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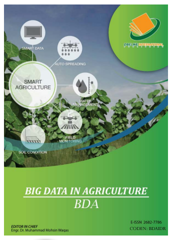

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RESEARCH ARTICLE

EVALUATION OF THE CULTIVAR MIXTURE STRATEGY AS A SUSTAINABLE TOOL FOR MANAGING WEEDS AND ENHANCING RICE YIELD

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ABSTRACT

The study was conducted to evaluate the potentiality of rice cultivar mixtures as a strategy for managing weeds and increasing the rice yield under different weeding regimes. Two rice cultivars having different plant stature and maturity periods *viz.* Binadhan-13 and BRRI dhan56 were used in this study. Factors included six cultivar mixture ratios *viz.* sole Binadhan-13, sole BRRI dhan56, 2:3, 3:2, 2:4 and 4:2 Binadhan-13 to BRRI dhan56, and four weed management practices *viz.* no, one, two and three weeding. The experimental design was randomized complete block with three replicates. Both the cultivars showed better growth, higher weed suppression and increased yield when grown in mixture irrespective of ratios compared to their monoculture performances. Based on the total rice grain yield, different mixture ratios performed in the order 4:2, 3:2, 2:3 and 2:4 Binadhan-13 to BRRI dhan56. Binadhan-13 and BRRI dhan56 inter-planted in 4:2 row ratio appeared as the best mixture ratio which resulted in 136% and 7% yield advantages and 17% and 24% weed dry matter reduction over sole culture of Binadhan-13 and BRRI dhan56, respectively. Hence, cultivar mixture strategy can be adopted as an effective tool for better weed management and increased yield of rice.

KEYWORDS

monsoon rice, cultivar interplanting, weed suppression, row ratio, rice productivity

1. INTRODUCTION

The yield level of monsoon rice in Bangladesh is not satisfactory despite the cultivation of high yielding varieties because of poor management practices. Severe weed infestation is one of the important factors for such low yield. Moreover, when weed control is neglected, there is a drastic reduction in yield because of weeds even if all other management practices are done properly. Reduction in yield due to weed has been estimated from 16 to 48% for monsoon rice [1]. Several options are available for controlling weeds in rice. Physical control is eco-friendly but tedious and labor-intensive [2]. Biological control by using bio-agents is ecofriendly but still not so effective for controlling weeds in rice field. Chemical control, on the contrary is the most effective, economic and practical way of weed management [3,4]. Although, weed management is mostly herbicide dependent in many rice growing areas but, concern over herbicide resistance in weeds and herbicide toxicity to crops may change the scenario in future [5,6]. Moreover, herbicides are often blamed for environmental hazard and considered as a threat to biodiversity [7]. Cultural method is another cost-effective and eco-friendly option of weed management. Cultural approaches play significant role to increase the competitiveness of a crop against weeds and hence suppress weed growth [8,9]. Cultural methods of weed control include stale seed bed, crop rotation, intercropping, growing allelopathic cover crops, weed competitive variety, and so on. Growing more than one cultivar in mixture is also a potential cultural tool for managing weeds [10,11].

Cultivar mixture refers to growing more than one cultivar of the same crop species simultaneously on the same piece of land [12]. Like species diversity, genetic diversity within single-species contributes to greater ecosystem productivity and stability as well and therefore cultivar mixtures offer a number of potential benefits especially under low-input and organic farming [13,14]. Cultivar mixture is a strategy to reduce pest infestation and increase crop growth and yield as well. Among other benefits, cultivar mixture gives the crop greater capacity to adjust under stress and compete against weeds [15]. A researcher listed three advantages of cultivar mixtures; stabilization of yield, compensation effects (a strong variety compensates for a weak or injured variety) and disease control [16]. Furthermore, inter-planting cultivars offers unique opportunities for on-farm conservation of genetic resources by allowing farmers to grow widely adopted traditional rice cultivars.

Reduction of weed growth due to cultivar mixture is well established. Cultivar mixtures can improve the competitive ability of rice reducing weed biomass production and diminishing rice biomass losses. A researcher concluded from their study with lowland rice that cultivars grown in mixture could reduce weed dry matter production by enhancing competitive ability of rice. Another researcher confirmed from his study with barley that inter-planting of barley cultivars improved the competitive ability of barley, reduced weed biomass production and diminished barley biomass losses. A previous researcher also opined that cultivar mixture could improve the competitive ability of crop against weed and he emphasized on devising a formula to design correct mixture ratio for effective weed suppression [17]. The use of cultivar mixtures thus be a potent supplement to weed management practices and could reduce production costs and environmental pollution.

Inter-planting cultivars is an alternative to monoculture which offers the advantages of both mixed cropping and monoculture [18-20]. As stated by some researchers, cultivar mixture is considered to be a very practical strategy for yield improvement in rice with less investment [21]. Yield advantages of cultivar mixture strategy is well documented in world literature. A researcher recorded yield advantages of cultivar inter-planting which was mostly due to the synergy of significant reduction in weed incidence and plant lodging. A group of researchers recorded higher productivity and yield stability in mixture cultivation of early- and long-duration rice cultivars [22]. A recent researcher opined that growing rice cultivars in mixture improves functional diversity by ensuring enhanced positive interactions between cultivars and in turn improves rice yield [23]. A scholar emphasized on the selection criteria of cultivars and opined that cultivars should be sensibly selected based on their plant architecture and growth duration to reduce intra-specific competition. Among others, yielding ability of the component cultivars is an important criterion for the success of cultivar mixture strategy. However, it is claimed that cultivar mixture resulted greater yield advantages in low-input farming than in high-input farming. The success of adopting cultivar mixture strategy will depend on the cultivar selection and their mixture ratio as well. Therefore, inter-planting cultivars could be a potential tool for yield enhancement and weed management in rice in a sustainable way.

Several research works have been reported on inter-planting cultivars in different crops and many encouraging findings regarding weed suppression, disease management and yield advantages of cultivar mixture [24]. Nevertheless, potentiality of rice cultivar mixture strategy has not been extensively investigated and properly documented so far. Therefore, it is necessary to evaluate cultivar mixture strategy as a tool for sustainable weed management in rice and for increasing growth and productivity of rice. The present study was initiated to assess the potentiality of cultivar mixture strategy in increasing productivity of rice and reducing weed pressure.

2. MATERIALS AND METHODS

2.1 Experimental site

The experimental field was located at 90º25'45.69" E and 24º43'07.27'' N and at an altitude of 18 meter above the sea level. The experimental area belongs to the non-calcareous dark grey soil under Agro-ecological Zone of the Old Brahmaputra Floodplain (AEZ-9). The region covers a large area of the Brahmaputra river borne sediments which were laid down before the river-shifted into its Jamuna Channel about 200 years ago [25].

The land was medium high and well drained with silty-loam texture. The soil of the experimental field was more or less neutral in reaction, low in organic matter content and the general fertility level of the soil was low. The experimental area was located under the sub-tropical climate, which is specialized by moderately high temperature and heavy rainfall during April to September and low rainfall with moderately low temperature during October to March. The monthly values of maximum, minimum and average temperature (°C), relative humidity (%), monthly total rainfall (mm) and sunshine (hour) received at the experimental site during the study period were 33.2°C, 14.6°C, 26.8°C, 83.6%, 176.9 mm, and 165.5 h, respectively.

2.2 Experimental treatments and design

The experimental treatments included in the experiment were as follows:

Factor A: Rice cultivar mixture ratio (6)	Factor B: Weed management (4)
1. Sole Binadhan-13	1. No hand weeding
2. Sole BRRI dhan56	2. One hand weeding
3. Binadhan-13+BRRI dhan56 in 2:3 row ratio	3. Two hand weeding
4. Binadhan-13+BRRI dhan56 in 3:2 row ratio	4. Three hand weeding
5. Binadhan-13+BRRI dhan56 in 2:4 row ratio	
6. Binadhan-13+BRRI dhan56 in 4:2 row ratio	

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replicates. Thus, total number of plot was 72. Each plot size was 4 m × 3 m.

2.3 Crop husbandry

The experimental land was prepared by a power tiller 10 days before transplanting. It was then puddled well with the help of a country plough to make the soil nearly ready for transplanting. Weeds and stubbles were removed, and the field was then leveled by laddering. The experimental field was then divided into unit plots as per layout one day before transplanting. The field was fertilized with 195 kg, 60 kg, 105 kg and 67.5 kg ha^{-1} as urea, triple superphosphate (TSP), muriate of potash (MoP), and gypsum, respectively. The full doses of TSP, MoP and gypsum were applied before transplanting. Urea was top dressed in three equal splits, at 15, 30 and 45 days after transplanting (DATs). Thirty days old seedlings were transplanted in the well-prepared puddled field on 12 August 2016 at the rate of three seedlings hill^{-1} maintaining row and hill distance of 25 cm and l5 cm, respectively. During transplanting, cultivar mixture ratio was maintained as per experimental treatments (Figure 1).

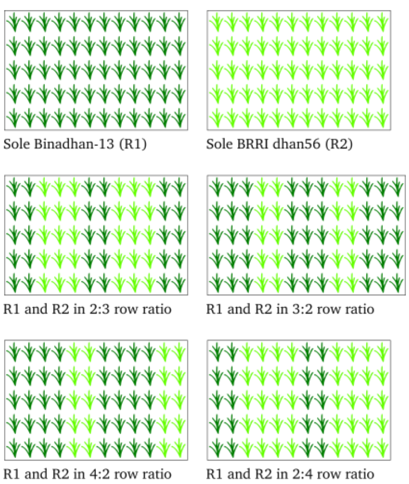

Figure 1: Rice cultivar mixture ratios

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Weed management was done as per experimental treatments. In case of no weeding, weeds were allowed to grow through the growing season. For one weeding treatment weeding was done manually once at 30 DAT. For two weeding, hand weeding was done twice at 30 and 45 DAT and for three weeding treatment, hand-weeding were done at 30, 45 and 60 DAT. Due to frequent rainfall during crop growth period no irrigation was needed and water was drained out before maturity. There were no remarkable infestations by insect pests or diseases during the crop growth period. Therefore, no plant protection measures were taken.

2.4 Data collection and harvesting

Data on weed population were collected at 75 DAT from each plot by using a 0.25 m × 0.25 m quadrate as per method described by a researcher [26]. The weeds within the quadrate were counted and converted to number m^{-2}. After counting the weed density, the weeds inside each quadrate were uprooted, cleaned, separated species-wise and dried first in the sun and then in an electric oven at 80°C for 72 hours. The dry weight of each species was taken by an electric balance and was expressed as g m^{-2}. Dominant weed species were identified using the summed dominance ratio (SDR) computed as follows [27]:

$$DR = \frac{Relative\ density\ (RD) + Relative\ dry\ weight\ (RDW)}{2} \ldots\ldots\ldots\ldots.(i)$$

Where,

$$Relative\ density = \frac{\text{Density of a given weed species}}{\text{Total weed density}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(ii)$$

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

Relative contribution of different weed groups (Grass, Broadleaf, Sedge) to the weed vegetation in terms of RD and RDW were also calculated.

The crops were harvested at full maturity. Maturity of crops was determined when 90% of the grains became matured. BRRI dhan56 and Binadhan-13 was harvested on 22 November and 20 December 2016, respectively. Five hills (excluding border hills) were selected randomly from each unit plot and uprooted before harvesting of each cultivar for recording data related to different yield components. Plant height measured from the collar zone of the plant to the tip of the longest leaf or panicle. All the tillers were counted from each hill and then average of five hills was calculated. It included both effective and non-effective tillers. Only the ear bearing tillers (having at least one filled grain) were counted from each hill and then average of five hills was calculated. Presence of any food material in the spikelet was considered as grain and total number of grains present on each panicle was counted. Thousand grains were taken randomly from five sample hills and weighed in an electric balance after proper sun drying. The weight was adjusted to seed moisture content of 14% and expressed in gram. The harvested crops of each plot was bundled separately, properly tagged and brought to threshing floor. The crops were then threshed and sun dried. The grains were cleaned and finally the weight was adjusted to moisture content of 14%. The yields of grain $plot^{-1}$ of both the cultivars finally converted to t ha^{-1}. Data on grain yield were collected from the whole plot. Data on yield contributing characters were recorded from 5 randomly selected hills of every variety from each plot. In case of cultivar mixture, total rice grain yield for each plot was calculated by adding the respective grain yield $plot^{-1}$ of both the cultivars; while for sole culture, grain yield of respective cultivar was considered as total grain yield.

2.5 Statistical analysis

The collected data were compiled and tabulated in the proper form and analyzed statistically. Analysis of variance was done following the Randomized Complete Block Design (RCBD) with the help of computer package MSTAT and the mean differences among the treatments were adjudged by Duncan's Multiple Range Test [28].

3. RESULTS

3.1 Plant height and tillering ability of rice

Effect of cultivar mixture ratio and weed management on plant height of Binadhan-13 was significant at harvest. The tallest plant of Binadhan-13 was observed in 3:2 row ratio which was statistically similar with 2:4 and 4:2 row ratios. Monoculture of Binadhan-13 resulted in the shortest plant of 152.2 cm (Table 1). It was found that plant height of Binadhan-13 was increased with the increasing number of weeding. No weeding resulted in the lowest plant height of 146.7 cm. One, two and three weeding resulted in 7, 11 and 16 cm increase, respectively in plant height of Binadhan-13 compared to no weeding treatment (Table 1).

Table 1: Effect of rice cultivar mixture ratio and weed management on plant height and tillering ability of Binadhan-13 and BRRI dhan56

Treatment	Binadhan-13		BRRI dhan56	
	Plant height (cm)	Total tillers $hill^{-1}$	Plant height (cm)	Total tillers $hill^{-1}$
Cultivar mixture ratio (Binadhan-13: BRRI dhan56)				
Sole (Binadhan-13 or BRRI dhan56)	152.20c	16.31bc	108.68	14.24bc
2:3	153.6bc	17.37a	106.77	15.30a
3:2	157.30a	16.38bc	106.91	14.32bc
2:4	155.80ab	17.22ab	107.65	15.15ab
4:2	155.3abc	15.65c	106.66	13.58c
$S\bar{x}$	1.12	0.310	1.38	0.310
Level of significance	*	**	NS	**
Weed management				
No weeding	146.70d	14.44d	100.70c	12.37d
One weeding	153.30c	15.82c	106.80b	13.75c
Two weeding	157.20b	17.25b	109.60ab	15.19b
Three weeding	162.10a	18.83a	112.20a	16.76a
$S\bar{x}$	1.003	0.276	1.23	0.277
Level of significance	**	**	**	**
CV (%)	2.51	6.47	4.44	7.39

In a column, figures with same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT). ** =Significant at 1% level of probability; *=Significant at 5% level of probability; NS= Non-significant

Weed management influenced plant height of BRRI dhan56, but cultivar mixture ratio failed to influence plant height. Plant height for BRRI dhan56 was highest in three weeding treatment which was statistically similar to that for two weeding treatment. As expected, plant height was found the lowest when no weeding was done (Table 1).

Effect of cultivar mixture ratio and weed management on tillering ability of Binadhan-13 was also significant. The highest tillering ability of Binadhan-13 was observed in 2:3 row ratio (17.37 $hill^{-1}$), which was statistically similar with the row ratio of 2:4, and the lowest tillering ability 15.65 $hill^{-1}$ was found in 4:2 row ratio (Table 1). Result shows that weed management positively influenced the tillering ability of Binadhan-13. With the increase in number of weeding, tillering ability was gradually increased. The highest number of tiller $hill^{-1}$ were recorded with three weeding treatment and it was on average 4 tillers $hill^{-1}$, more than that of no weeding (Table 1).

Cultivar mixture ratio and weed management significantly influenced the tillering ability of BRRI dhan56. The highest tillering ability (15.30 hill^{-1}) of BRRI dhan56 was observed in 2:3 row ratio and lowest one (13.58 hill^{-1}) was found in 4:2 row ratio of Binadhan-13 and BRRI dhan56 (Table 1). With the increase in number of weeding, tillering ability was gradually increased. The highest number of tillers hill^{-1} were recorded with three weeding treatment (Table 1).

3.2 Yield contributing characters and yield of rice

All yield contributing characters except 1000-grain weight and yield of Binadhan-13 and BRRI dhan56 were significantly affected by cultivar mixture ratio and weed management (Table 2). However, their interaction did not produce any significant effect on the yield contributing characters and yield of Binadhan-13 and BRRI dhan56.

Table 2: Effect of rice cultivar mixture ratio and weed management on yield contributing characters and yield of Binadhan-13 and BRRI dhan56

Treatment	No. of effective tillers hill^{-1}		Grains panicle^{-1}		1000-grain weight (g)		Grain yield hill^{-1} (g)	
	Binadhan-13	BRRI dhan56	Binadhan-13	BRRI dhan56	Binadhan-13	BRRI dhan56	Binadhan-13	BRRI dhan56
Cultivar mixture ratio (Binadhan-13: BRRI dhan56)								
Sole Binadhan-13	9.717c	9.617c	76.78b	106.1b	13.56	22.09	10.36b	22.85c
2:3	10.79ab	10.69ab	78.69a	108.0a	13.94	22.48	12.11a	26.31a
3:2	10.87a	10.77a	76.76ab	106.1ab	14.03	22.57	11.88a	25.98ab
2:4	10.48b	10.38b	76.27b	105.6b	14.01	22.54	11.45a	25.02b
4:2	10.97a	10.87a	75.63b	105.0b	13.63	22.16	11.53a	25.57ab
$S\bar{x}$	0.111	0.111	0.656	0.656	0.166	0.166	0.218	0.386
Level of sig.	**	**	*	*	NS	NS	**	**
Weed management								
No weeding	9.56d	9.47d	71.51d	100.80d	11.04d	19.57d	7.57d	18.70d
One weeding	10.33c	10.23c	75.03c	104.40c	12.95c	21.49c	10.04c	22.93c
Two weeding	10.88b	10.78b	77.83b	107.20b	15.23 b	23.76b	12.89b	27.44b
Three weeding	11.48a	11.38a	82.93a	112.30a	16.11a	24.65a	15.36a	31.52a
$S\bar{x}$	0.099	0.099	0.587	0.587	0.148	0.148	0.195	0.345
Level of sig.	**	**	**	**	**	**	**	**
CV (%)	3.63	3.67	2.96	2.14	4.16	2.57	6.60	5.33

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

The highest number of effective tillers hill^{-1} (10.97) of Binadhan-13 was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 4:2 row ratio which was statistically similar to those of 3:2 and 2:3 row ratios. Sole Binadhan-13, on the other hand, resulted in the lowest effective tillers hill^{-1} (9.72) (Table 2). The result shows that number of effective tillers hill^{-1} was increased with the increase in weeding frequency. No weeding resulted in the lowest number of effective tillers hill^{-1} (9.56). While three weeding resulted in the maximum numbers of effective tillers hill^{-1} (11.48). One weeding and two weeding resulted in 10.33 and 10.88 effective tillers hill^{-1}, respectively (Table 2).

In case of BRRI dhan56, the highest number of effective tillers hill^{-1} (10.87) was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 4:2 row ratio which was statistically similar to those of 3:2 and 2:3 row ratios. Sole BRRI dhan56, on the other hand, resulted in the lowest effective tillers hill^{-1} (9.62) (Table 2). Result showed that numbers of effective tillers hill^{-1} were increased with the increase in weeding frequency. No weeding resulted in the lowest numbers of effective tillers hill^{-1} (9.47). While three weeding resulted in the maximum numbers of effective tillers hill^{-1} (11.38). One weeding and two weeding resulted in 10.23 and 10.78 numbers of effective tillers hill^{-1}, respectively (Table 2).

Maximum number of grains panicle^{-1} (78.69) of Binadhan-13 was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 2:3 row ratio which was statistically similar with 3:2 row ratios. The 4:2 row ratio, on the other hand resulted in the lowest grains panicle^{-1} (75.63) which was statistically similar with the row ratio of 2:4 and monoculture of Binadhan-13 (Table 2). The table shows that number of grains per panicle was increased with the increase in weeding frequency. No weeding resulted in the lowest number of grains per panicle (71.51). Maximum number of grains panicle^{-1} (82.93) was found when three weeding was done (Table 2). As shown in table 2, 1000-grain weight of Binadhan-13 was increase with the increased in weeding frequency. Three weeding resulted in the highest 1000-grain weight (16.11 g) and lowest (11.04 g) was found when no weeding treatment was done (Table 2).

In BRRI dhan56, the highest number of grains panicle^{-1} (108.0) was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 2:3 row ratio which was statistically similar with 3:2 row ratios. The 4:2 row ratio, on the other hand, resulted in the lowest grains panicle^{-1} (105.0) which is statistically similar with the row ratios of 2:4 and monoculture of BRRI dhan56 (Table 2). As shown in Table 2, number of grains panicle^{-1} was increased with the increase in weeding frequency. No weeding resulted in the lowest number of grains panicle^{-1} (100.80). Maximum number of grains panicle^{-1} (112.30) was found when three weeding was done (Table 2). Result shows that 1000 grain weight was increase with the increase in weeding frequency. Three weeding resulted in the highest 1000-grain weight (24.65 g). Lowest 1000-grain weight (19.57 g) was found when no weeding treatment was given (Table 2).

Highest grain yield hill^{-1} (12.11 g) of Binadhan-13 was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 2:3 row ratio which was statistically similar with 3:2, 2:4, 4:2 row ratios. Sole Binadhan-13, on the other hand, resulted in the lowest grain yield hill^{-1} (10.36 g) (Table 2). Grain yield hill^{-1} was increased with the increase in weeding frequency. No weeding resulted in the lowest grain yield hill^{-1} (7.57 g). Maximum grain yield hill^{-1} (15.36 g) was found while three weeding treatment was done (Table 2).

On the other hand, the highest grain yield hill^{-1} (26.31 g) of BRRI dhan56 was recorded when Binadhan-13 and BRRI dhan56 were transplanted in 2:3 row ratio which was statistically similar with 3:2 and 4:2 row ratios. Sole Binadhan-13, on the other hand, resulted in the lowest grain yield hill^{-1} (22.85 g) (Table 2). Table 2 shows that grain yield hill^{-1} was increased with the increase in weeding frequency. No weeding resulted in the lowest grain yield hill^{-1} (18.70 g). Maximum grain yield hill^{-1} (31.52 g) was found when three weeding treatment was done (Table 2).

3.3 Total yield of rice

Cultivar mixture ratio exerted significant influence on total grain yield of rice (Figure 2). It is evident from the study that cultivar mixture ratio produced a significant advantage in grain yield over sole culture. Figure 2 shows that the highest total grain yield of 4.89 t ha^{-1} was obtained when

Binadhan-13 and BRRI dhan56 were transplanted in 4:2 row ratio. On the other hand, the lowest total grain yield (2.07 t ha^{-1}) of rice was recorded with sole culture of Binadhan-13. Sole culture of BRRI dhan56 produced the second highest grain yield which was statistically similar with that produced by transplanting Binadhan-13 and BRRI dhan56 in 3:2 row ratio. Transplanting Binadhan-13 and BRRI dhan56 in 2:3 or 2:4 row ratio resulted in significantly higher totalgrain yield than sole culture of Binadhan-13 but significantly lower than sole culture of BRRI dhan56 (Figure 2).

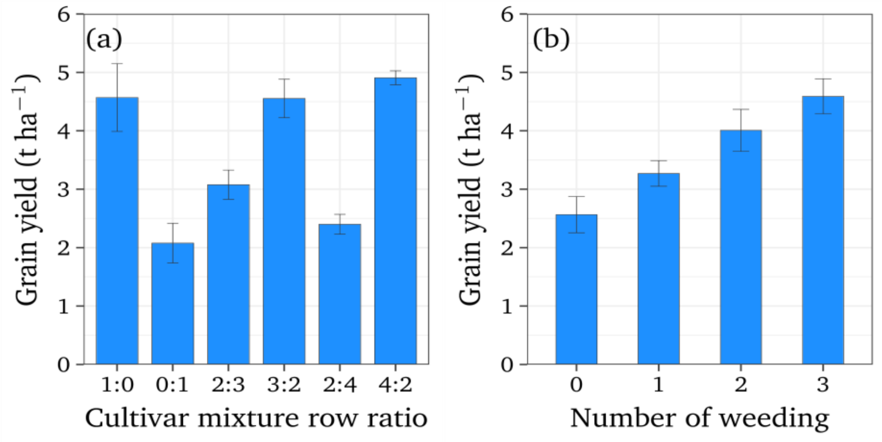

Figure 2: Effect of rice cultivar ratio (a) and weed management (b) on combined grain yield of rice

Total grain yield of rice was significantly affected by weed management practices. Total grain yield was increased gradually with the increasing number of weeding. It is evident from the study that one weeding, two weeding, three weeding resulted in respectively 27%, 55% and 78% increase in total grain yield compared to no weeding (Figure 2).

Interaction between cultivar mixture ratio and weed management significantly affected the total grain yield of rice (Table 3). Transplanting of Binadhan-13 and BRRI dhan56 interacted favorably with three weeding treatment to produce the highest total grain yield of 6.21 t ha^{-1}. On the other hand, the lowest grain yield of 1.28 t ha^{-1} was recorded when sole Binadhan-13 interacted with no weeding treatment. Result shows that three weeding coupled with sole or any rice cultivar mixture ratio always resulted in higher grain yield compared to two weeding or one weeding treatments. And, no weeding irrespective of cultivar mixture ratio produced very low total grain yield (Table 3).

Table 3: Interaction effects of rice cultivars and weed management on weed density, weed dry matter and combined grain yield of rice

Interaction (cultivars mixture ratio × weed management)		Weed density (no. m^{-2})	Weed dry matter (g m^{-2})	Combined grain yield (t ha^{-1})
Sole Binadhan-13	No weeding	119.52	150.67	3.26g
	One weeding	42.55	52.00	4.13f
	Two weeding	37.58	46.00	5.22d
	Three weeding	19.27	24.67	5.66b
Sole BRRI dhan56	No weeding	113.94	139.33	1.28l
	One weeding	61.88	78.33	1.80jk
	Two weeding	39.45	50.33	2.46hi
	Three weeding	24.93	32.00	2.74h
(Binadhan-13: BRRI dhan56) 2:3	No weeding	110.22	132.67	2.23i
	One weeding	36.39	46.00	2.66h
	Two weeding	31.00	38.00	3.37g
	Three weeding	19.37	24.33	4.03f
(Binadhan-13: BRRI dhan56) 3:2	No weeding	113.56	139.00	3.36g
	One weeding	31.55	40.33	4.26ef
	Two weeding	24.55	30.00	4.96d
	Three weeding	20.59	25.00	5.59bc
(Binadhan-13: BRRI dhan56) 2:4	No weeding	108.09	134.00	1.70k
	One weeding	42.48	52.33	2.11ij
	Two weeding	33.95	43.33	2.62h
	Three weeding	19.42	23.33	3.18g
(Binadhan-13: BRRI dhan56) 4:2	No weeding	99.05	125.33	3.54g
	One weeding	35.09	43.00	4.54e
	Two weeding	26.65	32.33	5.28cd
	Three weeding	21.42	27.33	6.21a
$S\bar{x}$		7.20	7.88	0.123
Level of sig.		NS	NS	**
CV (%)		19.57	26.59	5.89

In a column, figures with same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT). ** =Significant at 1% level of probability. NS = Non-significant.

3.4 Weed community and their growth

3.4.1 Floristic composition of weeds

Seven weed species belonging to six families infested the experimental field (Table 4). Based on their morphology, the following groups were distinguished: grass, broadleaved and sedges. Among the seven weed species, two were grasses, three were broadleaved and two were sedge. Scientific name, family name, morphological type and summed dominance ratio (SDR) of the weeds found in plots are presented in Table 4. The experimental field was mostly infested with broadleaved. Based on the SDR values, broadleaved weed species *Monochoria vaginalis* (SDR of 58.5%) was the predominant species and grass weed *Echinochloa crus-galli* emerged as second most dominant weed species (SDR 14.40%) in the experimental plots and the least dominant weed species was broadleaved weed *Nymphaea nouchali* (SDR 2.3%) (Table 4).

Table 4: List of weed species found in the experimental field with their summed dominance ratio (SDR)

Sl. no.	Scientific name	Family	Type	SDR (%)
1	*Monochoria vaginalis*	Pontederiaceae	Broad leaved	58.5
2	*Echinochloa crus-galli*	Gramineae	Grass	14.4
3	*Digitaria sanguinalis*	Gramineae	Grass	10.6
4	*Marsilea quadrifolia*	Marsileaceae	Broad leaved	6.3
5	*Scirpus juncoides*	Cyperaceae	Sedge	4.7
6	*Fimbristylis miliacea*	Cyperaceae	Sedge	3.2
7	*Nymphaea nouchali*	Nymphaeaceae	Broadleaved	2.3

3.4.2 Weed density and dry matter

Weed density was significant only for weed management (Table 5). As expected, weed density was decreased with the increase in number of weeding performed. The highest weed density of 110.7 weeds m^{-2} was recorded from no weeding treatment. One weeding, two weeding and three weeding resulted in around 63, 71 and 82% reduction in weed density (Table 5).

Weed dry matter was significantly affected by cultivar mixture ratio and weed management but their interaction was not significant (Table 3 and 5). Maximum weed dry matter 75 g m^{-2} was recorded from sole BRRI dhan56 plots which was statistically similar to sole Binadhan-13 plots. On the other hand, all the mixture ratios resulted in similar (ranged from 57 to 63.25 g m^{-2}) weed dry matter, which was significantly lower than those recorded from either monoculture of Binadhan-13 or BRRI dhan56 (Table 5).

Table 5: Effect of rice cultivar mixture ratio on weed density and weed dry matter

Treatment	Weed density (no. m^{-2})	Weed dry matter (g m^{-2})
Cultivar mixture ratio (Binadhan-13: BRRI dhan56)		
Sole Binadhan-13	54.73	68.33 ab
Sole BRRI dhan56	60.05	75.00 a
2:3	49.25	60.25 b
3:2	47.56	58.58 b
2:4	50.98	63.25 b
4:2	45.55	57.00 b
$S\bar{x}$	3.94	3.50
Level of significance	NS	**
Weed management		
No weeding	110.70a	136.80 a
One weeding	41.66 b	52.00 b
Two weeding	32.20 c	40.00 c
Three weeding	20.83 d	26.11 d
$S\bar{x}$	3.22	2.94
Level of significance	**	**
CV (%)	26.59	19.57

In a column, figures with same letter (s) or without letter do not differ significantly whereas figures with dissimilar letter differ significantly (as per DMRT). ** =Significant at 1% level of probability. NS = Non-significant. A significant effect of weed management on weed dry matter was observed in this study. Like weed density, weed dry matter was also found the highest (136.8 g m^{-2}) in weedy treatment. Weed dry matter was gradually decreased with the increase of in frequency of weeding. One weeding, two weeding and three weeding resulted in around 62, 71 and 81 % reduction in weed dry matter, respectively (Table 3).

4. DISCUSSION

Growing different rice cultivars in mixture enhances functional diversity and improves yield by providing positive interactions between cultivars and thus makes the system more efficient and sustainable as well. As mentioned by a researcher, advantages of cultivar mixture include yield stabilization, compensation effect and disease control. Disease control also helps to achieve other two goals. Furthermore, inter-planting cultivars offers a unique opportunity for on-farm conservation of genetic resources by allowing farmers to grow widely adopted traditional rice cultivars.

In this study Binadhan-13 and BRRI dhan56 were inter-planted in different row ratios under varying weed management practices to evaluate their combined yield performance and weed suppression ability. The selection criteria of the cultivars were mostly plant stature, growth duration, grain yield and quality/market price. Binadhan-13 was a tall (150-160 cm), lodging susceptible and late-maturing variety (140 days) with moderate yield and fine (14 g/1000 grains) aromatic grains with high market price; while BRRI dhan56 was a semi-dwarf (110 cm) and mid-maturing (110 days) variety with high yield potential and coarse (22 g/1000 grains) grains. Because of wide variation in agronomic traits between cultivars, it was expected that the peak demand for resources would occur in different times to satisfy the selection criteria of component cultivars in mixtures as mentioned by a researcher, and at the same time one variety will provide physical support to other to prevent lodging. Advantages of inter-planting rice cultivars over monoculture in terms of rice growth and yield are evident from our study. Based on the combined rice grain yield, the best row mixture ratios were in the order 4:2, 3:2, 2:3 and 2:4 Binadhan-13 to BRRI dhan56. Cultivar mixture also suppressed weed growth better than pure-line culture. These findings are in conformity with those of many researchers who confirmed that growing rice cultivars in mixture improves functional diversity by ensuring enhanced positive interactions between cultivars and in turn improves rice yield, and therefore cultivar mixture is considered to be a very practical strategy for yield improvement in rice with less investment.

Like species diversity, genetic diversity within single-species contributes to greater ecosystem productivity and stability as well and hence cultivar mixtures offer a number of potential benefits especially under low-input and organic farming. Several mechanisms are believed to account for the yield advantages in cultivar mixture like complementary use of above- and below-ground resources, compensatory effects between cultivars with different competitive abilities and facilitation effect of one cultivar on the growth of other [29-31]. In case of compensation, yield of one component cultivar increases while the other decreases without affecting combined yield when grown in mixtures [32].

In the present study, yield of both Binadhan-13 and BRRI dhan56 were increased when grown in mixture compared to their respective sole culture. So, compensation mechanism is not responsible for yield advantage in this case. While facilitation occurs when one component cultivar benefits another component by providing physical support (such as by preventing lodging), improving microclimate, ameliorating abiotic stresses and providing protection against different biotic stresses like weed, insects and diseases [33]. Although degree lodging of the rice cultivars and any changes in microclimate due to cultivar mixture were not monitored in this study but weed growth in terms of density and biomass production was studied. As weed biomass was recorded lower in different ratios of cultivar mixture than in sole culture of either cultivar, therefore, facilitation effect applies here. Moreover, higher resistance to lodging of tall cultivar Binadhan-13 in mixture due to physical support provided by short cultivar BRRI dhan56 might also contribute to increased combined yield of mixture. Higher yield in mixture might also be due to better disease control in cultivar mixture as reported by many researchers although that observation was beyond the scope of the present study. However, monitoring of any changes in microclimate, lodging resistance and disease incidence would better explain the mechanism behind yield advantages in cultivar mixture occurred in this study.

The mechanism which is mostly applicable here is complementary use of resources by the cultivars. In cultivar mixture, overall use of above- and below-ground resources are better than pure-line sole culture. This occurs only when component cultivars differ in their resource use in terms of space and time. Complementarity occurs when component cultivars vary in their architectures and growth duration. In this study, Binadhan-13 took 140 days to mature while BRRI dhan56 matured only in 110 days. They had also differences in their plant stature; Binadhan-13 was a tall variety (>150 cm) while BRRI dhan56 was a semi-dwarf one (< 110 cm). This huge difference in both plant stature and maturity period ensured the maximum utilization of the resources by the cultivars in space and time dimensions which ultimately resulted in increased combined yield.

In this study, performances of different mixture ratios in terms of yield were variable. This happened due to the differences in their spatial pattern resulted from inter-planting ratios of cultivars. As stated by many researchers [34,35] mixture ratio influences competitiveness of component cultivars and consequently the yield. A researcher on the contrary, opined that varying spatial arrangements determined plant population of each component cultivar that ultimately influenced the combined yield of the mixture [36]. As described by another researcher, when cultivars are planted in mixture heterogeneity is increased and both the cultivars enjoy greater capacity to adjust under different limited resources and various stresses resulting higher yield than pure-line mono culture.

Findings of the present study confirm that cultivar mixtures suppress weed growth better than sole culture of respective cultivar. Similar findings have been reported by many researchers who concluded from their studies that cultivars grown in mixture can reduce weed dry matter production by enhancing competitive ability of crop. Based on a study, cultivar mixture resulted in taller plants compared with pure-line sole crop due to intra-specific competition for resources especially for solar radiation and space [37]. Taller plants better suppress weeds than dwarf plants as reported by many researchers [38-42]. In our study, plant height of Binadhan-13 was recorded higher in different mixtures than in sole culture, which might help reduce weed growth (data not shown). However, mixture ratio had no effect on plant height of BRRI dhan56. Since plant height of Binadhan-13 varied with its relative proportion in the mixture, therefore there is scope for manipulating mixture proportions of component cultivars for better weed management. Another researcher also opined in the same tune.

Higher number of tillers in cultivar mixture compared with respective monocrop might also contribute to better weed suppression. Apart from taller plants, high tillering ability also is a good measure of plant vigor which enhances plant competitiveness against weeds. As reported by a scholar, tillering affects competitive ability of rice against weeds through changes in leaf area index and canopy coverage [43]. Although, contrasting findings have also been reported. High tillering resulted in faster canopy coverage which prevents sunlight from reaching the underlying weeds and thereby smothering the weeds. Another potential reason behind better weed control may be the allelopathic differences between the rice cultivars which was not taken into account in this analysis. However, the competitive effect of cultivar mixtures against weeds depends on several factors including plant architecture, growth behavior and weed species composition, botanical characteristics of weeds, agronomic management and agro-ecological conditions among others.

Findings of the present study confirms the advantages of inter-planting Binadhan-13 and BRRI dhan56 in terms of weed suppression and yield ability over their sole culture, and thus cultivar mixture could be considered as an effective tool for increasing yield and weed management in rice. Binadhan-13 and BRRI dhan56 inter-planted in 4:2 row ratios appeared as the best mixture ratio which resulted in 136% and 7% yield advantages and 17% and 24% weed dry matter reduction over sole culture of Binadhan-13 and BRRI dhan56, respectively. However, further site specific and in depth studies are required by including different functionally diverse (with respect to agronomic traits and pest resistance) potential rice varieties from the huge genetic pool, and by considering other agronomic management factors to harvest the maximum benefit of cultivar mixture approach.

In addition, to choose right combination and design proper mixture ratio, cultivars should be carefully selected considering their plant architecture, growth behavior and maturity period to reduce intra-specific competition. In general, farmers mostly prefer highly adopted traditional local varieties, varieties with high market price and varieties producing grains with special quality such as fine grains with aroma. Therefore, it can be recommended that farmers may prefer to that combination containing one cultivar having quality grain with high market price (for example Binadhan-13) and another one for high yield potential (such as BRRI dhan56). However, when weed management is of huge concern, one of the component cultivars should preferably be strongly weed-competitive or allelopathic which can support another one (weak-competitor) through facilitation mechanism. In conclusion, cultivar mixture strategy can be adopted as an effective tool for better weed management and increased yield of rice. Further in-depth studies are required to devise a formula for determining best cultivar combination and correct mixture ratios to achieve the maximum benefit.

5. CONCLUSION

Based on the combined rice grain yield, different mixture ratios performed in the order 4:2, 3:2, 2:3 and 2:4 Binadhan-13 to BRRI dhan56. Binadhan-13 and BRRI dhan56 inter-planted in 4:2 row ratio appeared as the best mixture ratio which resulted in 136% and 7% yield advantages and 17% and 24% weed dry matter reduction over sole culture of Binadhan-13 and BRRI dhan56, respectively. In conclusion, cultivar mixture strategy can be adopted as an effective tool for better weed management and increased yield of rice. Additional site-specific research on this aspect is required to devise a formula for determining best cultivar combination and correct mixture ratios to achieve the maximum benefit.

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