Yield and Relative Yield Loss

In both seasons, rice grain yield was significantly affected by the weeding regimes ($p < 0.0001$), rice varieties ($p < 0.0001$), and their interactions ($p = 0.004$ and $p = 0.02$, respectively, monsoon and winter season rice) (Table 4). In monsoon season rice, under weed-free condition, the highest grain yield was recorded from the hybrid variety Dhani Gold (6.3 t ha^{-1}), which was followed by hybrid variety Agrodhan-12 (6.0 t ha^{-1}) and inbred varieties BR10 (5.8 t ha^{-1}) and BRRI dhan72 (5.7 t ha^{-1}) (Figure 4). In the same condition, intermediate yield was recorded from the varieties BR11, BR22, BRRI dhan71, BRRI dhan79, and BRRI dhan80, and performed statistically at par to each other (Figure 4). In weed-free conditions the variety Bindhan-11 produced the lowest grain yield (3.0 t ha^{-1}) followed by BRRI dhan37 (3.5 t ha^{-1}) and BRRI dhan34, BU dhan 1, and Binashail.

Table 4. Analysis of variance results ($p < 0.05$) for different parameters measured in monsoon rice (2018) and winter rice (2018/19).

	Monsoon Rice						Winter Rice					
Source of Variance	**DF**	**GY**	**RYL**	**WD**	**WB**	**WCI**	**DF**	**GY**	**RYL**	**WD**	**WB**	**WCI**
Weeding Regimes (WR)	1	<0.0001					1	<0.0001				
Variety (V)	41	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	27	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
WR × V	41	0.004					27	00.02				

DF: degree of freedom, GY: rice grain yield, RYL: relative yield loss, WD: weed density, WB: weed biomass, WCI: weed competitive index.

Under the season-long weedy condition, the highest grain yield (4.03 t ha^{-1}) was found from hybrid Dhani Gold, followed by hybrid Agrodhan-12, and BRRI dhan31 followed by BR10, BR22, BRRI dhan33, BRRI dhan76, and BU dhan1 (Figure 4). The lowest grain yield (1.9 t ha^{-1}) was obtained from BRRI dhan38, followed by BRRI dhan78, BRRI dhan70, and Naizersail (Figure 4).

Considering the relative yield loss due to weed infestation, the monsoon rice varieties showed a wide diversity, which ranged from 15 to 61%. The relative yield loss was lowest in BU dhan1 (18%), which was followed by Binadhan-11 (21.2%), BRRI dhan31, and BRRI dhan57, which exhibited high weed tolerance. Variety BRRI dhan38 had the lowest tolerance to weeds with a yield penalty of 61%, closely followed by BRRI dhan38 (52.2%) and BRRI dhan78 (Figure 4).

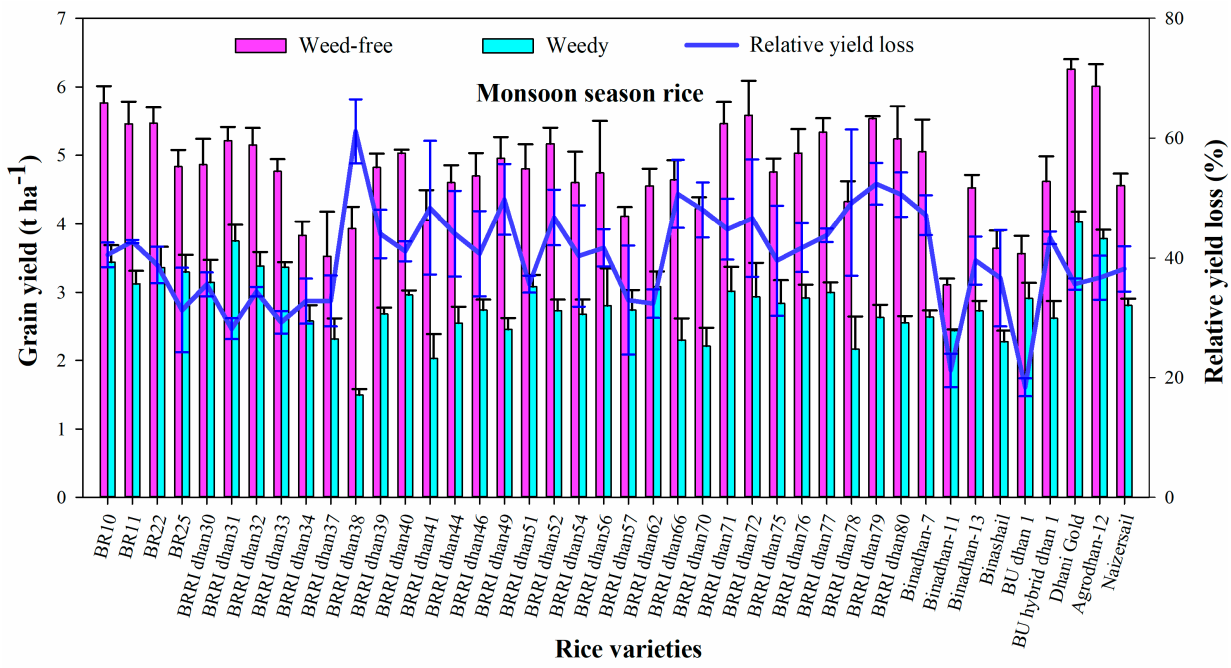

Figure 4. Grain yield (t ha^{-1}) and relative yield loss (%) of monsoon season rice varieties under season-long weed-free and weedy conditions. Vertical bars indicate the standard errors of the mean.

In winter rice, under weed-free conditions, the highest grain yield was observed from the rice variety hybrid Heera 6 (8.82 t ha^{-1}), followed by SL-8 (8.15 t ha^{-1}), BRRI hybrid dhan3, BRRI hybrid dhan5, and BRRI dhan29 (Figure 5). Intermediate grain yield was recorded from the varieties BR24, BRRI dhan58, BRRI dhan68, BRRI dhan69, BRRI dhan74, and hybrid Tej gold. The lowest grain yield was found in BRRI dhan36 (4.9 t ha^{-1}), followed by BRRI dhan50 (5.65 t ha^{-1}). Under season-long weedy condition, the highest grain yield (6.12 t ha^{-1}) was also found in hybrid Heera 6, followed by BRRI hybrid dhan5 (6.01 t ha^{-1}), BRRI hybrid dhan3 (5.65 t ha^{-1}), and hybrid SL-8 (5.18 t ha^{-1}) (Figure 5). The lowest grain yield (2.98 t ha^{-1}) was observed in BRRI dhan36, followed BRRI dhan61 (3.34 t ha^{-1}) and BRRI dhan50 (3.38 t ha^{-1}). Similar to the monsoon rice varieties, the winter rice varieties also showed wide diversity in terms of percent relative yield loss, which was ranged from 23.7 to 45.5% (Figure 5). The relative yield loss was lowest in BRRI hybrid dhan5 (23.7%) that was followed by BRRI dhan58 (27.7%) and BRRI dhan69 (27.9%), which exhibited considerably higher weed tolerance. On the other hand, BRRI dhan61 had the lowest tolerance to weeds with 45.5% yield penalty and that was closely followed by variety BR14 (Figure 5).

3.3. Weed Density and Biomass

The weed density and biomass differed significantly ($p < 0.0001$) among the rice varieties grown in both seasons (Table 4). In monsoon rice, weed density ranged from 50 to 255 (plant m^{-2}) (Figure 6). Not weed density, weed biomass is the actual parameter for weed competitiveness measurement, and in monsoon-season rice it varied from 106 to 245 (g m^{-2}) in season-long weedy plots at 45 DAT. The highest weed biomass was found in variety BRRI dhan70 (245 g m^{-2}), followed by BRRI dhan37 and BRRI dhan51, and the lowest one was recorded in Dhani Gold (106 g m^{-2}), followed by BU dhan 1, BRRI dhan41, and BRRI dhan78. In winter rice, weeds density and biomass ranged from 65 to 290 (plant m^{-2}) and 145 to 245 (g m^{-2}), respectively (Figure 7). Among the winter rice varieties, the highest weed biomass was recorded in BRRI dhan81 (245 g m^{-2}), followed by BRRI dhan45 (235 g m^{-2}), and the lowest one was recorded in BRRI dhan84 (145 g m^{-2}).

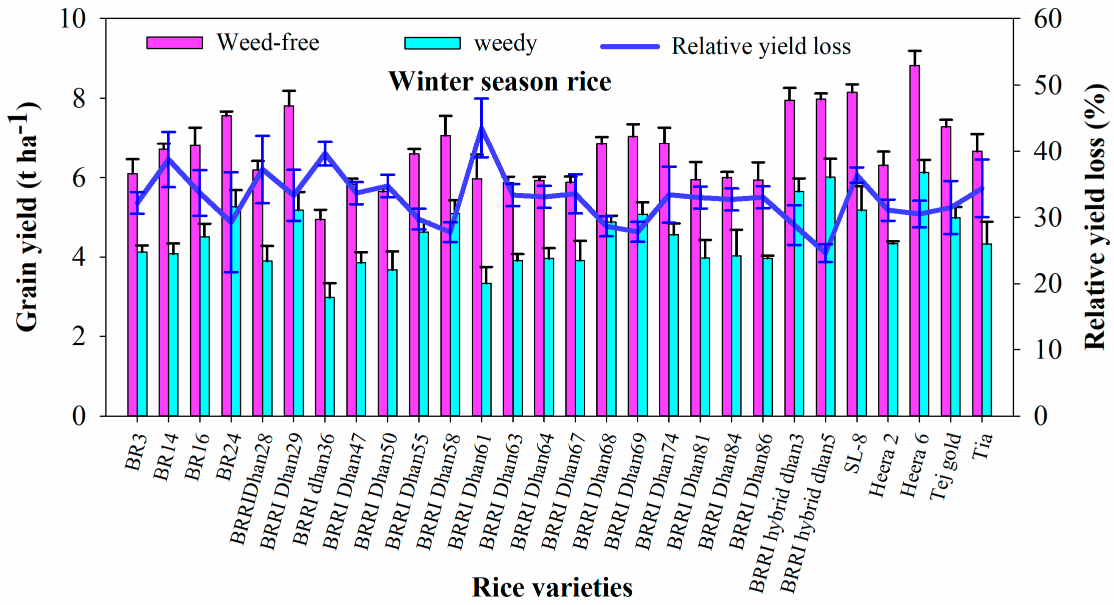

Figure 5. Grain yield (t ha^{-1}) and relative yield loss (%) of winter grown rice varieties under season-long weed-free and weedy conditions. Vertical bars indicate the standard errors of the mean.

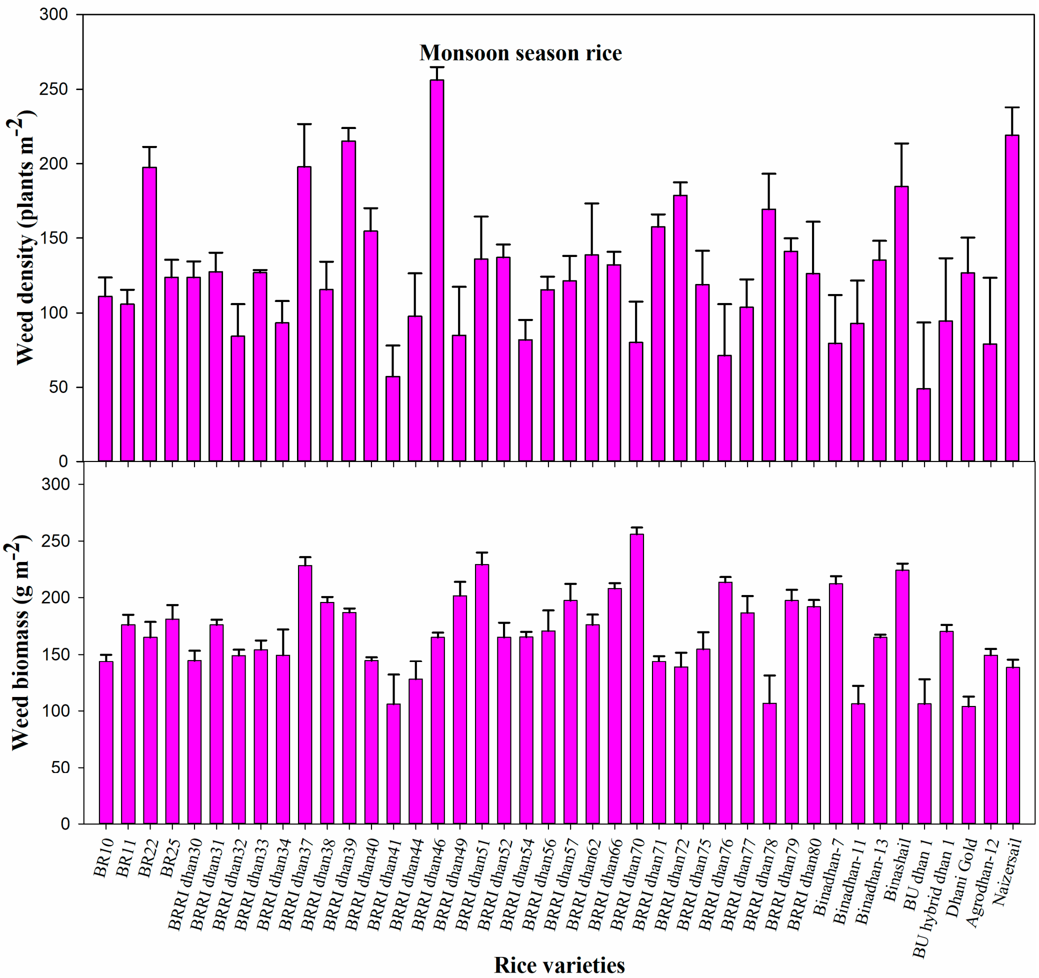

Figure 6. Weed density and biomass in monsoon season rice varieties in season-long weedy plots. Vertical bars indicate the standard errors of the mean.

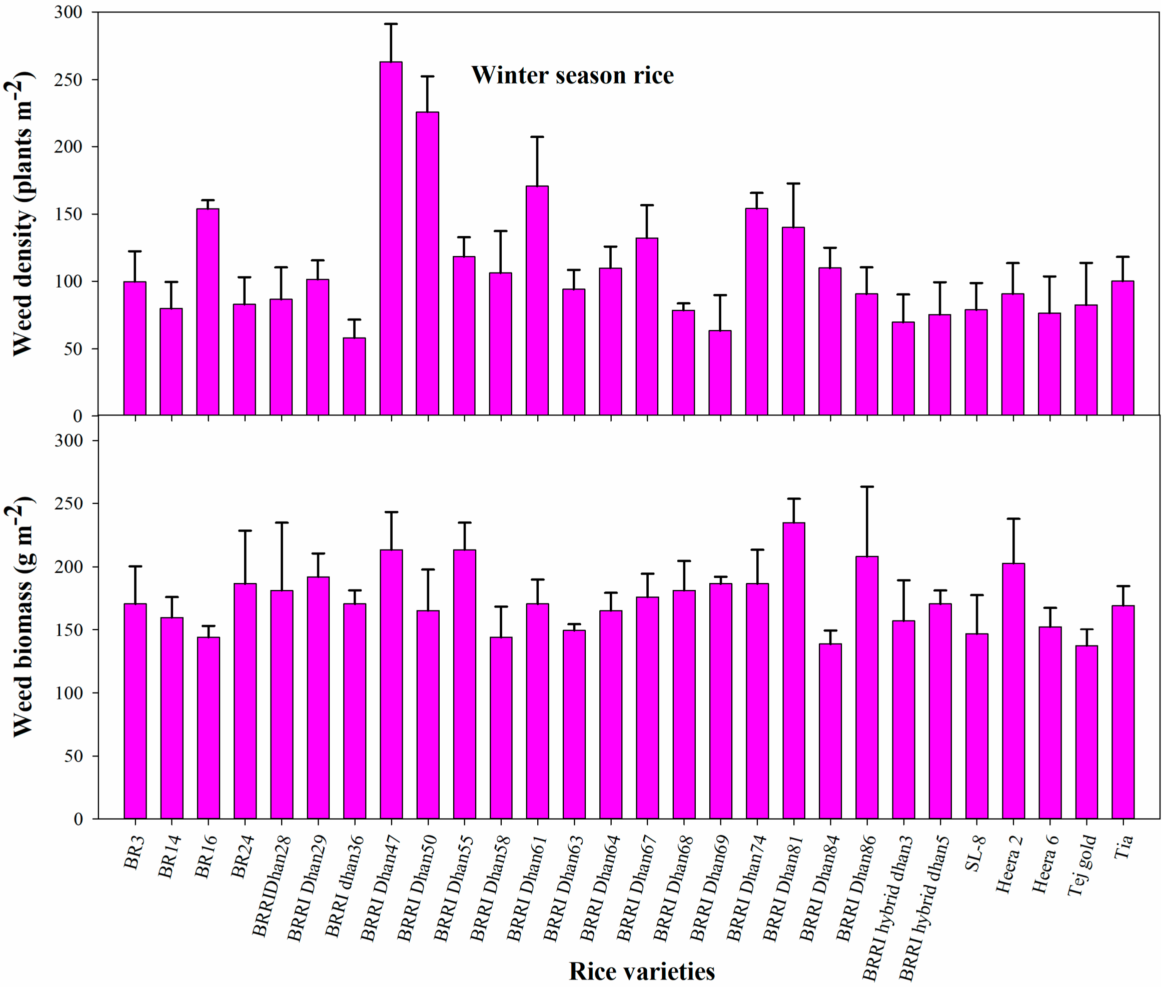

Figure 7. Weed density and biomass in winter season rice varieties in season-long weedy plots. Vertical bars indicate the standard errors of the mean.

3.4. Weed Competitive Index (WCI)

The WCI varied greatly among the varieties in both seasons (Table 4, Figures 8 and 9). In the monsoon season, WCI varied from 0.4 to 2.8 and the highest value was recorded from the hybrid variety Dhani Gold, followed by BU dhan 1, Hybrid Agrodhan-12, and BR10 (Figure 8). The intermediate WCI was found from the varieties BRRI dhan30, BRRI dhan32, BRRI dhan33, BRRI dhan41, BRRI dhan72, and Binadhan-11. The lowest WCI was found from the variety BRRI dhan38, followed by BRRI dhan70, BRRI dhan37, and Binashail.

In winter season rice, the WCI varied from 0.25 to 2.4 and the highest value was recorded from the variety BRRI hybrid dhan3, followed by hybrid variety Heera 6, BRRI dhan69, and BRRI hybrid dhan5 (Figure 9). The intermediate WCI was found from the varieties hybrid SL-8, BRRI dhan58, BR24, and Tejgold. The lowest WCI was recorded from the cultivar BRRI dhan50, followed by BRRI dhan47 and BR16.

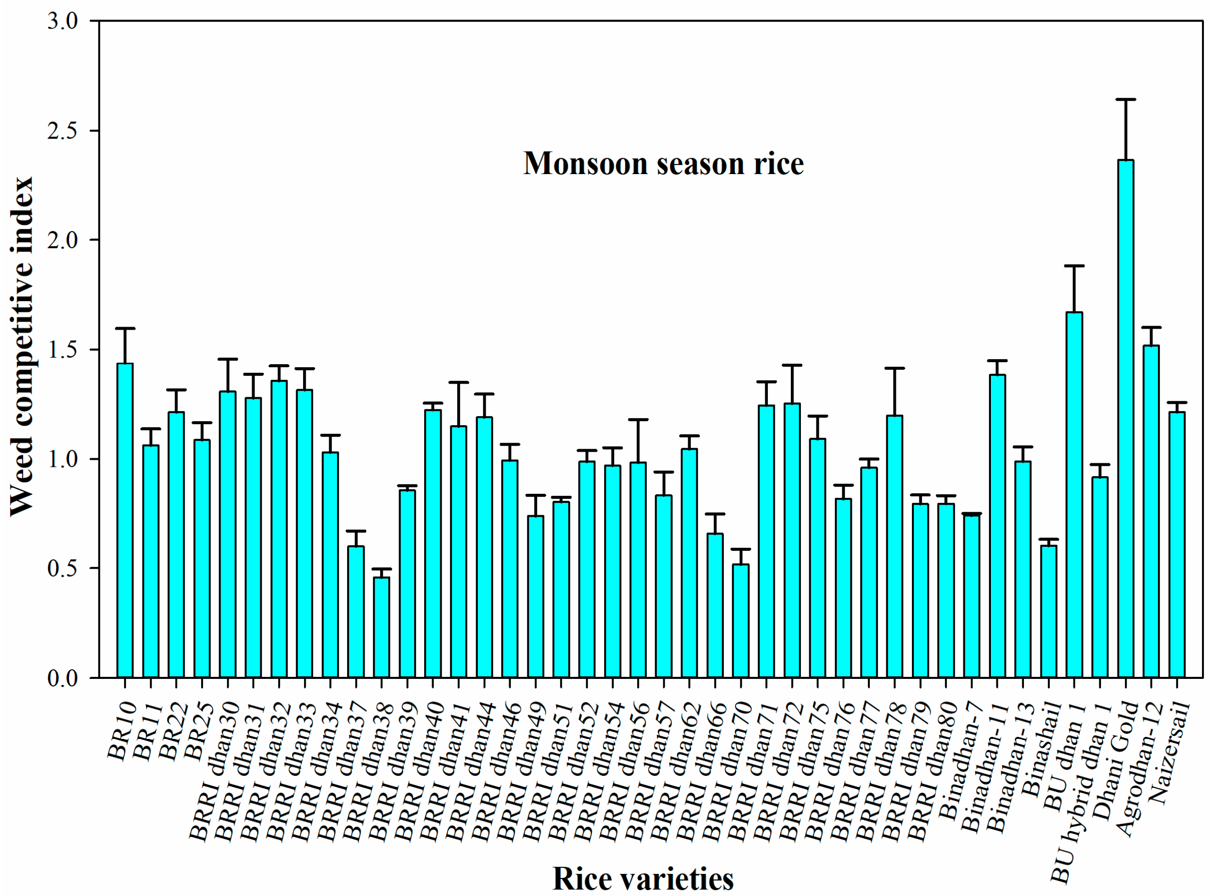

Figure 8. Weed competitive index of monsoon season grown varieties. Vertical bars indicate the standard errors of the'mean.

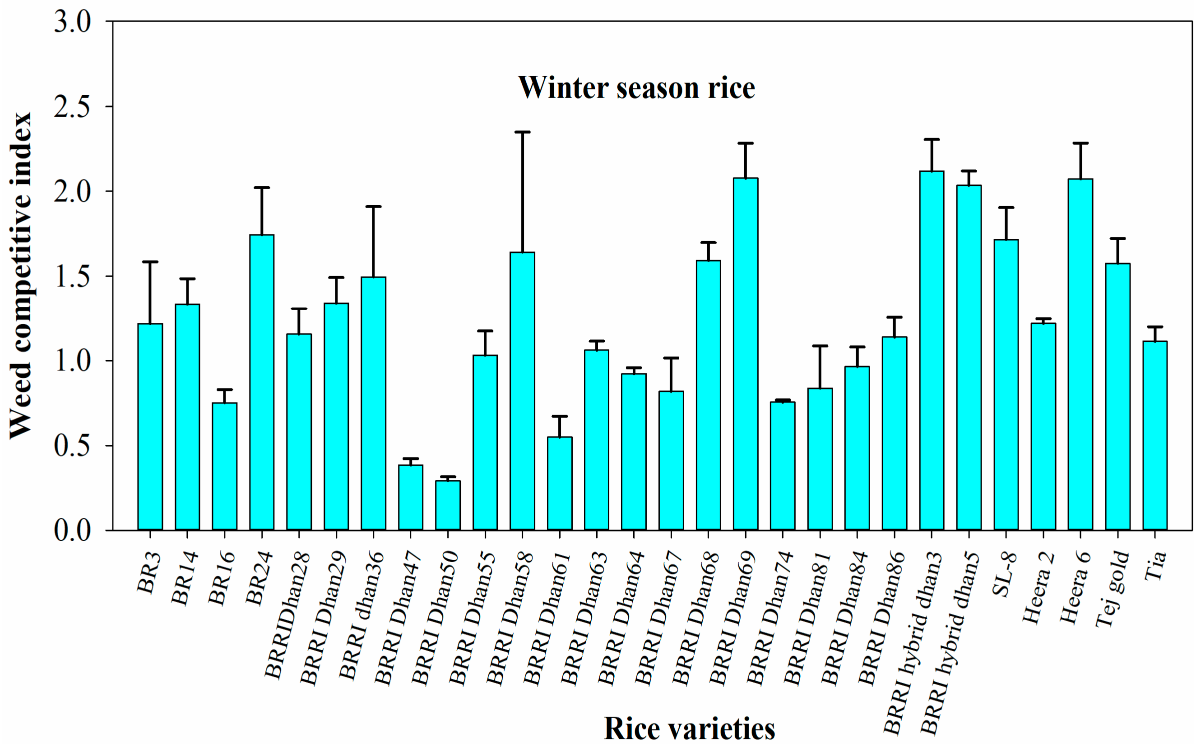

Figure 9. Weed competitive index of winter season grown varieties. Vertical bars indicate the standard errors of the mean.

4. Discussion

The WCI is the best parameter to measure the weed competitiveness of a variety [35]. In this study, we found a higher WCI value in hybrid varieties compared to the inbred, which indicates the higher weed competitiveness of hybrid varieties than inbred. Our results are supported by the previous study of Ahmed et al. [40] and Awan et al. [45]; they found that the hybrid cultivars had higher weed competitive ability than the inbred cultivars mainly due to higher early vigor, quick canopy coverage, higher tiller production, and higher biomass production. In general, varieties that produced higher yield in weed-free condition also had higher yield in weedy condition, resulting in a higher WCI; however, the relative yield loss did not maintain the same trends. For example, the varieties BU dhan 1 and Binadhan-11 in monsoon season produced low yield even in weed-free conditions, but RYL was low due to less yield reduction in weedy condition, indicating that these varieties have good weed competitive ability but less yield potential. Normally, the variety that gave lower relative yield loss had a higher degree of weed tolerance. Wide differences in weed competitiveness among rice varieties have already been reported [34,35,37–39,46,47]. The competitive ability of a variety not only depends on the varietal characteristics, it also depends on the types and abundance of weeds in the field.

In both seasons, the same number of weed species was found in the trial field and barnyard grass, *E. crus-galli*, was the most dominant weed. The possible reason for the same number of weed species is that both experiments were conducted in the same experimental fields. Although the weed species were the same in the both seasons, their dominance sequence varied and the variation was mainly due to the differences of seasonal weather and microenvironmental variation.

In both seasons, the highest grain yield was observed in season-long weed-free conditions compared to season-long weedy conditions, irrespective of varieties. It was due to the absence of crop–weed competition for resources in weed-free plots as also reported earlier in dry direct-seeded [35], modified aerobic system [37] of rice and wheat [36]. With few exceptions, hybrid rice varieties performed better than inbred or local varieties in terms of yield and weed suppression. Differential weed suppressive abilities of inbred and hybrid rice varieties were also reported by Chauhan et al. [48] and Dass et al. [42], who inferred that rice–weed competition remained stronger for weeds having similar morphological characteristics with rice plants. Similar to our findings regarding hybrid varieties, it was also established that droopy-plant-type rice varieties with long leaves exhibit a high early growth rate, faster canopy covering, and high tillering ability, and encounter less competition by weeds owing to offering less space to weeds to emerge and grow [34,38,39,46].

Among monsoon varieties, BU dhan 1 showed the lowest relative yield loss, which indicates its higher weed tolerance potential. Apart from these characteristics, BU dhan 1 is also drought resistant, and pest and pathogens tolerant. Dingkuhn et al. [49] suggested that competitive varieties need to be weed competitive and possess tolerance against other biotic and abiotic stresses, and that this research area must be explored further. However, the yield potential of BU dhan 1 was lower than many other monsoon rice varieties. It was reported that the strong weed suppressive ability of a low-yielding variety under weedy conditions could not always provide a guarantee of higher yield [34,35,37]. On the other hand, high-yielding varieties could not always have high weed suppressive ability, as in this study; high-yielding inbred varieties BRRI dhan61 and BRRI dhan71 suffered the highest relative yield loss.

The results showed that the average yield potential of winter rice varieties (6.0 t ha^{-1}) was higher than those of the monsoon varieties (4.8 t ha^{-1}). This is because of existing weather conditions (low temperature, clear sunshine, low humidity, etc.) that influence higher dry matter assimilation by the crop. The longer growth duration of the winter rice varieties, and less disease and insect infestation during the season also trigger higher grain yield. Moreover, the varietal characteristics (leaves are stiff and straight) and the longer life cycle of winter rice varieties help them to produce a higher yield than monsoon varieties.

None of the inbred varieties were found as strong weed suppressive combined with high yield potential, except hybrid rice varieties, Dhani Gold, Heera 6, and BRRI hybrid dhan3. However, the problem with hybrid rice seeds is that farmers always have to buy seeds from the seed companies. In addition, the seed price is very high to afford by the subsistence farmers. Hence, the development of weed competitive high-yielding inbred varieties for monsoon and winter seasons of Bangladesh warrant due attention.

Environmental factors such as water availability, temperature, humidity, and the incidence of pests greatly affect the performance of a particular crop plant/variety in a given environment. Crop weed competition is very common in nature and when crops are subjected to more competition in the community, the physiological characteristics of the growth and development of crops are usually changed. Procópio et al. [50] reported that in a community when the growth and development of a crop are changed due to competition, this result changes the differences in the use of environmental resources, especially the water, which directly affects the availability of CO_2 in leaf mesophyll and leaf temperature. Therefore, when plant breeders will have a target to develop weed competitive cultivar/s, they must be considered the ecophysiological aspects of crops and weed [51]. The ecology and physiology of crops and weeds also help in weed management decisions; e.g., *Echinochloa crus-galli*, a major rice weed, infests rice fields worldwide and is rarely found in shaded places. This species is capable of germinating even beneath 10 cm of water and can adapt to anaerobic environments [52].

5. Conclusions

Although the present study identified some promising weed competitive varieties of rice from both seasons, those are not feasible in terms of yield and profitability. Therefore, identification of morpho-physiological traits related to weed competitiveness and genetic characterization of the weed competitive inbred BU dhan 1 and hybrid Heera 6 are necessary to develop strong weed competitive, high yielding rice varieties to avoid the environmental impact of indiscriminate use of herbicide for weed control. This is the first report on the comparative weed competitiveness of Bangladeshi rice varieties, considering a huge genetic pool under puddle transplanted conditions. Since a highly competitive variety may not produce high yields, the rice breeder must consider those competitive varieties for breeding toward developing both high-yielding and weed-competitive rice varieties. As multiseason and/or multilocation trials with the same varieties were not conducted in this research, it is recommended to do these trials before drawing a final recommendation.

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