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Competitiveness of Winter Rice Varieties against Weed under Dry Direct Seeded Conditions

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Abstract

Aerobic rice or dry direct seeded rice is highly vulnerable to weeds because of lack of "head start" over weeds and standing water layer to suppress weeds. The risks of chemical control and the huge cost involvement in mechanical control demand an eco-friendly and cost-effective integrated weed management. Weed competitive rice cultivar may be considered as a viable tool for integrated weed management. In these circumstances, an experiment was designed to evaluate weed competitiveness of some selected winter rice varieties under aerobic soil conditions. The study was conducted during dry season (February to June) 2016 at the Agronomy Field Laboratory and Weed Management Laboratory, Bangladesh Agricultural University, Mymensingh. Fourteen rice varieties namely, BRRI dhan28, BRRI dhan29, BRRI dhan47, BRRI dhan50, BRRI dhan55, BRRI dhan58, BRRI dhan59, BRRI dhan67, Binadhan-5, Binadhan-6, Binadhan-8, Binadhan-10, BRRI hybrid dhan3 and Agrodhan-14 were grown under weedy and weed-free conditions. Plots with no rice were also maintained to observe the natural growth of weed in absence of rice. The experiment was conducted with split-plot design with three replications. Weeding regime was allocated in main plot and rice variety was allocated in sub-plot. Results showed that rice varieties varied widely in their yield performances and weed competitiveness. Among rice varieties, BRRI dhan59 allowed the minimum weed growth (19.2 g m^{-2}) while Binadhan-5 allowed the maximum weed growth (62.8 g m^{-2}). Grain yield ranged from 1.85 t ha^{-1} (BRRI dhan55) to 3.92 t ha^{-1} (Binadhan-5) under weed-free condition and between 0.41 t ha^{-1} (BRRI dhan55) and 2.06 t ha^{-1} (BRRI dhan59) under weedy condition. Weed inflicted relative yield loss ranged from 43.4% to 82.1% among the varieties. BRRI dhan59 allowed the least yield penalty (43.4%)

while Binadhan-5 had the maximum yield penalty (82.1%) due to weed competition. Although Binadhan-5 is the most productive variety (3.92 t ha^{-1}) for aerobic culture but its weed inflicted relative yield loss is higher (82.1%) than many other varieties with low yield potential. On the other hand, BRRI dhan59 appeared as the most weed competitive variety (only 43.4% relative yield loss) with productivity of 3.84 t ha^{-1}. Therefore, weed competitive variety should be considered as a vital tool while designing integrated weed management system for aerobic rice.

Keywords

Aerobic Rice, Rice-Weed Competition, Dryland Farming, Weed Pressure, Weed Management

1. Introduction

Rice (*Oryza sativa* L.) is the principal food for more than 50% people and contributes more than 60% and 25% to the cereals production of Asia and of the world, respectively, and it formulates nearly 30% of all the food being consumed in Asia [1]. Globally, rice crop occupies 158 million hectares of the arable land. The global production and productivity of rice is 744.9 million tons and 4.71 ton per hectare, respectively [2]. It is the major food item for billion residents of Asia and is the principal source of nutrition for many of the world's densely populated countries such as China and Bangladesh [3]. In fact, the approximate contribution of rice to the total calories being consumed is 30, 30, 50, 70, 60, 50, and 30% for China, India, Indonesia, Bangladesh, Vietnam, Philippines, and South Korea, respectively [1]. It is reported that, nearly a half of the world population consumes rice as their principal food. Alongside this, the labour force required to produce rice provides livelihood especially to those belonging to the underprivileged. The steady rise in population further underlines the importance of rice. World's rice demand is projected to increase by 50% from 1997 to 2050 to keep pace with population growth [4].

Compared to other field crops, rice is most widely grown under irrigated condition which accounts for about 50% of the total amount of water diverted for irrigation, which in itself accounts for 80% of the amount of fresh water diverted [5]. This is due to the high unproductive water losses by evaporation, surface run-off, and percolation. Producing one kilogram of unprocessed rice grain under irrigation is estimated to use between 1500 and 5000 L of water, depending on the local climate, soil type and rice variety [6]. This amount is about twice or even more than wheat or maize [7] [8]. However, declining water availability threatens the sustainability of traditional flood-irrigated rice ecosystems [9]. In Asia, it is predicted that 17 million hectares of irrigated rice areas may have "physical water scarcity" and 22 million hectares areas may be subject to "economic water scarcity" by 2025 [10]. In Asia, where about 60% of the world's

population lives, food security is challenged by increasing food demand and threatened by declining water availability [7]. It is, therefore, no longer feasible to flood rice fields for better crop establishment and weed control [11]. Among different water-saving approaches, aerobic rice cultivation has come up with a huge success in different parts of the world.

Growing rice in non-saturated and non-puddled aerobic soil is a promising water-wise technique of rice cultivation under the context of ever-mounting water scarcity [3] [12]. Growing rice under aerobic conditions requires 36% - 41% less water than under the conventional method [13]. In response to the labour and water shortage problem, some alternative rice production methods were suggested by researchers worldwide including alternate wetting and drying [14] [15], system of rice intensification [16] [17] [18] [19], and raised bed for saturated soil culture [20] [21]. Compared with flooded rice, aerobic rice had lower production cost, higher water productivity, and a comparable outcome [22] [23].

Weeds are a major yield limiting factor in rice production [24], and the literature reporting yield losses is numerous. Globally, actual rice yield losses due to pests have been estimated at 40%, of which weeds have the highest loss potential (32%). The worldwide estimated rice yield loss due to weeds is around 10% of the total production [25]. Yield reduction due to weeds is more critical in direct seeded rice than in transplanted rice [26] [27]. In dry seeded aerobic rice, relative yield loss caused by weeds is 50% - 91% [28], while in transplanted rice, yield loss has been estimated to be only 13% [29]. Among the rice ecosystems, yield losses are the highest in aerobic rice [30]. In extreme cases, weed infestation may cause complete failure of aerobic rice [31]. Weeds persist by adapting to cultural practices, and every cultural practice influences the competitive ability of both the crop and weed resulting complex interactions [32]. Cultural approaches play significant role to determine the competitiveness of a crop with weeds for above ground and below ground resources and hence might influence weed management [3] [33] [34] [35] [36]. Integrated weed management strategies offer several options, but risks of developing resistant weed biotypes [37], and environmental hazard resulting from herbicides from chemical control [38] [39] [40] [41], and labor-intensive manual weeding methods [42] demand an eco-friendly and less labor-dependent weed management system for sustainable aerobic rice production.

As observed by many researchers, the performance of herbicides can be enhanced if crop varieties with higher weed competitiveness are used especially in herbicide-dominant systems [27]. Weed competitiveness comprises two components: weed suppressive ability—the ability to lessen weed growth through competition, and weed tolerance—the capability of maintaining potential yields in the presence of weeds [43]. The potentiality of using weed competitive variety in integrated weed management has been documented in many crops including rice [44]-[49]. The deployment of weed competitive variety is not only eco-friendly [50] [51] but also a very cost effective [52] tool for integrated weed

management. Considering the high vulnerability of aerobic rice to weeds, development of weed competitive aerobic rice variety has been suggested by many researchers [9] [48] [53].

No work has so far been done to assess the ability of the huge pool of Bangladeshi rice germplasms to wrestle weeds under aerobic soil conditions. In this backdrop, the present study was undertaken to study the variation in weed competitiveness among selected high yielding rice varieties and to recognize agronomic traits conferring weed competitiveness of rice grown under aerobic soil conditions.

2. Materials and Methods

2.1. Description of the Experimental Site

The experiment was carried out at the Agronomy Field Laboratory and Weed Management Laboratory, Department of Agronomy, Bangladesh Agricultural University, Mymensingh during the period from February to June 2016. Geographically the experimental area is located at 24˚75'N latitude and 90˚50'E longitudes at the elevation of 18 m above the sea level. The experimental field was medium high land belonging to the Sonatola Soil Series of Grey Floodplain soil under the agro-ecological zone of Old Brahmaputra Floodplain (AEZ-9). The region occupies the large area of Brahmaputra sediments which were laid down before the river shifted into its present Jamuna Channel about 200 years ago [54] [55]. The soil of the experimental field was more or less neutral in reaction with pH value 6.8, low in organic matter content (1.96%) and bulk density (1.35 g cm^{-3}). The land type was medium high with silty-loam in texture (20% sand, 67% silt and 13% clay). Soil contained 0.11% total N, 50.40 ppm available P, 7.36 ppm available S, 0.16 me% exchangeable K.

During the growing season (February-June, 2016), monthly average maximum temperature, minimum temperature and relative humidity were 27.8˚C - 33.6˚C, 17.4˚C - 26.3˚C and 73.2% - 84.4%, respectively, while monthly total rainfall and sunshine hours were 0.3 - 13.0 mm and 140.1 - 171.3 h, respectively.

2.2. Experimental Treatments

This was a two factorial experiment, where factor A comprised two weeding regime *viz*., a) weed free and b) weedy condition. On the other hand, factor B consisted of 14 high yielding rice varieties e.g., i) BRRI dhan28, ii) BRRI dhan29, iii) BRRI dhan47, iv) BRRI dhan50, v) BRRIdhan55, vi) BRRI dhan58, vii) BRRI dhan59, viii) BRRI dhan67, ix) Binadhan-5, x) Binadhan-6, xi) Binadhan-8, xii) Binadhan-10, xiii) BRRI hybrid dhan3 and xiv) Agrodhan-14. A brief description of these varieties is given in **Table 1**.

2.3. Experimental Design

The experiment was laid out in split-plot design with three replications. Weeding regime was allocated in main plot and rice variety was allocated in sub-plot.

Table 1. Brief description of the rice varieties used in the experiment.

Varieties	Released year	Plant height (cm)	Life duration (days)	Average yield (t ha^{-1})	Special features
BRRI dhan28	1994	90	140	6.00	Early maturing, less water requiring
BRRI dhan29	1994	95	160	7.50	High yield potential
BRRI dhan47	2007	105	152	6.00	Salt tolerant
BRRI dhan50	2008	82	155	6.00	Premium quality rice, slightly aromatic
BRRI dhan55	2011	100	145	7.00	Salt and drought tolerant
BRRI dhan58	2012	100	155	7.20	Five day earlier than BRRI dhan29
BRRI dhan59	2013	83	153	7.10	Tolerant to lodging
BRRI dhan67	2014	100	143	6.00	Salt tolerant
Binadhan-5	1998	110 - 115	150 - 155	7.00	Tolerant to lodging
Binadhan-6	1998	110 - 115	160 - 165	7.50	Bears more tillers
Binadhan-8	2010	-	130 - 135	8.00	Salt tolerant
Binadhan-10	2012	-	127 - 132	8.00	Salt tolerant
BRRI hybrid dhan3	2009	110	145	9.00	Early maturing
Agrodhan-14 (Hybrid), Pioneer 27P31	-	100 - 110	140 - 145	8.5 - 9.00	Tolerant to lodging and seed shattering

Source: BRRI [56] and BINA [57].

The unit plot size was 2.5 m × 2.0 m. The distance maintained between blocks was 1.0 m and unit plots were 0.5 m, respectively. Moreover, three plots were left for weed monoculture, where no rice was grown. Thus, a total of 87 unit plots were maintained.

2.4. Crop Husbandry

Seed collection

Seeds of BRRI dhan28, BRRI dhan29, BRRI dhan47, BRRI dhan50, BRRI dhan55, BRRI dhan58, BRRI dhan59, BRRI dhan67 and BRRI hybrid dhan3 were collected from Bangladesh Rice Research Institute (BRRI), seeds of Agrodhan-14 were collected from Petrochem Agro-industries Ltd. and Binadhan-5, Binadhan-6, Binadhan-8 and Binadhan-10 were collected from Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh.

Land preparation

The land was first opened with a power tiller and subsequently leveled by laddering. Weeds and stubbles of the previous crop were collected and removed from the field. Before sowing, the field was prepared by plowing and harrowing to obtain a smooth seedbed.

Manure and fertilizer application

The land was fertilized with cowdung, urea, triple super phosphate, muriate of potash, gypsum and zinc sulphate at 10000, 220, 120, 75, 60 and 10 kg ha^{-1} re-

spectively. The whole amount of cowdung, triple super phosphate, muriate of potash, gypsum and zinc sulphate were applied at the time of final land preparation. Urea was applied in three equal splits at 30, 50 and 70 days after sowing (DAS).

Seed sowing and irrigation

Sowing was done on 3 February 2016. Before sowing seeds were soaked in water for 24 h and then were kept in a warm place for 48 h at 25˚C ± 5˚C temperature for seed incubation. Sprouted seeds were then sown in field following 25 cm × 15 cm spacing with 5 - 6 seeds hill^{-1}. To maintain soils at field capacity throughout the growing period three surface irrigations were provided.

2.5. Data Collection

A quadrate of size 0.5 m × 0.5 m was placed randomly in two places of each weedy plots for collecting weed samples. Weed were clipped at ground level, identified and counted by species, and separately oven dried at 70 ˚C to constant weight. Weed density (WD) and weed dry weight (WDW) were expressed as no. m^{-2} and g m^{-2}, respectively. Relative contribution of different weed groups (broad-leaved, grasses and sedges) to the weed vegetation in terms of relative density (RD) and relative dry weight (RDW) were also calculated. Dominant weed species were identified using the summed dominance ratio (SDR) computed as follows [58]:

$$\mathrm{RD}(\%) = \frac{\text{Density of a given weed species}}{\text{Total density of weed}} \times 100 \quad \text{(i)}$$

$$\mathrm{RDW}(\%) = \frac{\text{Dry weight of a given weed species}}{\text{Total weed dry weight}} \times 100 \quad \text{(ii)}$$

$$SDR = \frac{RD + RDW}{2} \quad \text{(iii)}$$

In weedy treatments, weed growth was visually rated weed rating (WR) at 9 weeks after sowing (WAS) on a 1 to 9 scale, with 1 for minimum weed growth and 9 for maximum. Days to flowering (DF) and maturity (DM) of the rice varieties were recorded when 50% plants in a field started to flower and more than 80% grains turned golden yellow colour, respectively. The early visual vigour (EVV) of the varieties was measured at 3 WAS. The relative chlorophyll content or greenness of rice leaves was measured at 45 DAS (SPAD 45) using a portable SPAD meter. Data was recorded from the youngest fully expanded leaf or flag leaf of 5 plants in each treatment. The rice plant height at different stages *i.e.* 15, 30, 45, 60, 75 DAS and harvesting time were measured from ground level to tip of the uppermost leaf/panicle. The average height of five hills was considered as the height to the plant for each plot and expressed in cm.

The crop was harvested at full maturity *i.e.* when about 80% of the seeds became golden yellow in color. Five hills (excluding border hills) were randomly selected in each plot and uprooted before harvesting to record data on yield

contributing characters e.g., effective tillers hill^{-1}, grains panicle^{-1} and 1000-grain weight. The harvested crop of each plot was separately bundled, properly tagged and then brought to the threshing floor. The crop was threshed by pedal thresher. Grains were sun dried and cleaned. Straws were also sun dried properly. Finally, grain and straw yields were converted to ton per hectare. The biological yield (t ha^{-1}), harvest index (%) and relative yield loss (RYL) (%) were then calculated from the grain and straw yield using the following equation:

$$\text{Biological yield} = \text{Grain yield} + \text{Straw yield} \quad \text{(iv)}$$

$$\text{Harvest index}(\%) = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100 \quad \text{(v)}$$

$$\text{RYL}(\%) = \frac{\text{Weed free yield} - \text{Treatment yield}}{\text{Weed free yield}} \times 100 \quad \text{(vi)}$$

2.6. Statistical Analysis

The collected data were compiled and tabulated in proper form and were subjected to statistical analysis. Data were analyzed using the analysis of variance (ANOVA) technique with the help of computer package program MSTAT-C and mean differences were adjudged by Duncan's Multiple Range Test [59].

3. Results

3.1. Floristic Composition of Weeds

Twenty-four weed species belonging to thirteen different families were observed in weedy plots, among which fifteen were broadleaves, seven grasses and two sedges (Table 2). Based on summed dominance ratio (SDR), the five most dominant weed species encountered were *Panicum disticum*, *Alternanthera sessilis*, *Spilanthes acmella*, *Paspalum commersonii* and *Echinochloa crusgalli*. Broadleaf weeds contributed 63% of the total dry matter and 44% of total density compared to grasses (34% and 54%, respectively) and sedges (3% and 2%, respectively) (Figure 1 and Figure 2).

3.2. Weed Pressure and Density

Visual weed rating, weed dry matter and weed density varied significantly among rice varieties (Figure 3 and Figure 4). Maximum weed growth was observed in weed monoculture. In terms of weed rating BRRI dhan59, BRRI dhan67 and Binadhan-10 appeared as the most weeds suppressive since weed ratings against these variety were low (<4) (Table 3). Weed growth was rated between 4 and 5 for BRRI dhan50, BRRI dhan58, BRRI hybrid dhan3, Binadhan-6 and Agrodhan-14, and between 5 and 6 for BRRI dhan28, BRRI dhan29 and BRRI dhan47 indicating moderate weed suppressive (Table 3). Weed rating (6 - 7) in BRRI dhan55 and Binadhan-8 and highest weed rating > 7 in Binadhan-5 signify poor competitiveness against weeds. Weed dry matter followed almost similar trend as visual weed rating. Mean weed pressure across variety was 37.83

g m^{-2} against 92.32 g m^{-2} recorded in weed monoculture, which denotes that on average, rice variety reduced weed pressure by about 59%. BRRI dhan59 emerged as the most weed suppressive variety reducing weed pressure by 79% followed by BRRI dhan67 (77%) and Binadhan-10 (75%) (Figure 3 and Figure 4). Highest weed pressure of 62.8 g m^{-2} was found in Binadhan-5 which was 32% less than in weed monoculture. Other varieties were intermediate in suppressing weeds within the range of 41 to 79%. Maximum weed density of 197 m^{-2} was recorded in weed monoculture. The rice variety did not significantly differ with respect to weed density, which was within a narrow range from 69 to 114 m^{-2} (Figure 4). The average weed density across variety was 94 m^{-2} which was 52% less compared to the weed monoculture.

Table 2. Dominant weed species with family name, type, relative density (RD), relative dry weight (RDW) and summed dominance ratio (SDR) (averaged over all weedy plots).

Common name	Scientific name	Family name	Weed type	RD (%)	RDW (%)	SDR (%)
Angta	*Panicum disticum*	Gramineae	Grass	20.97	8.25	14.61
Chanchi	*Alternanthera sessilis*	Amaranthaceae	Broad leaf	15.56	12.13	13.84
Halud nakful	*Spilanthes acmella*	Compositeae	Broad leaf	9.47	4.59	8.03
Gaicha	*Paspalum commersonii*	Gramineae	Grass	8.79	6.93	7.86
Shama	*Echinochloa crusgalli*	Gramineae	Grass	4.06	12.75	7.40
Durba	*Cynodon dactylon*	Gramineae	Grass	8.12	4.32	6.22
Foska begun	*Physalis minima*	Solanaceae	Broad leaf	2.03	10.05	5.35
Lazzabati	*Mimosa pudica*	Leguminaceae	Broad leaf	1.32	7.63	4.48
Anguli ghas	*Digitaria sanguinalis*	Gramineae	Grass	6.76	1.56	4.16
Tit begun	*Solanum torvum*	Solanaceae	Broad leaf	4.38	4.59	3.99
Khude shama	*Echinochloa colonum*	Gramineae	Grass	4.73	4.77	3.75
Pani marich	*Polygonum orientale*	Polygonaceae	Broad leaf	3.38	3.24	3.31
Bon pat	*Melochia corchorifolia*	Malvaceae	Broad leaf	1.67	5.55	3.11
Hazar dana	*Phyllanthus niruri*	Euphorbiaceae	Broad leaf	2.03	1.21	2.62
Biskatali	*Polygonum hydropiper*	Polygonaceae	Broad leaf	0.67	3.82	2.24
Bon tamak	*Nicotiana plumbaginifolia*	Solanaceae	Broad leaf	1.04	2.19	2.19
Bon tula	*Sanchu arvensis*	Asteraceae	Broad leaf	0.67	1.51	1.59
Keshuti	*Eclipta alba*	Compositae	Broad leaf	2.03	0.69	1.36
Bathua	*Chenopodium album*	Chenopodiaceae	Broad leaf	0.67	1.04	0.85
Shial leja	*Dysophylla crassicaulis*	Lamiaceae	Broad leaf	0.67	0.95	0.81
Kanai bashi	*Commelina bengalensis*	Commelinaceae	Broad leaf	0.67	0.61	0.64
Mutha	*Cyperus rotundus*	Cyperaceae	Sedge	0.67	1.10	0.64
Guccha mutha	*Cyperus nemoralis*	Cyperaceae	Sedge	0.67	0.26	0.46
Arail	*Leersia hexandra*	Gramineae	Grass	0.67	0.26	0.46

Here, RD = Relative density, RDW = Relative dry weight, SDR = Summed dominance ratio

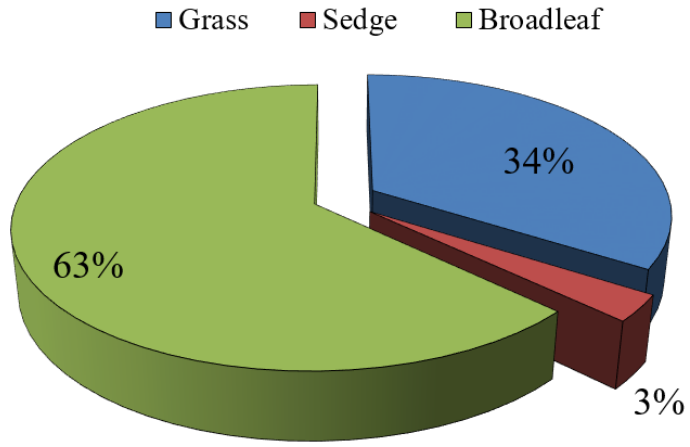

Figure 1. Relative dry weight of different weed groups.

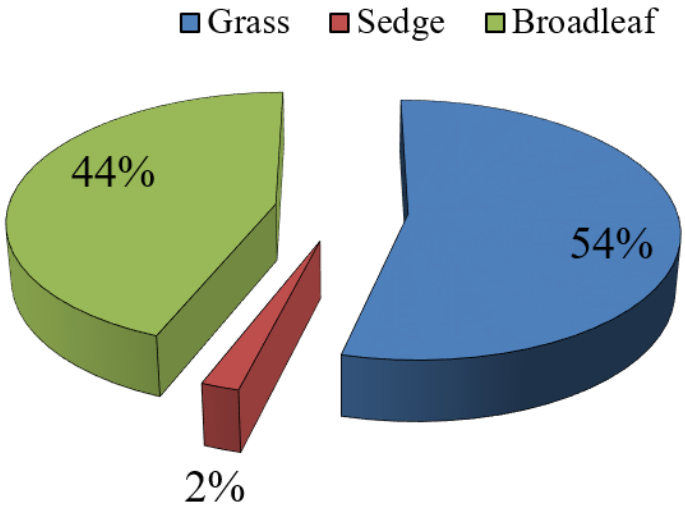

Figure 2. Relative density of different weed groups.

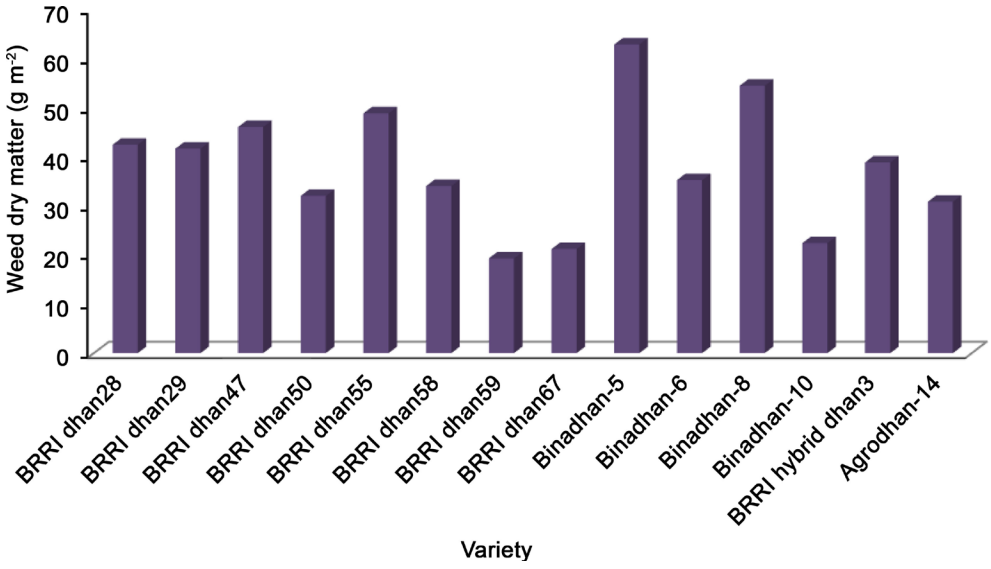

Figure 3. Effect of variety on weed dry weight (g m^{-2}) of winter rice under aerobic system of cultivation.

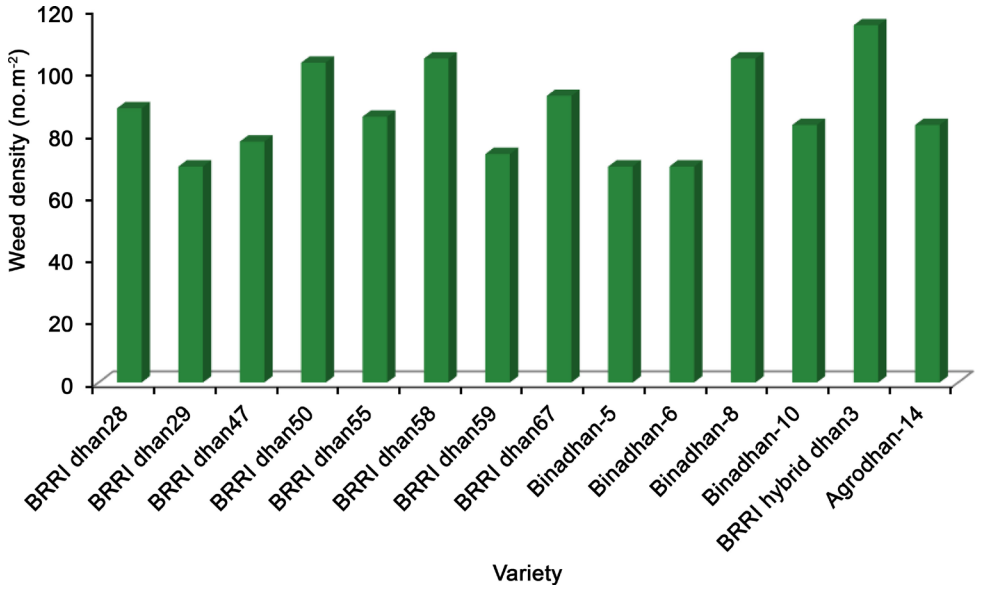

Figure 4. Effect of variety on weed density of winter rice under aerobic system of cultivation.

Table 3. Effect of variety and weeding regime on relative chlorophyll content, early visual vigor and weed rating of winter rice under aerobic system of cultivation.

Variety	Chlorophyll content (SPAD value)	EVV at 3 WAS	Weed rating at 9 WAS
BRRI dhan28	37.87	6.00de	5.00de
BRRI dhan29	34.46	6.00de	5.00de
BRRI dhan47	35.11	5.33ef	5.33d
BRRI dhan50	34.15	7.17abc	4.00g
BRRI dhan55	38.50	4.67f	6.00c
BRRI dhan58	35.61	7.00a-d	4.33fg
BRRI dhan59	35.90	8.00a	3.33h
BRRI dhan67	32.21	7.83ab	3.33h
Binadhan-5	35.96	3.50g	7.33a
Binadhan-6	34.63	6.83bcd	4.33fg
Binadhan-8	32.68	4.33fg	6.67b
Binadhan-10	36.13	7.50ab	3.33h
BRRI hybrid dhan3	34.48	6.17cde	4.67b
Agrodhan-14	33.71	7.17abc	4.00g
CV%	9.67	8.48	14.21
Level of significance	NS	**	**
Weeding Regime			
Weed free	39.22a	6.50a	-
Weedy	30.98b	6.00b	-
CV%	1.05	5.24	-
Level of significance	**	*	-

In a column figures with same letter or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT). * = Significant at 5% level of probability, ** = Significant at 1% level of probability, NS = Not significant, WAS = Weeks after sowing.

3.3. Relative Chlorophyll Content (SPAD Value)

Relative chlorophyll content was not significantly influenced by variety (Table 3). Numerically, the highest chlorophyll content was observed in BRRI dhan55 (38.5) and the lowest chlorophyll content was observed in BRRI dhan67 (32.22). Higher SPAD values indicate greener and healthier plants. Relative chlorophyll content was significantly affected by weeding regimes (Table 3). In weed free condition higher chlorophyll value was found (39.22) and in weedy treatment lower chlorophyll content (30.98) was found. Weed competition was severe in weedy condition and thus lowest chlorophyll was produced. On the other hand, in weed free treatment throughout the crop growth period, higher chlorophyll value was produced (Table 3). SPAD value was higher in weed-free condition than in weedy condition. SPAD values were greatly reduced by weed interference and this was reflected in yield performance.

3.4. Early Visual Vigor

Early visual vigor was significantly influenced by variety (Table 3). In the present study, early vigor varied widely among varieties. Early visual vigor ranged from 3.5 to 8.0. The highest early visual vigor was observed in BRRI dhan59 (8.0) and the lowest was observed in Binadhan-5 (3.5). Early visual vigor was significantly affected by weeding regimes (Table 3). Higher early visual vigor (6.5) was found in weed free treatment and lower in weedy treatment (6.0).

3.5. Rice Phenology

The varieties from diverse genetic sources and origins demonstrated a broad range in phonological parameters (Table 4). Growth duration of the varieties in this study ranged from 117 to 143 days. Average flowering period was 109 days in weed free and 107 days in weedy condition. Average growth duration was 134 and 132 days in weed free and weedy condition, respectively. BRRI dhan28 and BRRI dhan55 took less than 100 days for flowering and near about 120 days for maturing in both conditions. BRRI dhan67, BRRI dhan47 and BRRI dhan58 commenced flowering between 100 and 105 DAS and consequently matured by 125-130 days in weed free condition and matured 2-3 days early in weedy condition. BRRI dhan29 required the longest duration of more than 115 days to initiate flowering and matured after 140 days.

3.6. Plant Height

The variety and weeding regime exhibited significant differences in plant height at most of the sampling dates, however, their interaction had no significant effect (Table 5 and Table 6). At 15 DAS plant height ranged from 7.65 to 11.55 cm. Here, highest plant height at 15 DAS was produced by BRRI dhan59, followed by Binadhan-10 and the lowest plant height was obtained from Binadhan-5 followed by Binadhan-8. At 30 DAS, plant height ranged from 13.05 to 18.55 cm.

Table 4. Means for varieties over weeding regimes and for weeding regimes over varieties for days required to flowering and maturity of rice.

Variety	Days to 50% flowering		Days to maturity	
	Weed free	Weedy	Weed free	Weedy
BRRI dhan28	92	90	117	115
BRRI dhan29	118	115	143	140
BRRI dhan47	105	103	130	127
BRRI dhan50	112	111	138	136
BRRI dhan55	97	95	122	120
BRRI dhan58	105	103	130	128
BRRI dhan59	113	110	138	136
BRRI dhan67	100	98	126	125
Binadhan-5	115	113	141	138
Binadhan-6	116	114	141	139
Binadhan-8	113	110	138	135
Binadhan-10	112	110	138	136
BRRI hybrid dhan3	115	113	140	137
Agrodhan-14	116	115	141	138
Average	109	107	134	132

Table 5. Effect of variety and weeding regime on plant height of winter rice under aerobic system of cultivation.

Variety	Plant height (cm)					
	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	Harvest
BRRI dhan28	8.85efg	15.77bc	30.25	56.87ab	63.53c	80.93def
BRRI dhan29	9.15def	16.60b	33.00	62.40a	66.13abc	82.00cde
BRRI dhan47	8.60efg	13.25d	31.35	61.47a	67.58abc	82.67c
BRRI dhan50	10.65a-d	16.60b	29.93	58.00ab	61.57c	74.40f
BRRI dhan55	7.65fgh	13.25d	32.52	63.60a	68.60abc	81.77c
BRRI dhan58	9.05d-g	17.45ab	30.82	60.80a	64.60bc	77.50f
BRRI dhan59	11.55a	18.55a	31.52	57.52ab	65.00bc	80.13def
BRRI dhan67	10.80abc	17.70ab	31.62	64..97a	72.63ab	84.03b-e
Binadhan-5	6.80h	13.05d	32.22	60.43a	70.00abc	88.23abc
Binadhan-6	9.20c-f	17.00ab	33.15	64.00a	73.63ab	90.27ab
Binadhan-8	7.45gh	14.55cd	30.15	61.30a	69.87abc	82.97cde
Binadhan-10	10.90ab	17.10ab	32.15	58.87a	64.83bc	79.23def
BRRI hybrid dhan3	8.70efg	14.05cd	32.52	61.93a	74.53a	84.53bcd
Agrodhan-14	9.70b-e	15.95bc	32.70	62.70a	75.10a	91.97a
CV%	8.69	6.05	9.15	6.95	6.56	4.18
Level of significance	**	**	NS	*	**	**
Weeding Regime						
Weed free	9.35	17.24a	34.19a	61.69a	69.06a	87.42a
Weedy	9.09	14.32b	29.22b	59.72b	66.89b	78.39b
CV%	12.82	9.83	7.84	14.11	15.81	5.55
Level of significance	NS	*	*	*	*	*

Other details are same as **Table 3**.

Table 6. Interaction effect of variety and weeding regime on plant height of winter rice under aerobic system of cultivation.

Interaction (Variety × Weeding regime)		Plant height (cm)					
		15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	Harvest
Weed free	BRRI dhan28	9.00	17.40	33.03	55.37b	62.33	86.73
	BRRI dhan29	9.20	18.30	34.96	65.73ab	66.33	87.53
	BRRI dhan47	8.90	14.70	34.73	63..07ab	68.33	89.26
	BRRI dhan50	10.80	18.50	34.63	61.13ab	65.13	77.13
	BRRI dhan55	7.70	14.50	35.20	66.13ab	71.00	85.33
	BRRI dhan58	9.10	18.70	31.76	58.00ab	64.60	81.26
	BRRI dhan59	11.80	19.80	32.16	55.47b	64.20	82.13
	BRRI dhan67	10.90	18.90	33.90	59.67ab	74.46	89.66
	Binadhan-5	6.90	14.80	34.43	58.20ab	69.93	93.20
	Binadhan-6	9.50	18.40	37.00	69.20a	72.20	95.20
	Binadhan-8	7.70	16.30	32.73	62.33ab	70.06	86.86
	Binadhan-10	10.90	18.30	34.73	62.93ab	67.80	85.66
	BRRI hybrid dhan3	8.70	15.40	34.83	64.53ab	73.26	86.33
	Agrodhan-14	9.80	17.30	34.50	68.60a	77.13	97.53
Weedy	BRRI dhan28	8.70	14.13	27.46	58.27ab	64.73	75.13
	BRRI dhan29	9.10	14.90	31.03	59.07ab	65.93	76.53
	BRRI dhan47	8.30	11.80	27.96	59.87ab	66.83	76.06
	BRRI dhan50	10.50	14.70	25.23	54.87b	58.00	71.66
	BRRI dhan55	7.60	12.00	29.83	61.07ab	66.20	78.20
	BRRI dhan58	9.00	16.20	29.86	63.60ab	64.60	73.73
	BRRI dhan59	11.30	17.30	30.86	59.67ab	65.80	78.13
	BRRI dhan67	10.70	16.50	29.33	61.33ab	70.80	78.40
	Binadhan-5	6.70	11.30	30.00	62.67ab	70.06	83.26
	Binadhan-6	8.90	15.60	29.30	58.80ab	70.13	85.333
	Binadhan-8	7.20	12.80	27.56	60.27ab	69.66	79.067
	Binadhan-10	10.90	15.90	29.56	54.80b	61.86	72.8
	BRRI hybrid dhan3	8.70	12.70	30.20	59.33ab	66.00	82.73
	Agrodhan-14	9.60	14.60	30.90	62.47ab	75.80	86.40
CV%		8.69	6.05	9.15	6.95	6.56	4.18
Level of significance		NS	NS	NS	**	NS	NS

Other details are same as **Table 3**.

Here, BRRI dhan59 was the tallest variety and Binadnan-5 was the shortest one which was at par with BRRI dhan47, BRRI dhan55, Binadhan-8 and BRRI hybrid dhan3. At 45 DAS, values are not significant. Both at 60 and 75 DAS, Agrodhan-14 was the tallest cultivar which was followed by BRRI hybrid dhan3, and

BRRI dhan28 was the shortest one which was at par with BRRI dhan59 and BRRI dhan50. At harvest, plant height ranged from 74.4 to 91.97 cm. Agrodhan-14 appeared as the tallest variety which was at par with Binadhan-6, and BRRI dhan50 was the shortest variety which was closely followed by BRRI dhan58. Weed infestation reduced plant height at all growth stages. The magnitude of reduction varied with growth phase, and reduction in plant height in weedy treatments followed a declining trend with advancement of crop growth. Presence of weeds markedly decreased plant height by 3, 16, 14, 3.5, 3.5 and 10% at 15, 30, 45, 60, 75 DAS and harvesting time, respectively. In case of interaction, the tallest variety was Binadhan-6 (69.2 cm) which was followed by Agrodhan-14 (68.6 cm) in weed free condition at 60 DAS. The shortest variety was Binadhan-10 (54.8 cm) which was statistically similar with BRRI dhan50 in weedy condition and BRRI dhan28 and BRRI dhan59 in weed free condition (Table 6).

3.7. Yield Contributing Characters and Yield

Except 1000-grain weight, all other yield contributing characters and yield were significantly influenced by variety, weeding regime and their interactions (Table 7 and Table 8). The highest number of effective tillers hill^{-1} and 1000-grain weight was observed in BRRI dhan28 (7.95) and Binadhan-5 (25.55 g), respectively. However, both of this parameter was statistically identical with BRRI dhan59 (7.77 and 24.7 g, respectively). The highest grains panicle^{-1} (55), grain yield (2.95 t ha^{-1}) and biological yield (6.80 t ha^{-1}) was found in BRRI dhan 59 (Table 7). The lowest number of number of grains panicle^{-1} (24.9), grain yield (1.10 t ha^{-1}) and biological yield (2.55 t ha^{-1}) was found in BRRI dhan55. But the lowest number of effective tillers hill^{-1} and 1000-grain weight was observed in Binadhan-8 (4.62) and BRRI dhan29 (19.03 g), respectively. On the other hand, weed free treatment gave the higher values for all the yield contributing characters and yield, and weedy treatment performed the lowest (Table 7). In case of interaction, the highest number of number of effective tillers hill^{-1} (11.67) and grains panicle^{-1} (66.5) were observed in BRRI dhan28 and BRRI dhan29, respectively under weed free treatment (Table 8). In contrast, highest 1000-grain weight, grain and biological yield were observed in Binadhan-5 under the same condition. Moreover, grain yield of BRRI dhan59 and BRRI dhan47 was statistically identical with Binadhan-5 under weed free condition. BRRI dhan55 performed the lowest under weedy treatment for most of the yield contributing characters and yield (Table 8).

3.8. Harvest Index (%)

Variety and weeding regime had significant effect on harvest index however; their interaction had no significant effect on harvest index (Table 7 and Table 8). Harvest index ranged from 40.73 to 42.78%. The highest harvest index was found in BRRI dhan59 (42.78%) and the lowest one was found in BRRI dhan28 (40.73%). Higher harvest index (45.49%) was found in weed free treatment.

Table 7. Effect of variety and weeding regime on different yield contributing characters and yield of winter rice under aerobic system of cultivation.

Variety	Effective tillers hill^{-1} (no.)	Grains panicle^{-1} no.)	1000 grain weight (g)	Grain yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
BRRI dhan28	7.95a	36.90fg	19.15c	2.11ef	4.97def	42.45
BRRI dhan29	6.60cd	54.60a	19.03c	2.28cd	5.19de	43.93
BRRI dhan47	5.467ef	49.69b	21.85abc	2.30cd	5.20d	44.23
BRRI dhan50	6.13de	48.15b	20.15bc	2.16def	4.94ef	41.53
BRRI dhan55	4.967f	24.90h	20.60bc	1.103i	2.55i	43.13
BRRI dhan58	6.33de	33.95g	22.42abc	1.77g	4.04g	43.81
BRRI dhan59	7.76ab	55.00a	24.70ab	2.95a	6.80a	43.38
BRRI dhan67	7.46abc	43.45cd	21.85abc	2.62b	6.04b	43.37
Binadhan-5	6.46d	47.65b	25.50a	2.31cd	5.19de	44.51
Binadhan-6	7.03a-d	40.90de	22.10abc	2.24de	5.14de	43.15
Binadhan-8	4.61f	38.65ef	20.20bc	1.34h	3.03h	44.22
Binadhan-10	6.98bcd	47.10bc	21.10abc	2.39c	5.49c	43.53
BRRI hybrid dhan3	6.30de	39.35ef	23.50abc	2.23de	5.05de	44.15
Agrodhan-14	6.51cd	36.40fg	22.30abc	2.07f	4.74f	43.67
CV%	12.75	8.02	10.42	5.88	4.62	5.17
Level of significance	**	**	**	**	**	NS
Weeding Regime						
Weed Free	8.43a	49.40a	23.63	3.18a	6.997a	45.49a
Weedy	4.52b	35.84b	19.87	1.10b	2.77b	39.35b
CV%	2.48	18.71	26.64	12.43	6.22	6.67
Level of significance	**	*	NS	**	**	**

Other details are same as **Table 3**.

Lower harvest index (39.35%) was found in weedy treatment (**Table 7**). Harvest index percentage was ranged from 35.99 to 45.53. Numerically, highest harvest index was produced by BRRI dhan59 (45.53%) in weed free treatment, and the lowest one (35.99%) was found in BRRI dhan28 under weedy condition (**Table 8**).

3.9. Relative Yield Loss

Relative yield loss is an excellent indicator of weed tolerance of a variety. Lower the relative yield loss, higher the degree of weed tolerance, since weed tolerance refers to the ability to maintain high yield in the presence of weed competition. The rice varieties showed wide diversity in relative yield loss, which ranged from 43.4% to 82.1% (**Figure 5**). The relative yield loss was lowest in BRRI dhan59, followed by BRRI dhan67 and Binadhan-10 which exhibited high weed tolerance.

Binadhan-5 had the lowest tolerance to weeds with a yield penalty of 82.1% closely followed by Binadhan-8, BRRI dhan55 and others (Figure 5).

Table 8. Interaction effect of variety and weeding regime on different yield contributing characters and yield of winter rice under aerobic system of cultivation.

Interaction (Variety × Weeding regime)		Effective tillers hill^{-1} (no.)	Grains panicle^{-1} (no.)	1000 grain weight (g)	Grain yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Weed Free	BRRI dhan28	11.67a	42.30h-k	20.80	3.27cd	7.19d	45.46
	BRRI dhan29	9.66b	66.50a	18.46	3.47bc	7.63c	45.51
	BRRI dhan47	7.86de	54.90bcd	24.30	3.73a	8.20b	45.51
	BRRI dhan50	7.73de	57.40bc	21.50	3.18de	6.99d	45.48
	BRRI dhan55	6.86ef	28.30o	23.90	1.85h	4.07i	45.44
	BRRI dhan58	8.46bcd	38.70j-m	24.63	2.65f	5.83f	45.47
	BRRI dhan59	8.76bcd	57.20bc	26.60	3.84a	8.44ab	45.53
	BRRI dhan67	8.73bcd	50.50def	23.40	3.47bc	7.63c	45.48
	Binadhan-5	9.53bc	58.60b	27.70	3.92a	8.62a	45.50
	Binadhan-6	8.26cd	50.50def	23.70	3.18de	7.03d	45.44
	Binadhan-8	6.26fg	48.40efg	23.50	2.22g	4.88g	45.51
	Binadhan-10	7.76de	52.80cde	22.60	3.23d	7.10d	45.50
	BRRI hybrid dhan3	8.33bcd	45.20fgh	26.30	3.52b	7.74c	45.52
	Agrodhan-14	8.03de	40.30h-l	23.40	2.98e	6.55e	45.50
Weedy	BRRI dhan28	4.23ijk	31.50no	17.50	0.96klm	2.74k	35.99
	BRRI dhan29	3.53jk	42.70hij	19.60	1.10jkl	2.75k	39.97
	BRRI dhan47	3.06k	44.48ghi	19.40	0.88mn	2.2l	40.03
	BRRI dhan50	4.53hij	38.09i-m	18.80	1.15jk	2.87k	40.00
	BRRI dhan55	3.06k	21.50p	17.30	0.41o	1.02n	39.89
	BRRI dhan58	4.20ijk	29.20o	20.20	0.90lmn	2.25l	39.99
	BRRI dhan59	6.76ef	52.80cde	22.80	2.06g	5.15g	40.04
	BRRI dhan67	6.20fg	36.40lmn	20.30	1.78h	4.45h	40.02
	Binadhan-5	3.40jk	36.70k-n	23.40	0.70n	1.75m	40.02
	Binadhan-6	5.80fgh	31.30no	20.50	1.30j	3.25j	37.13
	Binadhan-8	2.96 k	28.90o	16.90	0.47o	1.17n	39.85
	Binadhan-10	6.20fg	41.40h-l	19.60	1.55i	3.87i	38.01
	BRRI hybrid dhan3	4.26ijk	33.50mno	20.70	0.94lm	2.35l	39.97
	Agrodhan-14	5.00ghi	32.50no	21.20	1.17j	2.92jk	40.01
CV%		12.75	8.02	10.42	5.88	4.62	5.17
Level of significance		**	**	NS	**	**	NS

Other details are same as Table 3.

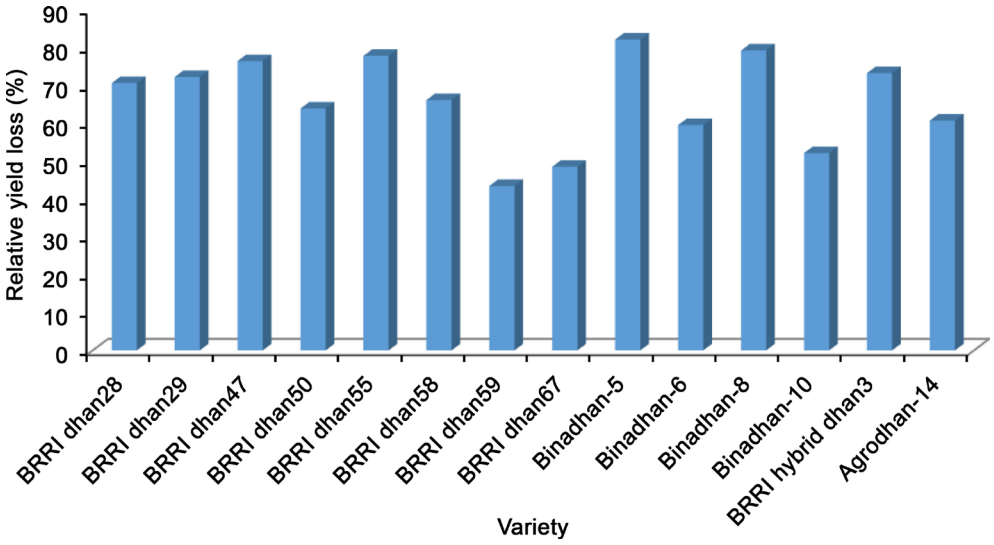

Figure 5. Effect of variety on relative yield loss (%) of winter rice under aerobic system of cultivation.

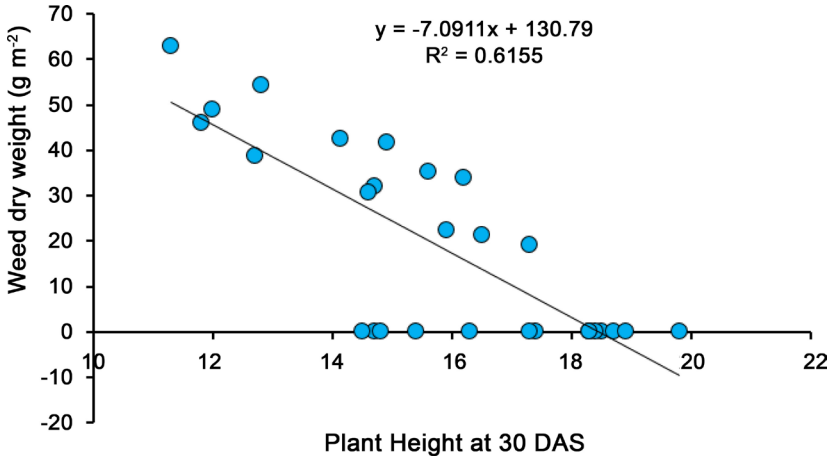

Figure 6. Relationship between Plant height at 30 DAS and weed dry weight.

3.10. Relationship among Traits

Regression study showed that weed dry weight was strongly and negatively correlated with early plant height (PH30) and early visual vigor and highly (negatively) correlated with above ground crop biomass and grain yield (**Figure 6**). Plant height beyond 30 DAS maintained a weak negative correlation with weed dry weight (**Figure 7**). As expected, weed rating was strongly and positively correlated with weed dry weight, but negatively correlated with early plant height (PH30), early visual vigor and grain yield. Grain yield showed a very strong positive correlation with above ground crop biomass and highly positive correlation with early plant height (PH30). While percent filled grains had maximum predictive power for grain yield ($R^2 = 0.62$) (**Figure 6**). Weed biomass could explain grain yield by 83% (**Figure 7**) and relative yield loss by 95% (**Figure 8**). Early plant height at 30 DAS appeared to be the most important trait in predicting weed biomass ($R^2 = 0.62$) (**Figure 6**).

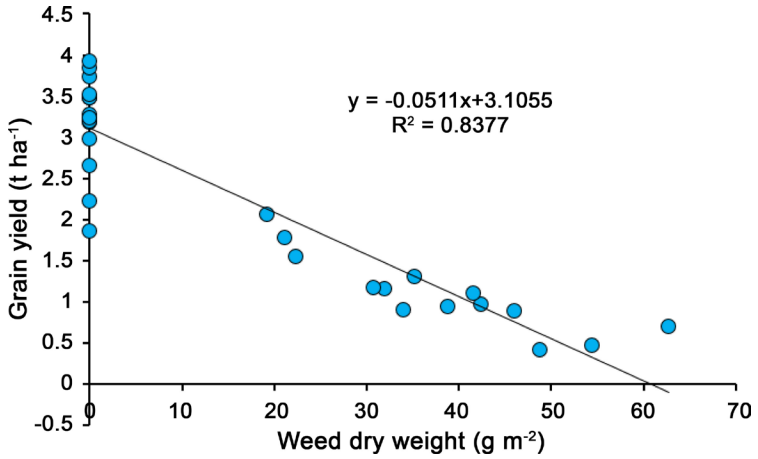

Figure 7. Relationship between weed dry weight and grain yield.

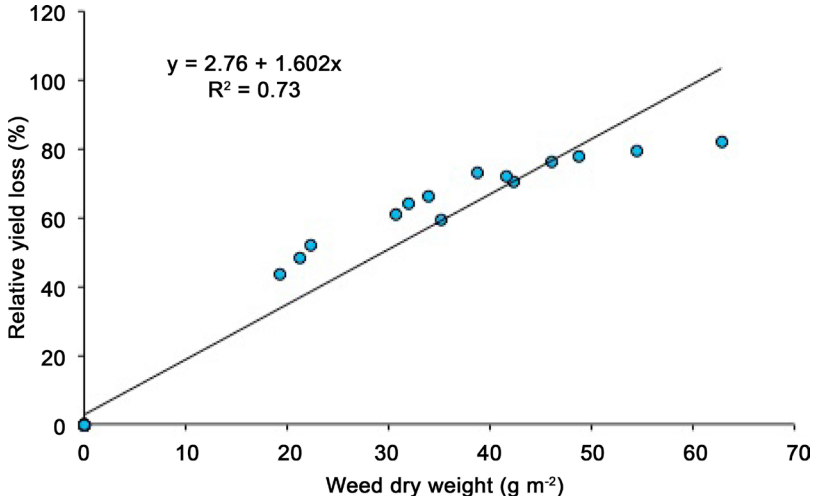

Figure 8. Relationship between weed dry weight and relative yield loss.

4. Discussion

The cultivars evaluated in this study varied not only in yield and weed suppressing ability, but also in all the agronomic traits measured. Although a wide variation in traits was observed among cultivars, none of them gave satisfactory yield under aerobic conditions. Binadhan-5 emerged as the most productive, whereas BRRI dhan59 appeared as the most weed suppressive rice variety. The least productive cultivar was BRRI dhan55, which was closely followed by Binadhan-8 and BRRI dhan58. Based on reports in earlier studies [9], the present study included a variety of commonly cited traits including plant height, tillering ability, early visual vigor, duration, and SPAD values. Significant variations among the varieties were recorded suggesting that selection based on those traits was practical. Plant height is considered as desirable characters for weed suppressive cultivars. Although plant height varied widely among the cultivars, early plant height *i.e.* height at 30DAS was strongly and negatively correlated with weed dry weight. Earlier and faster growth allowed the rice crop to compete with weeds

for plant resources, and this was reflected in the crop yield. The results indicate that only early plant height can be considered as vital selection criteria for weed competitiveness under aerobic soil conditions. Similar type of results has also been reported by Gibson *et al.* [60], Caton *et al.* [50], Zhao *et al.* [61], Anwar *et al.* [9].

Early visual vigor or vigor index, a reliable predictor of crop biomass integrating both height and tiller number, is an important selection criterion for weed competitiveness. Yield and weed competitiveness are effectively predicted by early visual vigor. Vigor rating is rapid, non-destructive, less labor-intensive and reliable, and therefore a promising and feasible tool for making decisions on weed competitiveness [9]. In this study, early visual vigor varied widely among varieties, and its strong correlation with other parameters confirms its acceptability. It has been reported previously that early season vigor is directly linked with the competitive ability of the crop [62] [63] [64] [65] and later in the crop growing season, it confers competition against weeds [66].

The SPAD (Silicon Photon Activated Diode) meter provides a very easy, swift and non-destructive method for estimating relative leaf chlorophyll content. Higher SPAD values indicate greener healthier plants. The results showed SPAD values varied among the varieties. SPAD values were greatly reduced by weed interference and this was reflected in yield performance. Weed interference negatively and markedly affected all yield components which cumulatively impaired grain yield. The rice varieties used in the current research showed wide diversity in relative yield loss, which ranged from 43% to 82%. Weed biomass was strongly and negatively correlated with grain yield, indicating that weed suppressive ability can be combined with yield potential. Anwar *et al.* [9] and McGregor *et al.* [67] also observed a similar relationship. Weed interference negatively and markedly affected all yield components which cumulatively impaired grain yield. Weed biomass was strongly and negatively correlated with grain yield, and positively correlated with relative yield loss indicating that weed suppressive ability can be combined with yield potential.

5. Conclusion

The findings of our study indicate that strong weed suppressive cultivars could be adopted as an integral part of sustainable weed management package aimed at reducing dependence on synthetic herbicides. However, strong weed suppressive ability does not always ensure high yields. Therefore, higher yields along with strong weed competitive cultivar should be the selection criteria for dry direct seeded aerobic rice. Competitiveness of rice cultivars against weeds will be an important key to the sustainable weed management in aerobic rice. As no cultivar in our study produced economically acceptable yield, therefore it is recommended to develop high yielding and weed competitive rice varieties that can be successfully grown following aerobic system with least weed management.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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