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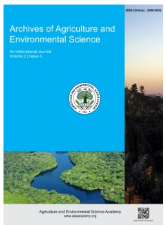

ORIGINAL RESEARCH ARTICLE

Weed competitiveness of winter rice (*Oryza sativa* L.) under modified aerobic system

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ABSTRACT

The study was conducted during winter season (February-June) of 2016 at the Agronomy Field 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 hybriddhan3 and Agrodhan14 were grown under weedy and weed- free conditions. Plots with no rice were also maintained to study the natural growth of weed in absence of rice. Primed rice seeds were dry seeded following 25 cm ×15 cm spacing with 5 seeds hill^{-1} on non-puddled soil. Plots were surface irrigated as and when necessary to maintain aerobic condition (at around field capacity) up to heading stage followed by wet condition from heading to grain filling stage. The results revealed that rice varieties varied widely in yield performance and weed suppressive ability. Among varieties, BRRI dhan59 allowed the minimum weed growth (20.8 g m^{-2}) while Binadhan-5 allowed the maximum weed growth (65.8 g m^{-2}). Grain yield ranged from 2.2 t ha^{-1} (BRRI dhan55) to 4.67 t ha^{-1} (Binadhan-5) under weed-free condition and from 0.62 t ha^{-1} (BRRI dhan55) to 2.48 t ha^{-1} (BRRI dhan59) under weedy condition. Weed infected relative yield loss ranged from 40.1% to 78.2% among varieties. BRRI dhan59 incurred the least yield penalty (40.1%) while Binadhan-5 performed the best in terms of grain yield (4.67 t ha^{-1}) but its weed inflicted relative yield loss was higher (76.4%) than any other variety with low yield potential. BRRI dhan59, on the other hand, appeared as the most weed competitive variety (only 40.1% relative yield loss) with yield of 4.19 t ha^{-1}. Present study confirms that the varieties tested under study varied widely in terms of weed suppressive ability and yield performance. Considering both yield and weed competitiveness, BRRI dhan59 can be recommended for cultivation following modified aerobic system.

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INTRODUCTION

Rice is the single largest user of fresh water consuming about 30% of world freshwater utilization and more than 45% of total freshwater used in Asia (Barker *et al*., 1998). It requires around 1000 to 5000 liters of water for producing one kg grain which is about twice or even more than wheat or maize (Bouman and Tuong, 2000; Cantrell and Hettel, 2005). Water is becoming scarce with time and its declining availability and high cost threatens traditional irrigated rice production system. On the other hand, the lack of sufficient rainfall and its uneven distribution over the growing season are among the major constraints to rainfed rice culture. By 2025, 15 out of 75 million hectares of Asia's irrigated rice may experience severe water shortage (Tuong and Bouman, 2003). Different water saving technologies have been developed for rice e.g., saturated soil culture (Borell *et al.*, 1997), alternate wetting and drying (Li, 2001; Tabbal *et al.*, 2002), ground cover system (Lin *et al.*, 2002) and system of rice intensification (Stoop *et al.*, 2002). But, none of these systems has been established as a suitable alternative. High weed pressure and lower yield are among the major constraints to adoption of aerobic rice. Rice yield loss under aerobic system can be minimized to a greater extent by following a modified aerobic system where aerobic condition up to heading stage is followed by wet condition from heading to grain filling stage. Rice variety with strong weed suppressive ability may also play a vital role in minimizing weed infestation and reducing rice yield loss in a sustainable way.

Aerobic rice production is a revolutionary way of growing rice in well-drained, non-puddled, and non-saturated soils without ponded water. This system uses input-responsive specialized rice cultivars and complementary management practices to achieve at least 4-6 t ha^{-1} using only 50-70% of the water required for irrigated rice production. A true aerobic rice variety combines drought resistance of upland rice with high yielding characteristics of lowland rice, and is capable of producing high yield with a limited total water supply (irrigation + rainfall) of 500 to 600 mm, resulting in twice the water productivity of lowland rice (Dingkuhn *et al.*, 1999; Bouman *et al.*, 2002; Wang *et al.*, 2002). But yield of aerobic rice is comparatively lower than traditional flood irrigated rice because of water stress during critical growth stages. A modification in this system by maintaining aerobic condition till heading stage and then wet condition up to grain filling stage might increase yield up to some content.

This technology however is impeded by high weed pressure with a broader weed spectrum compared to flooded rice (Balasubramanian and Hill, 2002) since aerobic rice germinates concurrently with weeds without any 'head start' over weeds and lacks standing water to suppress weeds (Moody, 1982). Weed competitiveness (WC) comprises two components: weed suppressive ability (WSA) - the ability to lessen weed growth through competition, and weed tolerance (WT) - the capability of maintaining potential yields in the presence of weeds (Jannink *et al.*, 2000; Fischer *et al.*, 1999, 2005). Weeds are the greatest constraint to yield in upland or aerobic rice systems, resulting in yield losses between 30 and 98% (De Datta and Llagas, 1984; Oerke and Dehne, 2004). Losses due to weeds are more severe than those caused by N deficiency, pests, or diseases (WARDA, 2002). Successful aerobic rice and will largely depend on effective weed control. WSA should be emphasized more than WT for long term weed management. However, the roles of WSA, WT and yield potential to influence yield under weedy conditions are generally ambiguous (Zhao *et al.*, 2006a), and strong WSA will not guarantee high yield of a low yielding variety under weedy conditions (Zhao *et al.*, 2006b). Therefore, high yield potential and strong WSA need to be pooled to ensure economically acceptable yields under weed competition. In general, cultivars with high tillering ability, high early growth rate, high leaf area index and specific leaf area, long leaves and droopy plant type are more weed suppressive, but at the same time conflicting findings have also been reported. It is mainly based on the cultivation of aerobic rice by keeping saturated or wet condition during part of reproductive phase which is very sensitive to water stress. Hence plant physiologists and breeders have to address the challenges in breeding varieties with better physiological adaptations for higher yield and better weed competitiveness under aerobic conditions. Information on weed competitiveness of rice under aerobic soil condition has been well documented, but it must be recognized that the genetic resources available in Bangladesh. Weeds compete for nutrient, space, sunlight and consume the available moisture with crop plant resulting in crop yield reduction. Weeds in direct seeded rice may cause yield losses up to 35% (Oerke and Dehne, 2004). Comparative studies on weed competitiveness among germplasm from diverse genetic sources and origins comprising of a wide range of traits are limited. In view of the wide variation in the available genetic resources it is indeed a challenge to undertake comparative studies to continue to identify germplasm with significant weed suppressive potential, and to recognize agronomic traits conferring weed competitiveness of rice under aerobic cultivation system for further use by the breeders while developing weed-competitive rice varieties. Plant to plant competition is common but not universal in natural ecosystems. However, weed-crop competition is abundant, natural and undesirable in agricultural plant communities (Zimdahl, 2004). Therefore, choosing a competitive crop can be a way to potentially suppress weed growth without sacrificing crop yield. However, crop cultivars often differ in competitive ability against weeds. Cultivars may also perform differently in different regions and growing conditions (Gibson *et al.*, 2003; Mason and Spaner, 2006). It is also important to note that the most competitive cultivars are not always the highest yielding cultivars. All these factors may influence the choice of crop cultivars. Differences between rice cultivars in response to weed competition have been recognized (Suzuki *et al.*, 2002; Estorninos *et al.*, 2005; Zhao *et al.*, 2007). In view of the above discussion, the present experiment was undertaken to assess the variation in weed competitiveness and yield among selected high yielding rice varieties grown under modified aerobic system and to identify promising rice germplasm(s) with high yield potential and strong weed competitiveness for cultivation with minimal water.

MATERIALS AND METHODS

The experiment was conducted at the Agronomy Field Laboratory and Weed Management Laboratory, Bangladesh Agricultural University, Mymensingh in winter (locally known as *boro*) season (February-June) 2016 to evaluate the competitiveness of some winter rice varieties against weed under modified aerobic condition.

Description of the experimental site

The experimental field is located at 24.75° N latitude and 90.50° E longitude at an average altitude of 18 m above the mean of sea level. The experimental site belongs to the Old Brahmaputra

Floodplain Agro-ecological zone (AEZ-9) (UNDP; FAO, 1988; FAO, 2014). The experimental field belongs to non-calcareous dark-grey floodplain soil. The land was medium high and the soil was silty-loam in texture with medium fertility level. The soil of the experimental field was more or less neutral in nature (pH 6.82) and low in organic matter content (1.19%). Soil contained 0.1% total N, 26 ppm available P, 7.36 ppm available S, 0.13 me% exchangeable K. During the growing season (February-June, 2016), monthly average maximum temperature, minimum temperature and relative humidity were 27.8 – 33.6°C, 17.4 – 26°C and 73.2 – 84.4%, respectively, while monthly total rainfall and sunshine hours were 0.3 – 13.0 mm and 140 – 171.3 h, respectively.

Plant materials

Fourteen high yielding inbred and hybrid winter rice varieties developed by Bangladesh Rice research Institute (BRRI) and Bangladesh Institute of Nuclear Agriculture (BINA, 2012) were used as plant materials in this study.

Experimental treatments and design

The experiment included two factors. Where Factor A consisted of 14 winter rice varieties namely - BRRI dhan28 (V_1), BRRI dhan29 (V_2), BRRI dhan47 (V_3), BRRI dhan50 (V_4), BRRI dhan55 (V_5), BRRI dhan58 (V_6), BRRI dhan59 (V_7), BRRI dhan67 (V_8), BINA dhan5 (V_9), BINA dhan6 (V_{10}), BINA dhan8 (V_{11}), BINA dhan10 (V_{12}), BRRI Hybrid dhan3 (V_{13}) and Agrodhan14 (V_{14}). And Factor B comprised two weeding regimes namely weed free (F) and weedy (W). The experiment was laid out in a split-plot design with three replications. Weeding regime was allocated in main plot and rice variety in sub plot. The total number of unit plots was 84. Each plot size was 2.5 m × 2.0 m. The spaces between blocks and between plots were 1 m and 0.5m, respectively. Moreover, three plots were maintained as weed monoculture where no rice was grown. Thus, a total of 87 unit plots were maintained.

Crop husbandry

The seeds were dipped into water buckets for 24 hours and then taken out of water and packed in the gunny bags and kept in a warm place for sprouting. The seeds sprouted after 72 hours of steeping. A medium high land was selected and the land was first opened with a power tiller and subsequently leveled by laddering on 3rd February 2016. 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 land. Sprouted rice seeds were dry seeded on 4th February 2016 following 25 cm × 15 cm spacing with 5 seeds hill^{-1} on non-puddled soil. Plots with no rice were also maintained to study the natural growth of weed in absence of rice. Fertilizers were applied as per BRRI recommendation with 10 ton cowdung, 120 kg triple super phosphate, 75 kg muriate of potash, 60 kg gypsum and 10 kg zinc sulphate ha^{-1} as basal dose (BRRI, 2015). The fertilizers were broadcast and incorporated into the soil at final land preparation. Urea @ 220 kg ha^{-1} was applied in 3 equal splits at 30, 50 and 70 days after sowing (DAS). Plots were surface irrigated as and when necessary to maintain aerobic condition (at around field capacity) up to heading stage followed by wet condition from heading to grain filling stage.

Data collection

Data on rice were collected on plant height, height growth rate, early visual vigor, tillering ability, leaf chlorophyll content (SPAD), phenology, yield attributes and yield. Height growth rate was considered as increase in plant height per day (cm day^{-1}) and was calculated based on the height measurements at different growth stages, and designated as HGR $_{0-15}$ and HGR $_{15-30}$. Relative chlorophyll content or greenness of leaves was measured at 45 DAS (SPAD-45) using a portable SPAD meter. Readings were recorded from 10 randomly selected fully expanded leaves. Early visual vigor was rated at 3 WAS on a 1 to 9 scale, with 1 for plants with the most growth and 9 for least growth. The biological yield was calculated with the following formula:

Biological Yield = Grain Yield + Straw Yield.

Harvest index of each plot was calculated by using the following formula:

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

Data on weed were collected on weed species composition, weed density, dry matter, summed dominance ratio (SDR) and weed rating (1 to 9 scale). A quadrate of size 0.5 m× 0.5 m was placed randomly in two places of weedy plots for collecting data over weed. Weeds 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. Dominant weed species were identified using the summed dominance ratio (SDR) computed as follows (Hia *et al.*, 2017):

$$\text{SDR of a weed species} = \frac{\text{Relative density (RD)} + \text{Relative dry weight (RDW)}}{2}$$

Where,

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

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

Relative contribution of different weed groups (broad-leaved, grasses and sedges) to the weed vegetation in terms of RD and RDW were also calculated.

Statistical analysis

The recorded data on various plant characters were statistically analyzed to find out the significance of variation resulting from the experimental treatments. Analysis of variance (ANOVA) for each of the characters under study was done with the help of computer package MSTAT. The differences among treatment means were compared by Duncan's New Multiple Range Test (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Plant height and height growth rate

Rice varieties exhibited significant differences in plant height at 15, 30, 45, 60 DAS and at harvest but not at 75 DAS (Table 1). At harvest, plant height ranged from 85 to 94 cm. BINA dhan6 appeared as the tallest variety which was at par with BINA dhan5, whilst BRRI dhan59 was the shortest in stature. At early growth stages (15 and 30 DAS), BRRI dhan59 was the fastest growing and consistently performing variety with BRRI dhan50, BRRI dhan67 and BINA dhan10 in attaining height and thereafter grew at the same pace. Conversely, BRRI dhan28, BRRI dhan29, BRRI dhan47, BRRI dhan58 had the medium plant height at early stages of growth. BRRI dhan55, BINA dhan8 had the lowest plant height at 15 DAS. And BINA dhan5 attained only about half the plant height of BRRI dhan59 at 15 DAS. At mid growth stages (45 and 60 DAS), BRRI dhan55 gained maximum height. Early growth is considered as an important trait associated with weed competitiveness. Hence, it is noteworthy that within 15 days of seeding the varieties attained 7-15% of their respective ultimate plant height; BRRI dhan59 topping the list (15%) closely followed by BRRI dhan67 (14%) and BINA dhan10 (14%), while BINA dhan5 attained the least (7%). At all growth stages, plant height varied considerably with weeding regimes (Table 1). 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 by a growing trend with advancement in crop growth. However, weedy treatments at harvest recorded more than 16% reduction in height compared to weed-free treatments. Presence of weeds markedly decreased plant height by 5, 6, 7, 4 and 10% at 15, 30, 45, 60 and 75 DAS, respectively.

The combined effect of variety and weeding regime showed significant differences in plant height at 15, 30, 60 and harvest but not at 45 and 75 DAS (Table 2). At harvest, plant height ranged from 77 cm to 104 cm. BINA dhan6 appeared as the tallest variety interacting with weed free condition and BRRI dhan59 as the shortest variety under weedy condition which was at par with BRRI dhan50. At early plant growth stages (PH15 and PH30), BRRI dhan59 was the fast growing variety with combination of weed. All other varieties showed average growth with the interaction of weed. Significant differences were also found for height growth rate (Table 1). BRRI dhan59 showed maximum height growth rate during 0-15 DAS followed by BINA dhan10, BRRI dhan67 and BRRI dhan50. During 15-30 DAS, these varieties maintained slow growth rate and BINA dhan6 had maximum growth rate followed by BRRI dhan58. Entries like BRRI dhan28, BRRI dhan29, BINA dhan5, BINA dhan8, BRRI hybrid dhan3 and Agrodhan14 maintained steady growth rate, while BRRI dhan55 and BRRI dhan47 appeared the slowest during early growth stages HGR_{0-15} and HGR_{15-30} respectively. A differential response in height growth rate was evident with varying weeding regimes (Table 1). Height growth rates were higher in weed-free treatments compared to weedy treatments. The difference was both significant at 15 and 30 DAS. Height growth rate during 0-15 DAS and 15-30 DAS were both significant for interaction between variety and weeding regime (Table 2). For HGR_{0-15}, the highest height growth rate was found from the variety BRRI dhan59 under weed free condition and the lowest one from the variety BINA dhan5 with weedy condition. The highest height growth rate for HGR_{15-30} was found from the variety BINA dhan8 with combination of weed free condition and the lowest height growth rate was found from BRRI dhan47 combined with weedy condition. Plant height is an important character associated with weed competitiveness. In fact, plant height is a genetic character but influenced by environment and crop management to some extent. Variation in plant height among rice varieties has also been reported by many researchers (Rahman *et al.*, 2017; Anwar *et al.*, 2010).

Relative chlorophyll content and early visual vigor

The Silicon Photon Activated Diode (SPAD) value observed at 45 DAS had no significant difference over the varieties. The varieties under the study were almost same in relative chlorophyll content (Table 3). Weeding regime had significant influence on SPAD values at 45 DAS (Table 3), with much higher values in weed- free treatments than weedy treatment. The variation was more than 5 unit. This indicates considerable rice-weed competition resulting in poor growth of rice plants. The combined effect of varieties with weeding regime had significant difference in chlorophyll content at 45 DAS (Table 4). The SPAD values at 45 DAS ranged from 27 to 42% with highest chlorophyll content for the variety BRRI dhan28 interacting with weed free condition which was at par with the variety BRRI dhan47 and the lowest chlorophyll content for the variety BINA dhan8 under weedy condition. The SPAD meter provides a very easy, swift and non-destructive method for estimating relative leaf chlorophyll content. Higher SPAD values indicate greener healthier plants. The varieties exhibited almost same chlorophyll content across the weeding regimes which indicate similar outlook of the rice plants. SPAD values were greatly reduced by weed interference and this was reflected in yield performance. The combined effect of SPAD value under varieties over weeding regime was significant due to the dissimilarity between the weedy and weeds free condition. Anwar *et al.* (2010) has reported that the SPAD values under weedy condition were very much lower in different varieties of rice crop than the weed free condition.

Vigor index was significantly different among the rice varieties (Table 3). At 21 DAS, BRRI dhan59 appeared as the most vigorous with vigor scores of more than 7, closely followed by BRRI dhan67, BINA dhan10, Agrodhan14, BRRI dhan50, BRRI dhan58 and BINA dhan6. BRRI dhan55 and BINA dhan8 were the least vigorous scoring around 4.5, while the others were fairly vigorous with scores between 5 and 6. Early visual vigor in rice varieties responded significantly to weeding regimes (Table 3). Higher vigor was observed under weed-free condition in contrast to weedy condition with average scores of 6 and 5, respectively. The combined effect of varieties over weeding regime had significant difference in early visual vigor at 21 DAS (Table 4). The value of EVV ranges from 3 to 8 at 21 DAS. The variety BRRI dhan59 exhibited the highest score interacting with weed free condition followed by BRRI dhan67 and BINA dhan10. BRRI dhan67 and BINA dhan5 were the least vigorous interacting under weedy condition. Yield and weed competitiveness can effectively predicted by early visual vigor, and early visual vigor is considered to be one of the most important traits to explain weed biomass (Anwar *et al*., 2010). In the present study, early vigor varied widely among varieties, but its strong correlation with other traits confirms its acceptability as reported by other researchers (Lemerle *et al*., 2001; Caton *et al*., 2003; Zhao *et al*., 2006b). A variety attaining higher early biomass will compete better throughout growth (Cousens *et al*., 2003).

Rice phenology

The varieties from diverse genetic sources and origins demonstrated a broad range in phenological parameters (Table 5). Growth duration of the varieties in this study ranged from 114 to 142 days in weed free condition and 112 to 139 days in weedy condition. BRRI dhan28 took 90 days in weed free condition and 88 days in weedy condition for 50% flowering and matured within 114 and 112 days respectively. BRRI dhan55, BRRI dhan58, BRRI dhan67and Agrodhan14 commenced flowering between 90 and 100 DAS and consequently matured by 120 - 130 days in weed free condition. In weedy condition, these varieties along with BRRI dhan47 took less than 100 days to commence flowering and consequently matured by 115 to 125 days. BINA dhan-6 required the longest duration of more than 115 days to initiate flowering and matured after 140 days in weed free condition and more or less similar in weedy condition. All other varieties started flowering between 110 and 115 days in weed free condition and 108 to 113 days in weedy condition and required more than 135 days to attain maturity under weed free condition and more than 130 days under weedy condition. The varieties raised with weed matured earlier than weed free condition due to excessive pressure on essential elements. This finding is not in conformity with that reported by Anwar *et al.* (2010) who found no effect of weed competition on rice phenology.

Yield components and yield of rice

Rice varieties differed significantly in yield components, yield and biomass production among themselves (Table 6). With regard to total no of tillers hill^{-1}, it ranged from 6 to 11 no of tillers hill^{-1}. BRRI dhan59 produced the most with 11 tillers hill^{-1}followed by BRRI dhan28; BINA dhan8 produced the lowest with 6 tillers hill^{-1}. Number of effective tillers hill^{-1} had significant differences ranging from 5 to 9. BRRI dhan59 ranked first in producing no of effective tillers of about 9 tillers hill^{-1}, followed by BRRI dhan28 and BINA dhan10, while BINA dhan8 produced only 5 tillers hill^{-1}. Non effective tillers hill^{-1} significantly varied among the rice varieties. Number of non-effective tillers hill^{-1} fluctuated from 1 to 3 over varieties. BRRI hybrid dhan3 and Agrodhan14 had maximum non effective tillers hill^{-1}, while BINA dhan8 had the least non effective tillers hill^{-1}. Sterile spikelets panicle^{-1} showed significant differences over the varieties ranging from 42 to 46. BRRI dhan55 had the most no of sterile spikelets panicle^{-1} followed by BINA dhan8, whilst BINA dhan5 exhibited the lower no of sterile spikelets panicle^{-1}. Grains panicle^{-1}was significantly different over the varieties which ranged from 27 to 58. BRRI dhan29 contained most number of grains panicle^{-1} and BRRI dhan55 had the lowest grains panicle^{-1}. BRRI dhan47 developed the heaviest grains with a thousand-seed weight of over 26 g, followed by Agrodhan14 with a value of nearly 25 g; while BRRI dhan29 produced the smallest grains with a thousand-seed weight of only 20 g. Grain yields recorded among the varieties ranged from 1.42 to 3.40 t ha^{-1}. The recorded yields were unsatisfactory, and BRRI dhan59 topped the list with a modest yield of 3.40 t ha^{-1}, marginally followed by BRRI dhan67. The high grain yield in BRRI dhan59 is reflected by the highest no. of total tillers hill-1, no of effective tillers hill^{-1}. Amongst others, BRRI dhan67, BINA dhan10 and BINA dhan6 produced more than 3 t ha^{-1} of grain. BRRI dhan55produced the lowest yield of 1.42 t ha^{-1}, followed by BINA dhan8. Harvest index did not vary significantly among the varieties. Straw production showed significant differences among the varieties which ranged between 1.773 and 4.437t ha^{-1}. BRRI dhan59 produced the highest straw yield closely followed by BRRI dhan67, while BRRI dhan55 had the lowest straw production followed by BINA dhan8. All the yield components vary from variety to variety due to their genetic made up that result a variation in the yield of the related varieties of rice.

Weeding regime showed significant effects on yield components and yield of rice (Table 6). Rice varieties performed better under weed-free conditions compared to weedy condition. Prevalence of weed decreased total tillers hill^{-1}, effective tillers hill^{-1}, non-effective tillers hill^{-1}, sterile spikelets panicle^{-1}, grains panicle^{-1} and 1000-grains weight by 39, 28, 71, 7, 24 and 14%, respectively. Weed infestation reduced grain yield and straw production by nearly 59 and 50%, respectively compared to weed-free conditions. Gobrial (1981) reported that the weed competition in rice lowered panicle number per unit area by 37 per cent, filled grains per panicle by 13 per cent and test weight by 4 per cent. Rice weed competition decreased the panicle production considerably, perhaps due to less tiller production (Biswas *et al*., 1992). Uncontrolled weeds, on an average caused 75.8, 70.6 and 62.6 per cent reduction in grain yield of rice when compared with weeded situation in dry seeded rice, wet seeded rice and transplanted rice respectively (Singh *et al*., 2005a). Weeds posed major problem in rice production due to the prevalence of congenial atmosphere and uncontrolled weeds competed with dry seeded rice and reduced yield up to 30.17 per cent (Singh *et al*., 2005b).

The combined effect of varieties over weeding regime exhibited significant differences in yield components, yield and straw production (Table 7). With regard to total no of tillers hill^{-1}, it ranged from 4 to 15 no of tillers hill^{-1}. BRRI dhan28 produced the most with 15 tillers hill^{-1} interacting with weed free condition followed by Agrodhan14; BINA dhan8 produced the lowest with 4 tillers hill^{-1}under weedy condition. Number of effective tillers hill^{-1} had significant differences ranging from 3 to 11. BRRI dhan28 ranked first in producing no of effective tillers of about 11 tillers hill^{-1} interacting with weed free condition, followed by BRRI dhan67 under weedy condition and BINA dhan10 under weed free condition, while BINA dhan8 produced only 3 tillers hill^{-1} in weedy condition. Non effective tillers hill^{-1} had significant differences in combined effect of weeding regime over the rice varieties. The number of non-effective tillers hill^{-1}fluctuated from 0.4 to 4 over varieties. BRRI hybrid dhan3 and Agrodhan14 had maximum non effective tillers hill^{-1} interacting with weed free condition, while BRRI dhan29 had the least non effective tillers hill^{-1} in weedy condition. Sterile spikelets panicle^{-1} showed significant differences ranging from 37 to 47. BRRI dhan55 had the most no of sterile spikelets panicle^{-1} under weed free condition followed by BRRI dhan28 under weedy condition, whilst BINA dhan5 exhibited the lower no of sterile spikelets panicle^{-1} interacting with weed free condition. Grains no panicle^{-1} was significantly different in combined effect of weeding regime over the varieties which ranged from 24 to 70. BRRI dhan29 contained most no of grains panicle^{-1} with the interaction of weed free condition and BRRI dhan55 had the lowest no grains panicle^{-1} under weedy condition. BRRI dhan47 developed the heaviest grains with a thousand-seed weight of over 28 g in weed free condition, followed by Agrodhan14 with a value of nearly 27 g under weed free condition, while BINA dhan8 produced the smallest grains with a thousand-seed weight of only 17 g with the interaction of weed. Grain yields recorded in the combined effect of varieties over weeding regime ranged from 0.6 to 4.67 t ha^{-1}. The recorded yields were unsatisfactory, and BINA dhan5 topped the list with a yield of 4.67 t ha^{-1} under weed free condition. Amongst others, BRRI dhan28, BRRI dhan29, BRRI dhan47, BRRI dhan59, BRRI dhan67, BINA dhan10 and BINA dhan6, BRRI hybrid dhan3 and Agrodhan14 produced more than 4 t ha^{-1} of grain under weed free condition. BRRI dhan55 produced the lowest yield of 0.62 t ha^{-1}, followed by BINA dhan8 under weedy condition. Harvest index did not exhibit significant differences among the varieties. Varieties with different characteristics give different result and output when combined with weed. Aerobic soil conditions and dry tillage practices, beside alternate wetting and drying conditions are conductive for germination and growth of highly competitive weeds, which cause grain yield loss of 50-91 per cent (Singh *et al*., 2006). The extent of yield reduction due to weeds is 50 per cent in direct seeded upland rainfed rice, 51-74 per cent in rainfed lowland rice, 30 to 35 per cent in direct-seeded puddled rice and 15-20 per cent in puddle transplanted rice (Sharma, 2007). Singh *et al.* (2008) reported loss of 38-92 percent of grain yield in aerobic rice due to weed competition. Yield losses as high as 46 per cent caused by weeds was reported in direct seeded rice (Arunvenkatesh and Velayatham, 2010). Ramachandiran (2012) reported that grain yield was reduced by 66.47 per cent of aerobic rice in unwedded check. Rahman *et al.* (2017) also recorded similar findings from their experiment conducted under aerobic soil condition at the same experimental site.

Straw production showed significant differences due to combined effect of weeding regime and the varieties which ranged between 0.9 and 5.58 t ha^{-1}. BINA dhan5 produced the highest straw yield under weed free condition closely followed by BRRI dhan29 in weed free condition, while BRRI dhan55 had the lowest straw production followed by BINA dhan8 interacting with weedy condition. Weed interference negatively and markedly affected all yield components which cumulatively impaired grain yield. Weeds thus caused a yield decrease of around 60% across varieties. Weed biomass was strongly and negatively correlated with grain yield, indicating that weed suppressive ability can be combined with yield potential. A similar relationship has also been reported by McGregor *et al.* (1988) and Anwar *et al.* (2010) who observed strong negative correlation between weed biomass and crop yield. In the present study, grain yield was significantly affected by interaction between variety and weeding regime, indicating that variety performing better in weed-free condition is unlikely to perform fairly better under weed competition. Cultivar differences in weed-suppressive ability are determined by assessing variation in weed biomass in plots under weed competition. Jannink *et al.* (2000) and Jordan (1993) advocated breeding for weed-suppressive ability over weed tolerance because of suppressing weeds reduces weed seed production and benefits weed management in the future, while tolerating weeds only benefits the current growing season, and may result in increased weed pressure from unsuppressed weeds.

Floristic composition of weeds

Fifteen weed species belonging to ten different families were observed in weedy troughs, among which eight were broadleaves, six grasses and four sedges (Table 7). Based on summed dominance ratio (SDR), the five most dominant weed species encountered were *Panicum distichum*, *Echinochloa crusgali*, *Leptochloa chinensis*, *Paspalum commersonii* and *Digitaria sangunalis* (Table 8). Grassy weeds contributed 84% of the total dry matter and 81% of total density compared to broadleaf (11 and 13%) and sedges (3 and 4%), respectively (Figure 1). The total density of weed was about 115 no m^{-2} and weed dry matter was 22 g m^{-2}.

Weed pressure

Weed pressure was evaluated in terms of visual weed rating and weed dry matter and which varied significantly among varieties (Table 9). Maximum weed growth was observed in weed monoculture. In terms of weed rating BRRI dhan59, BRRI dhan67 and BINA dhan10 appeared as most weed suppressive since weed ratings against these varieties were low (only 3).Weed growth was rated between 4 and 5 for BRRI dhan50, BRRI dhan58, BINA dhan10 and BRRI hybrid dhan3 and between 5 and 6 for

BRRI dhan28, BRRI dhan29 and BRRI dhan47 indicating moderately weed suppressive. Highest weed rating (6-8) in BRRI dhan55, BINA dhan5 and BINA dhan8 signify their poor competitiveness against weeds. Weed dry matter followed almost similar trend as visual weed rating. Mean weed pressure across varieties was 22.63 g m^{-2} against 98.48 g m^{-2} recorded in weed monoculture, which denotes that on average, rice variety reduced weed pressure by about 77%. BRRI dhan59 emerged as the most weed suppressive variety reducing weed dry matter by 79% followed by BRRI dhan59 (74%), Agrodhan14 (72%), BINA dhan6 (69%), BINA dhan10 (68%), BRRI dhan50 (68%) and BRRI dhan47 (61%). Highest weed pressure of 66g m^{-2}was found in BINA dhan5 which was 39% less than in weed monoculture, and thus BINA dhan8 was identified as the weakest competitor with 33% less weed dry matter than in weed monoculture. Other varieties were intermediate in suppressing weeds within the range of 44 to 58%. Differences in weed rating and weed pressure in direct seeded aerobic rice have also been reported by many researchers (Rahman *et al.*, 2017; Anwar *et al.*, 2010; Zhao *et al.*, 2006b).

Relative yield loss

Relative yield loss is an excellent indicator of weed tolerance of a crop. The lower the relative yield loss the higher the degree of weed tolerance, since weed tolerance refers to the ability to maintain high yield in the presence of weed competition. Rice varieties showed wide diversity in relative yield loss which ranged from 40 to 78% (Figure 2). Relative yield loss was lowest in BRRI dhan59, followed by BRRI dhan67 and BINA dhan10 which exhibited high weed tolerance. BINA dhan8showed the lowest tolerance to weeds with a yield penalty of 78% closely followed by BINA dhan5, BRRI dhan55, BRRI dhan28 and BRRI dhan29. These findings closely resemble to those reported by Rahman *et al.* (2017).

Relationship among traits

Diversity in weed suppressive ability among varieties is reflected by the differences in growth traits especially traits associated with early faster growth. However, the regression analysis showed that weed biomass could be explained by early plant height and early visual vigor, by as much as 83% and 87%, respectively; while weed biomass itself was found to be effective for explaining grain yield (R^2= 0.43, n=14) and relative yield loss (R^2= 0.88, n=14). Regression analysis showed that early plant height at 15 DAS and early visual vigor appeared to be the two most important traits in predicting weed biomass (R^2=0.83 and R^2= 0.87, respectively, n=14). Weed biomass could explain grain yield by 43% and relative yield loss by 88% (Figure 3).

Table 1. Means for varieties over weeding regimes and for weeding regimes over varieties for plant height (cm) and height growth rate (cm day^{-1}) of rice.

Treatment	PH_{15}	PH_{30}	PH_{45}	PH_{60}	PH_{75}	PH_H	HGR_{0-15}	HGR_{15-30}
Variety#								
BRRI dhan28	9.05bcd	15f	29.58a-d	56.84cd	77.86	89.6abc	0.60bc	0.39cd
BRRI dhan29	8.95bcd	15.6de	28.03bcd	60.01bcd	72.12	91.57abc	0.59bc	0.43abc
BRRI dhan47	8.65cd	12.3i	31.30ab	64.27ab	72.47	87.35bc	0.57c	0.24g
BRRI dhan50	10.82a	15.75cde	28.18a-d	60.07bcd	73.83	87.2bc	0.71a	0.32ef
BRRI dhan55	7.75e	12.35hi	31.52a	65.68a	72.15	89.6abc	0.51d	0.30f
BRRI dhan58	9.25bcd	16.2bc	28.59a-d	60.59bcd	72.37	86.56bc	0.61bc	0.46a
BRRI dhan59	11.45a	17.3a	27.77cd	55.62d	71.08	85.93c	0.75a	0.38cd
BRRI dhan67	10.85a	16.65b	26.51d	60.77abc	69.83	89.73abc	0.71a	0.40bcd
BINA dhan5	6.75f	12.25i	27.04d	57.47cd	71.55	94.63a	0.44e	0.36de
BINA dhan6	9.3bc	16.3bc	29.39a-d	64.77ab	71.40	94.87a	0.61bc	0.46a
BINA dhan8	7.2ef	13.95g	29.49a-d	62.87ab	73.83	88.83abc	0.47de	0.44ab
BINA dhan10	11.05a	15.95cd	30.77abc	63.48ab	71.29	87.97bc	0.73a	0.32ef
BRRI hybrid dhan3	8.6d	12.9h	28.67a-d	63.34ab	73.26	89abc	0.57c	0.28fg
Agrodhan14	9.6b	15.3ef	30.74abc	64.14ab	74.42	92.47ab	0.63b	0.37de
CV (%)	2.62	1.36	4.2	4.91	3.92	4.38	2.63	5.35
Level of significance	**	**	*	**	NS	*	**	**
Weeding regime##								
Weed free	9.46a	15.32a	32.23a	64.55a	76.2a	97.58a	0.62a	0.38a
Weedy	9.007b	14.36b	29.99b	62.29b	69.0b	81.74b	0.59b	0.35b
CV (%)	0.99	1.51	2.59	2.83	3.51	3.42	0.99	2.02
Level of significance	**	**	**	*	**	**	**	**

PH_{15}, PH_{30}, PH_{45}, PH_{60}, PH_{75} and PH_H indicate plant height at 15 days after sowing (DAS), 30 DAS, 45 DAS, 60 DAS, 75 DAS and at harvest, respectively; HGR_{0-15} and HGR_{15-30} indicate height growth rate between 0 and 15 DAS and 15 and 30 DAS. #Data pooled across two weeding regimes; ##Data pooled across fourteen varieties within a column for each parameter. Means followed by different letters are significantly different at P=0.05 probability level according to least significant difference (LSD) test. ** indicates significant at 1% level of probability and * indicates significant at 5% level of probability, NS indicates non-significant.

Table 2. Means for interaction of varieties with weeding regimes for plant height (cm) and height growth rate (cm day^{-1}) of rice.

Treatment interaction	PH_{15}	PH_{30}	PH_{45}	PH_{60}	PH_{75}	PH_H	HGR_{0-15}	HGR_{15-30}
V_1F	9.3def	15.7de	26.42	56.13ghi	78.17	96.53abc	0.62cd	0.42a-f
V_1W	8.8efg	14.3f	32.75	57.55e-i	77.55	82.67fgh	0.58de	0.36f-i
V_2F	9.2def	16.2bcd	25.96	56.75f-i	75.58	100.5ab	0.61cd	0.46abc
V_2W	8.7efg	15ef	30.11	63.27a-g	68.66	82.6fgh	0.57de	0.41a-f
V_3F	8.9ef	12.7ghi	30.48	66.88abc	78.95	94.23bcd	0.59cde	0.25m
V_3W	8.4f-i	11.9ij	32.11	61.66b-g	66.0	80.47gh	0.56def	0.23m
V_4F	10.93ab	16.7bc	27.7	57.37e-i	73.0	96.33abc	0.726ab	0.38e-h
V_4W	10.7bc	14.8f	28.67	62.78a-g	74.66	78.07h	0.71ab	0.27j-m
V_5F	7.9ghi	12.5g-j	32.68	65.65a-d	75.83	97abc	0.52efg	0.30i-l
V_5W	7.6hij	12.2hij	30.36	65.72a-d	68.47	82.2gh	0.50fgh	0.30i-m
V_6F	9.5de	16.5bcd	25.97	56.97f-i	76.42	91.13c-f	0.62cd	0.46abc
V_6W	9.0def	15.9cd	31.22	64.22a-e	68.33	82.0gh	0.59cd	0.45a-d
V_7F	11.7a	17.6a	26.1	51.92i	72.17	94.0b-e	0.77a	0.39d-g
V_7W	11.2ab	17.0ab	29.44	59.33d-h	70.0	77.87h	0.74a	0.38d-h
V_8F	10.9ab	16.9ab	27.12	60.22c-h	73.0	99.33abc	0.72ab	0.39c-g
V_8W	10.8abc	16.4bcd	25.9	61.33b-g	66.66	80.13gh	0.71ab	0.41a-f
V_9F	6.9jk	12.8gh	24.47	53.92hi	74.0	102.4ab	0.46gh	0.39d-g
V_9W	6.6k	11.7j	29.61	61.03b-h	69.11	86.87d-g	0.43h	0.33g-j
$V_{10}F$	9.9cd	16.7bc	28.9	62.1a-g	75.25	104.1a	0.65bc	0.45a-e
$V_{10}W$	8.7efg	15.9cd	29.89	67.44ab	67.55	85.67e-h	0.57de	0.47ab
$V_{11}F$	7.5ijk	14.8f	29.68	62.42a-g	78.67	97.53abc	0.49fgh	0.48a
$V_{11}W$	6.9jk	13.1g	29.3	63.33a-f	68.99	80.13gh	0.45gh	0.41b-f
$V_{12}F$	11.2ab	16.2bcd	29.33	63.08a-g	75.5	96.6abc	0.74a	0.33g-k
$V_{12}W$	10.9ab	15.7de	32.22	63.89a-f	67.08	79.33gh	0.72ab	0.31h-l
$V_{13}F$	8.7efg	13.3g	27.82	65.25a-d	78.42	97.4abc	0.57de	0.30i-l
$V_{13}W$	8.5fgh	12.5g-j	29.53	61.44b-g	68.11	80.6gh	0.56def	0.26klm
$V_{14}F$	9.9cd	15.9cd	32.7	69.12a	83.17	99.07abc	0.66bc	0.39c-g
$V_{14}W$	9.3def	14.7f	28.77	59.16d-h	65.66	85.87d-h	0.61cd	0.35f-i
CV (%)	3.71	1.93	5.94	4.11	4.13	3.37	3.73	7.55
Level of sig.	**	*	NS	**	NS	*	**	**

PH_{15}, PH_{30}, PH_{45}, PH_{60}, PH_{75} and PH_H indicate plant height at 15 days after sowing (DAS), 30 DAS, 45 DAS, 60 DAS, 75 DAS and at harvest, respectively; HGR_{0-15} and HGR_{15-30} indicate height growth rate between 0 and 15 DAS and 15 and 30 DAS. Means followed by different letters are significantly different at P=0.05 probability level according to least significant difference (LSD) test. ** indicates significant at 1% level of probability and * indicates significant at 5% level of probability, NS indicates non-significant. V1=BRRI dhan28, V2=BRRI dhan29, V3=BRRI dhan47, V4=BRRI dhan50, V5=BRRI dhan55, V6=BRRI dhan58, V7=BRRI dhan59, V8=BRRI dhan67, V9=BINA dhan5, V10=BINA dhan6, V11=BINA dhan8, V12=BINA dhan10, V13=BRRI hybrid dhan3, V14=Agrodhan14: F indicates weed free condition, W indicates weedy condition.

Table 3. Means for varieties over weeding regimes and for weeding regimes over varieties for relative chlorophyll content (SPAD) and early visual vigor (EVV).

Treatment	EVV at 21 DAS	SPAD value at 45 DAS
Variety#		
BRRI dhan28	6.17ef	35.65
BRRI dhan29	5.83fg	36.2
BRRI dhan47	5.5g	38.15
BRRI dhan50	7.17bc	35.85
BRRI dhan55	4.5h	37.63
BRRI dhan58	7.0cd	35.63
BRRI dhan59	7.83a	34.87
BRRI dhan67	7.67ab	34.47
BINA dhan5	3.33i	36.07
BINA dhan6	7.0cd	34.77
BINA dhan8	4.33h	32.77
BINA dhan10	7.67ab	34.55
BRRI hybrid dhan3	6.5de	34.13
Agrodhan14	7.33abc	34.78
CV (%)	3.21	3.32
Level of significance	**	NS
Weeding regime##		
Weed Free	6.64a	39.75a
Weedy	5.9b	31.03b
CV (%)	1.21	1.26
Level of Significance	**	**

Data pooled across two weeding regimes; ## Data pooled across fourteen varieties within a column for each parameter. Means followed by different letters are significantly different at P=0.05 probability level according to least significant difference (LSD) test. ** indicates significant at 1% level of probability and * indicates significant at 5% level of probability, NS indicates non-significant.

Table 4. Means for interaction of varieties with weeding regimes for early visual vigor (EVV) and relative chlorophyll content (SPAD).

Treatment interaction	EVV at 21 DAS	SPAD value at 45 DAS
V_1F	0.67def	42.37a
V_1W	5.67ghi	28.93gh
V_2F	6.33efg	39.77ab
V_2W	5.33hij	32.63efg
V_3F	6.0fgh	42.23a
V_3W	5.0ij	34.07def
V_4F	7.67abc	41.1ab
V_4W	6.67def	30.6e-h
V_5F	5.0ij	40.43ab
V_5W	4.0kl	34.83cde
V_6F	7.33bcd	38.67a-d
V_6W	6.67def	32.6efg
V_7F	8.33a	37.47bcd
V_7W	7.33bcd	32.27efg
V_8F	8.0ab	39.43abc
V_8W	7.33bcd	29.5fgh
V_9F	3.67lm	40.23ab
V_9W	3.0m	31.9e-h
$V_{10}F$	7.0cde	40.5ab
$V_{10}W$	7.0cde	29.03gh
$V_{11}F$	4.67jk	38.03a-d
$V_{11}W$	4.0kl	27.5h
$V_{12}F$	8.0ab	39.9ab
$V_{12}W$	7.33bcd	29.2gh
$V_{13}F$	6.67def	37.5bcd
$V_{13}W$	6.33efg	30.77e-h
$V_{14}F$	7.67abc	38.87abc
$V_{14}W$	7.0cde	30.7e-h
CV (%)	4.54	4.7
Level of significance	**	**

Means followed by different letters are significantly different at P=0.05 probability level according to least significant difference (LSD) test. ** indicates significant at 1% level of probability and * indicates significant at 5% level of probability, NS indicates non-significant. V1= BRRI dhan28, V2= BRRI dhan29, V3= BRRI dhan47, V4= BRRI dhan50, V5= BRRI dhan55, V6= BRRI dhan58, V7= BRRI dhan59, V8= BRRI dhan67, V9= BINA dhan5, V10= BINA dhan6, V11= BINA dhan8, V12= BINA dhan10, V13= BRRI hybrid dhan3, V14=Agrodhan14: F indicates weed free condition, W indicates weedy condition.

Table 5. Days required for flowering (DF) and maturity (DM) of the rice varieties.

Variety	Days to 50% flowering (DF)		Days to maturity (DM)	
	Weed free	Weedy	Weed free	Weedy
BRRI dhan28	90	88	114	112
BRRI dhan29	111	110	136	132
BRRI dhan47	100	97	126	123
BRRI dhan50	113	110	137	134
BRRI dhan55	95	93	120	117
BRRI dhan58	99	96	127	125
BRRI dhan59	114	113	138	135
BRRI dhan67	99	97	125	121
BINA dhan-5	114	112	140	137
BINA dhan-6	116	114	142	139
BINA dhan-8	112	109	135	133
BINA dhan-10	110	108	136	133
BRRI hybrid dhan3	113	110	139	136
Agrodhan14	98	95	124	121
Average	106	103.7	131.4	128.4

Table 6. Means for varieties over weeding regimes and for weeding regimes over varieties for yield attributes, yield and straw production of rice.

Treatment	Total tillers hill^{-1} (no.)	Effective tillers hill^{-1} (no.)	Non effective tillers hill^{-1} (no.)	Sterile spikelets panicle^{-1} (no.)	Grains panicle^{-1} (no.)	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	HI (%)
Variety#									
BRRI dhan28	11.2ab	8.87ab	2.35abc	43.25de	44.63g	20.55gh	2.90cd	3.67cd	42.75
BRRI dhan29	9.1fg	7.4def	1.7de	43.23de	58.10a	20.10h	2.97bcd	3.77cd	42.81
BRRI dhan47	7.65h	5.82hi	1.75de	43.15de	50.20de	26.65a	2.98bcd	3.80cd	42.78
BRRI dhan50	9.1fg	7.55cde	1.55ef	45.77ab	52.80c	20.55gh	2.69d	3.46d	42.81
BRRI dhan55	8.25gh	6.68fg	1.56ef	46.33a	27.90k	21.1fgh	1.42g	1.77g	42.85
BRRI dhan58	9.65def	7.82cd	1.83de	43.87cde	38.20j	22.80cd	2.32e	2.95e	42.80
BRRI dhan59	11.75a	9.35a	2.4ab	43.17de	56.50b	22.5cde	3.40a	4.43a	42.81
BRRI dhan67	9.95c-f	8.1bcd	1.85cde	42.35de	48.43f	22.40de	3.33ab	4.35ab	42.80
BINA dhan5	8.65g	6.57gh	2.08bcd	42.23e	50.80d	22.2def	2.88cd	3.60cd	42.81
BINA dhan6	10.3cde	8.33bc	1.97b-e	44.05b-e	49.15ef	22.3def	3.08abc	3.97bc	42.80
BINA dhan8	6.75i	5.65i	1.1f	46.10a	42.60h	20.75gh	1.81f	2.27f	42.85
BINA dhan10	10.4cd	8.8ab	1.65de	44.13bcd	51.25d	21.5efg	3.09abc	4.08abc	42.80
BRRI hybrid dhan3	9.55ef	6.76efg	2.78a	43.65cde	43.25h	23.70bc	2.72cd	3.47d	42.80
Agrodhan14	10.8bc	8.07bcd	2.7a	45.43abc	40.90i	24.90b	2.97bcd	3.83cd	42.81
CV (%)	3.19	3.76	9.28	3.61	4.02	2.01	4.68	4.65	0.23
Level of sig.	**	**	**	**	**	**	**	**	NS
Weeding regime##									
Weed Free	11.85a	8.8a	3.03a	42.4b	53.1a	24.06a	3.95a	4.72a	45.5a
Weedy	7.17b	6.3b	0.86b	45.69a	40.01b	20.52b	1.56b	2.33b	40.1b
CV (%)	2.2	1.42	3.51	3.55	4.37	2.76	3.77	2.75	0.49
Level of sig.	**	**	**	**	**	**	**	**	**

Data pooled across two weeding regimes; ## Data pooled across fourteen varieties within a column for each parameter. Means followed by different letters are significantly different at P=0.05 probability level according to least significant difference (LSD) test. ** indicates significant at 1% level of probability and * indicates significant at 5% level of probability, NS indicates non-significant.

Table 7. Means for interaction of varieties and weeding regimes for yield attributes, yield and straw production of rice.

Treatment	Total tillers hill^{-1} (no.)	Effective tillers hill^{-1} (no.)	Non effective tillers hill^{-1} (no.)	Sterile spikelets panicle^{-1} (no.)	Grains panicle^{-1} (no.)	1000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	HI (%)
V_1F	15.03a	11.3a	3.73ab	39.8i	52.37f	21.4fgh	4.42abc	5.27ab	45.44
V_1W	7.4jkl	6.43gh	0.967i-l	46.7ab	36.9l	19.7hi	1.39lmn	2.07ijk	40.07
V_2F	12.2bcd	9.2bc	3cde	39.27i	70.9a	20.2ghi	4.54ab	5.43ab	45.52
V_2W	6mn	5.6hi	0.4l	47.2ab	45.3h	20hi	1.41k-n	2.12ijk	40.11
V_3F	10.1gh	6.93fg	3cde	39.7i	55.6cd	28.2a	4.44abc	5.32ab	45.46
V_3W	5.2no	4.7ij	0.5kl	46.6ab	44.8h	25.1bc	1.52k-n	2.28hij	40.10
V_4F	10.8efg	8.06c-f	2.73def	45.8a-e	60.5b	21.9efg	3.73de	4.45cd	45.54
V_4W	7.4jkl	7.03fg	0.367l	45.73a-e	45.1h	19.2ij	1.66j-m	2.4ghij	40.09
V_5F	11.1d-g	8.53b-e	2.57def	47.83a	31.7n	24.3cd	2.22hi	2.6ghi	45.53
V_5W	5.4no	4.83ij	0.567kl	44.83b-g	24.1o	17.9j	0.62o	0.92m	40.17
V_6F	12.1bcd	9.03bcd	3.07b-e	42.57gh	42.6ij	25.1bc	3.36ef	3.96de	45.53
V_6W	7.2klm	6.6gh	0.6kl	45.17b-f	33.8m	20.5ghi	1.29mn	1.93jk	40.07
V_7F	11.5def	8.93bcd	2.56def	40.27hi	59.9b	23.4cde	4.19a-d	5abc	45.54
V_7W	8.4ijk	7.26fg	1.13h-k	46.07abc	53.1ef	21.4fgh	2.48gh	3.70ef	40.07
V_8F	12.8bc	9.3bcd	3.67abc	39.17i	54.8de	23.9cd	4.35abc	5.2ab	45.46
V_8W	10.7fg	9.56b	1.13h-k	45.53a-f	42J	21.2fgh	2.46h	3.67ef	40.17
V_9F	12.2bcd	8.93bcd	3.27bcd	37.9i	60.1b	24.47cd	4.67a	5.58a	45.53
V_9W	5.1no	4.2j	0.9jkl	46.57ab	41.5j	20.1hi	1.1no	1.61kl	40.11
$V_{10}F$	11.6c-f	9.33b	2.27fg	43.1fg	59.2b	24cd	4.28abc	5.12ab	45.53
$V_{10}W$	9hi	7.33fg	1.66ghi	45b-g	39.1k	20.6ghi	1.88i-l	2.81gh	40.07
$V_{11}F$	9.1hi	7.4efg	1.7gh	45.97a-d	52.7f	23.9cd	2.98fg	3.57ef	45.56
$V_{11}W$	4.4o	3.9j	0.5kl	46.23abc	32.5mn	17.6j	0.6467o	0.96lm	40.15
$V_{12}F$	12b-e	9.56b	2.43ef	43.37efg	57.2c	22.9def	4.08bcd	4.87bc	45.54
$V_{12}W$	8.9hi	8.03def	0.867Jkl	44.9b-g	45.3h	20.1hi	2.1hij	3.13fg	40.06
$V_{13}F$	12.3bcd	8.06c-f	4.23a	43.83c-g	47.4g	26.5ab	4.01cd	4.81bc	45.53
$V_{13}W$	6.8lm	5.46hi	1.33hij	43.47d-g	39.1k	20.9ghi	1.44k-n	2.14ijk	40.08
$V_{14}F$	13.1b	8.86bcd	4.23a	45.13b-g	44.2hi	26.8ab	4.03bcd	4.83bc	45.54
$V_{14}W$	8.5ij	7.26fg	1.17h-k	45.73a-e	37.6kl	23def	1.91ijk	2.85gh	40.08
CV(%)	4.51	5.32	13.12	2.07	3.39	2.83	6.63	6.57	0.32
Level of significance	**	**	**	**	**	**	**	**	NS
LSD	1.22	1.14	0.72	2.58	1.85	1.79	0.52	0.66	0.35

Means followed by different letters are significantly different at P=0.05 probability level according to least significant difference (LSD) test. ** indicates significant at 1% level of probability and * indicates significant at 5% level of probability, NS indicates non-significant.V1=BRRI dhan28, V2=BRRI dhan29, V3=BRRI dhan47, V4=BRRI dhan50, V5=BRRI dhan55, V6=BRRI dhan58, V7=BRRI dhan59, V8=BRRI dhan67, V9=BINA dhan5, V10=BINA dhan6, V11=BINA dhan8, V12=BINA dhan10, V13=BRRI hybrid dhan3, V14=Agrodhan14: F indicates weed free condition, W indicates weedy condition.

Table 8. 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	Group	RD (%)	RDW (%)	SDR (%)
Angta	*Panicum distichum*	Gramineae	Grass	40.37	31.99	36.48
Bara shama	*Echinochloa crusgali*	Gramineae	Grass	11.24	25.72	18.48
Fulka	*Leptochloa chinensis*	Gramineae	Grass	10.38	17.94	14.17
Gaicha	*Paspalum commersonii*	Gramineae	Grass	8.08	6.98	7.54
Anguli	*Digitaria sangunalis*	Gramineae	Grass	10.38	0.77	5.58
Bara chucha	*Cyperusiria*	Cyperaceae	Sedge	4.60	3.44	4.03
Bonpat	*Melochia corchorifolia*	Malvaceae	Broadleaf	1.14	5.78	3.47
Titbegun	*Solanum torvum*	Solanaceae	Broadleaf	3.46	0.97	2.22
Hazardana	*Phyllanthus niruri*	Euphorbiaceae	Broadleaf	3.46	0.85	2.16
Bontula	*Sanchus arvensis*	Asteraceae	Broadleaf	1.14	2.47	1.82
Keshuti	*Eclipta alba*	Compositae	Broadleaf	1.14	1.14	1.14
Khudeshama	*Echinochloa colonum*	Gramineae	Grass	1.14	1.14	1.14
Kanaibashi	*Commelina bengalensis*	Commelinaceae	Broadleaf	1.14	0.26	0.70
Shialleja	*Dysophylla crassicaulis*	Lamiaceae	Broadleaf	1.14	0.26	0.70
Bathua	*Chenopodium album*	Chenopodiaceae	Broadleaf	1.14	0.17	0.67

Table 9. Varietals' effect on weed rating (1 to 9 scales) and weed dry weight (g m^{-2}).

Variety	Weed rating	Weed dry matter (g m^{-2})
BRRIdhan28	5.33de	45.2d
BRRI dhan29	5.33de	43.6de
BRRI dhan47	5.67cd	37.6g
BRRI dhan50	4.67ef	31.2h
BRRI dhan55	6.33bc	54.8b
BRRI dhan58	4.67ef	42.4ef
BRRI dhan59	3.0g	20.8k
BRRI dhan67	3.0g	25.2j
BINA dhan5	7.67a	65.5a
BINA dhan6	4.67ef	30.4h
BINA dhan8	6.67b	50.3c
BINA dhan10	3.0g	30.8h
BRRI hybrid dhan3	4.33f	41.2f
Agrodhan14	4.0f	27.2i
CV(%)	6.69	4.87
Level of Significance	**	**
LSD	0.95	1.7

Means followed by different letters are significantly different at P=0.05 probability level according to least significant difference (LSD) test. ** indicates significant at 1% level of probability and * indicates significant at 5% level of probability, NS indicates non-significant.

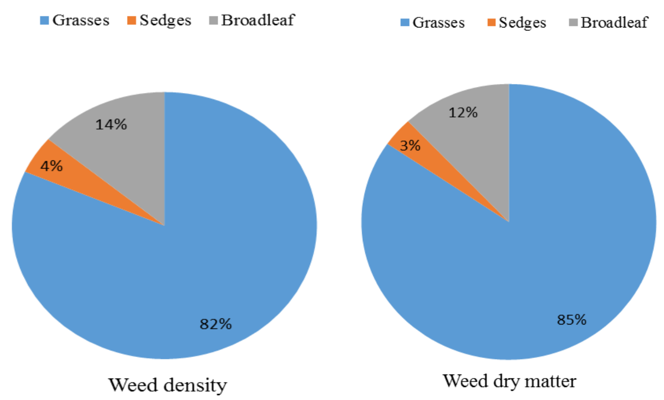

Figure 1. *Relative density and relative dry weight of different weed groups.*

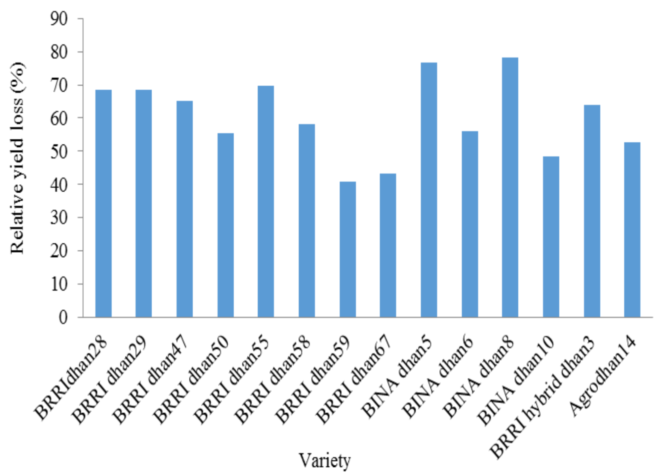

Figure 2. *Effect of variety on relative yield loss of rice.*

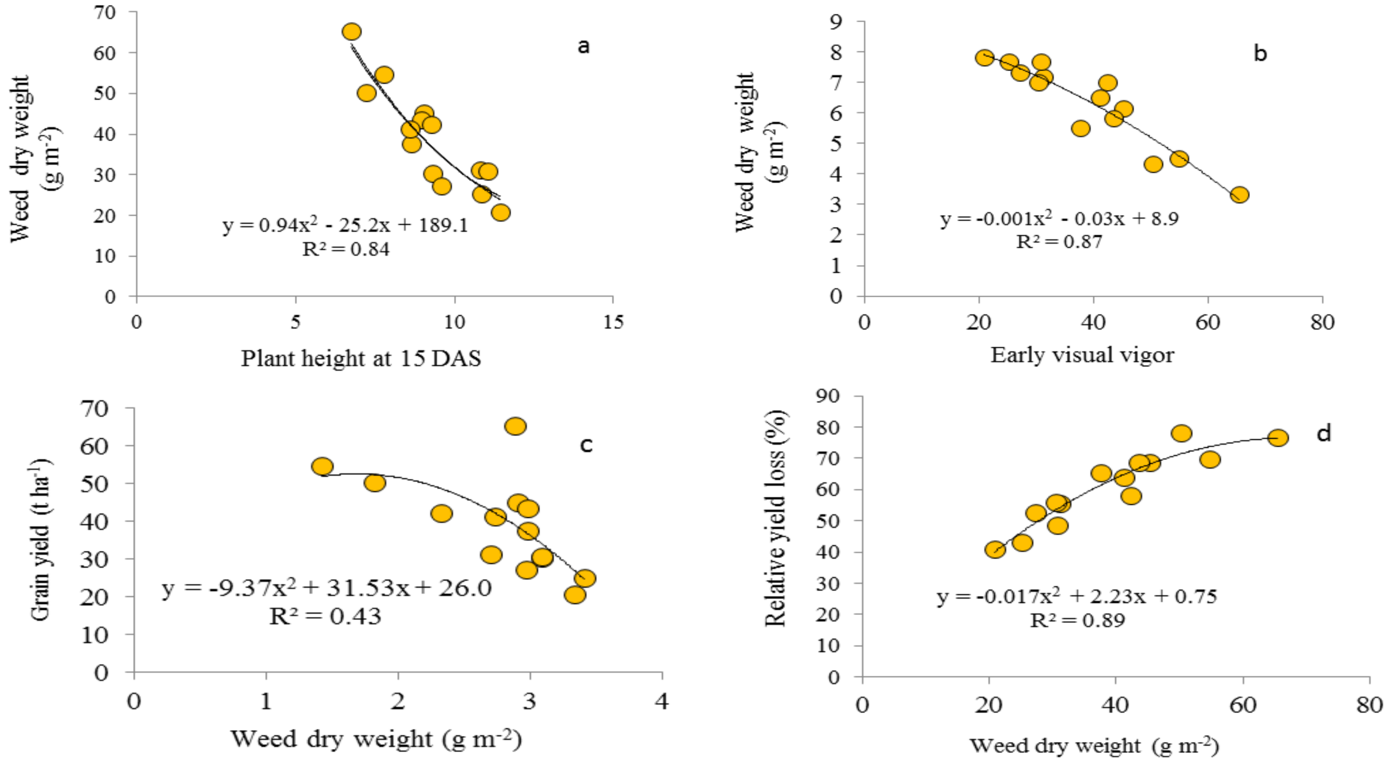

Figure 3. *Relationship between (a) plant height at 15 DAS and weed dry weight (b) early visual vigor and weed dry weight (c) weed dry weight and grain yield (d) weed dry weight and relative yield loss.*

Conclusion

The results of the study confirms that the varieties differed widely among themselves in their weed suppressive ability and yield performance, and fast early growth was the most desirable trait for weed competitiveness. Moreover, weed inflicted yield loss of rice can be minimized by selecting variety with strong weed suppressive ability. Therefore, considering productivity and weed suppressive ability, BRRI dhan59 can be recommended for cultivation following modified aerobic system to ensure satisfactory yield with less effort to weed management.

Conflict of interest

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

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