CONTENTS

Evaluation of Exotic Genotypes under Controlled Drought Conditions at Reproductive Phase

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ABSTRACT

A study was conducted in the Plant Physiology Division, Bangladesh Rice Research Institute (BRRI), Gazipur during T. Aman seasons 2018 to evaluate the genotypes collected from India under controlled drought conditions. Seven genotypes (CR Boro Dhan 2 (CR-898), CR Dhan 300, CR Dhan 10, Naveen, CR Sugangh Dhan 907, Geetanjali, and DRR Dhan 44) along with drought tolerant check BRRI dhan56, BRRI dhan71 and susceptible check IR64 were tested. Regarding growth characteristics genotype x treatment interaction effect was not significant but plant height, tiller number and straw weight were reduced due to drought stress indicating growth was arrested by drought stress. A similar observation was also found in panicle number. Under drought stress, more than 90% of panicle could exert fully only in CR Sugangh Dhan 907 and DRR Dhan 44 among the exotic genotypes which also showed 44.1% and 39.0% yield reduction, respectively compared to control plants. The grain yield reduction was mainly due to increased percent sterility (41.4% and 33.4% respectively) under stress conditions. Below 30 cm soil depth, the highest cumulative root length (CRL) was found in CR Sugangh Dhan 907 and DRR Dhan 44. DRR Dhan 44 also had the highest root length density (RLD) (0.73 cm cm^{-3}) and root weight density (RWD) (0.44 mg cm^{-3}). The exotic genotype DRR Dhan 44 produced the highest amount of root (572.7 mg) per gram of shoot. The results suggest that genotypes DRR Dhan 44 and CR Sugangh Dhan 907 appear to be suitable for cultivation in drought-prone areas and these could be used for the development of drought-tolerant variety as donor parents in the hybridization program.

Key words: Rice (*Oryza sativa* L.), drought stress, drought tolerance, reproductive phase.

INTRODUCTION

Drought is a major abiotic constraint in areas of rainfed rice (*Oryza sativa* L.) cultivation. About 50% of the world's rice is grown in a rainfed culture where drought stress may cause a substantial amount of yield loss (Lilley and Fukai, 1994). The rainfed lowland rice of Bangladesh is popularly known as transplanted Aman rice, which is usually seeded in July and transplanted in August. The seeding and transplanting may be delayed due to unpredictable drought, which causes the crop to have mild to severe drought stress at the reproductive and ripening phase when rainfall is minimal or none during October to November.

Drought is a complex phenomenon than most of the stresses like salinity, submergence, pests and diseases. It may occur at any crop growth stage and affects a large array of physiological, biochemical and molecular processes. Severe drought stress

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can be detrimental to plant development at all stages. However, the rice plant is most sensitive to the reduction division stage (Yoshida *et al.,* 1981). Yield loss can arise up to 100 % due to drought stress depending on the growth stage of the plant (Oladosu *et al.,* 2019). Yang *et al.* (2019) reported that drought stress at the flowering stage has a strong influence on rice physiological traits and yield. They also stated that stronger recovery capability can contribute to maintaining relatively high grain production, which could be a great target for the breeder in developing drought-tolerant rice cultivars.

Drought tolerance is a complex quantitative trait with a complicated phenotype (Oladosu *et al.,* 2019). However, the physiological pathways of both yield and drought tolerance are very complex. The development of drought-resistant cultivars will considerably improve rice production. According to Fukai and Cooper (1995) a drought-resistant genotype will have a higher grain yield than others when all the genotypes are exposed to the same level of water stress. Deep rooting ability can contribute to drought tolerance in several plants such as peanuts (Junjittakaran *et al.,* 2014), common beans (Polania *et al.,* 2017) and rice (Nakata *et al.,* 2011). Under water-limited conditions, the root length and thickness are important traits that determine the uptake of water from the sub-surface layer of soil (Pinta *et al.,* 2018). Seven genotypes were collected from India which were evaluated based on drought-tolerant mechanisms. The present study was undertaken to observe the performance of these materials under control drought stress at the reproductive phase in greenhouse conditions.

MATERIALS AND METHODS

Seven genotypes namely CR Boro Dhan 2 (CR-898), CR Dhan 300, CR Dhan 10, Naveen, CR Sugangh Dhan 907, Geetanjali, and DRR Dhan 44 collected from India were evaluated along with check variety BRRI dhan56, BRRI dhan71 and IR64 under control drought condition for reproductive stage drought tolerance in Plant Physiology Division at BRRI HQ, Gazipur during T. Aman season 2018. Twenty-five-day-old seedlings were transplanted in the aluminium pot (56 cm x 43 cm) containing 110 kg of puddled soil in a net house shaded by a polythene sheet. The soil was fertilized with Urea-TSP-MP@ 50-25-25 g/drum. Four hills were maintained in each drum using one seedling per hill. The experiment was laid out in two sets where the 1st set was grown in well-watered conditions and the 2nd set under stress conditions. At the panicle initiation stage water was drained out from the 2nd set so that the plants experience drought stress from the reduction division stage. Cultural operations were applied as and when necessary. The experiment was laid out in a completely randomized design with three replications. The water table depth was measured daily by installing a PVC pipe. The portion of PVC pipe (35 cm) below the ground surface was perforated. Soil moisture was recorded at 3-day intervals. At severe drought stress some lifesaving water was applied and calculated as follows: $= \Pi r^2 h$

Where, r = 56/2 = 28 cm (The radius of the circumference of the pot at the base of the hill.)

h = 0.5 cm/day (the approximate evapotranspiration at the period of Nov-Dec.

For the root study of these genotypes, another experiment was conducted following the protocol of screening for deep rooting ability with the deep-rooted check variety Morichboti (BRRI, 2005). Sprouted seeds were sown in a root elongation tube in the net house. The root elongation tube is a 70 cm long and 9.5 cm diameter perforated polyethylene tube filled up with 60:40 sand: soil mixture. Three seedlings were maintained in each tube and the tubes were

irrigated with Yoshida's culture solution throughout the experimental period. At 35 days after sowing the plants were harvested and the following observations were recorded: root length, cumulative root length (CRL), root length density (RLD), root and shoot dry weight, root weight density (RWD), and root shoot ratio.

RESULTS AND DISCUSSIONS

Water table depth and soil moisture

Plants were grown under an artificial rain-out shelter made of polythene sheet. So that plants could not receive any rainwater. Water was withheld from the drum at the PI stage.

At severe drought stress leaf rolling symptoms were found. When it existed overnight till the next morning then some lifesaving water was applied. Fig. 1 shows the average water table depth. Seven days after withholding of irrigation water the parched water table remained more than 30 cm depth below surface in all the variety. About eight days after withholding water there was no water in the PVC pipe in all the variety. The average soil moisture ranged from about 24.8 to 35.9 percent during the reduction division stage and 17.1 to 28.4 percent during the flowering stage to maturity, which reveals plants experience water stress in both the reproductive and ripening phases (Fig. 2).
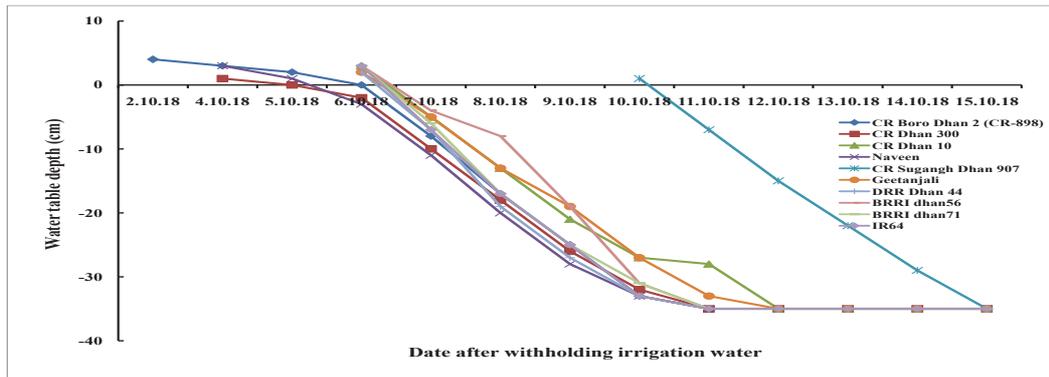

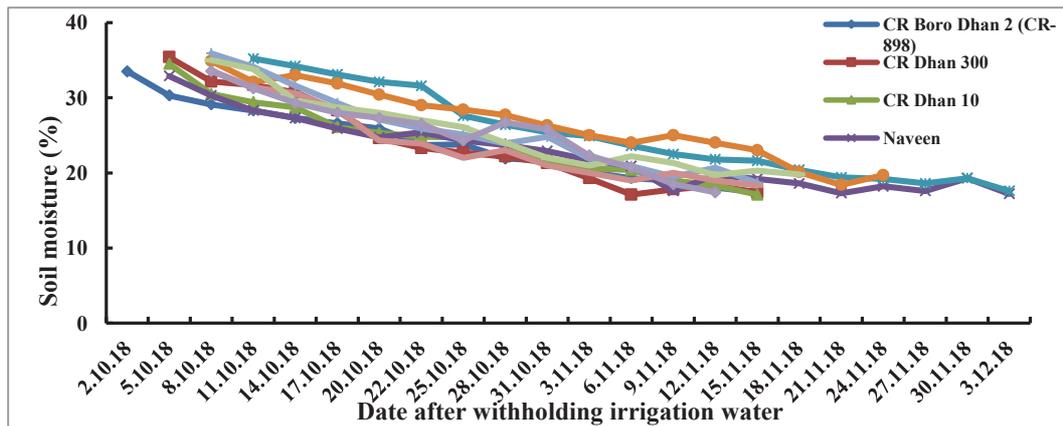Fig. 1. Parch water table depth at pot after withholding of irrigation water.

Fig. 2. Soil moisture status at pot after withholding of irrigation water.

Growth characteristics

Seven genotypes were tested for drought tolerance under control conditions. Due to water stress plant height, tiller number and straw weight all the growth characters were reduced in all the genotypes but the genotype treatment interaction effect was not significant (Fig. 3, 4 and 5). Plant height was reduced significantly only in CR dhan 10 among the tested genotypes. The tiller number was statistically similar under control and drought conditions in all the genotypes except CR BORO Dhan2 (CR-898) and IR64. Similarly, straw weight was reduced significantly only in CR BORO Dhan 2 (CR-898), CR Dhan 300, CR Dhan 10, Naveen, Geetanjali and BRRI dhan56. Rice plants are very sensitive to water stress during their entire growth period (Zeng and Shannon, 2000; Khan Abdullah, 2003). For its growth and development, it requires a considerable amount of water. Rice plants can transpire at their potential rate. Under soil moisture below field capacity, it cannot meet the demand of evapotranspiration and the plant begins running under water stress conditions. As a result, growth was arrested due to water stress compared to control plants. Murthy and Ramakrishnayya (1982) found that stem and leaf elongation decreased due to water deficit during vegetative and reproductive growth, which ultimately reduced plant height. Decreased tiller number due to water stress has also been reported in upland rice by Cruz *et al.* (1986). Decreased straw weight under drought stress might be due to a reduction of leaf area, plant height and a lower number of tillers.
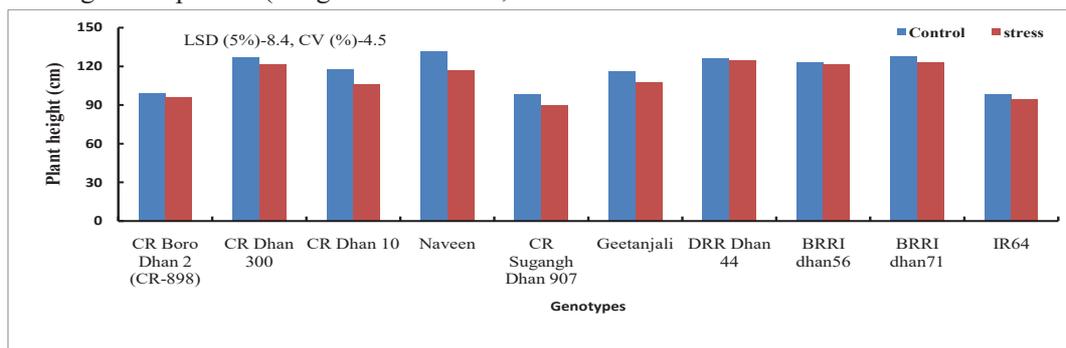

Fig. 3. Plant height of seven genotypes as affected by water stress at reproductive phase.
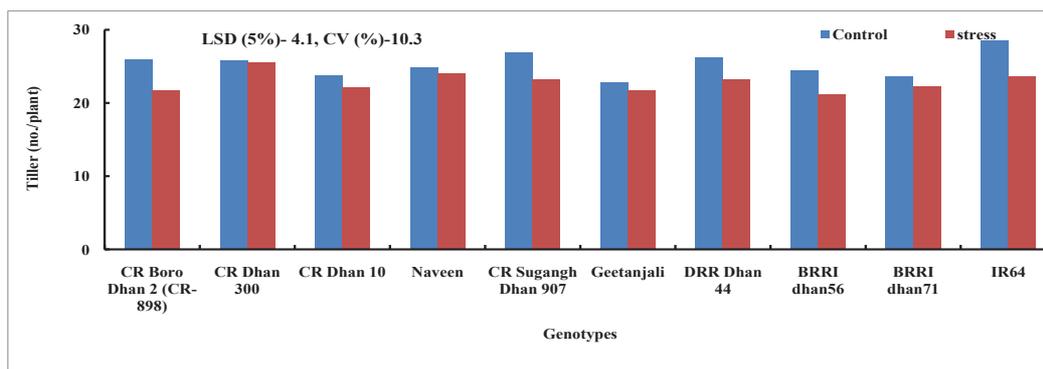
Fig. 4. Tiller number of seven genotypes as affected by water stress at reproductive phase.
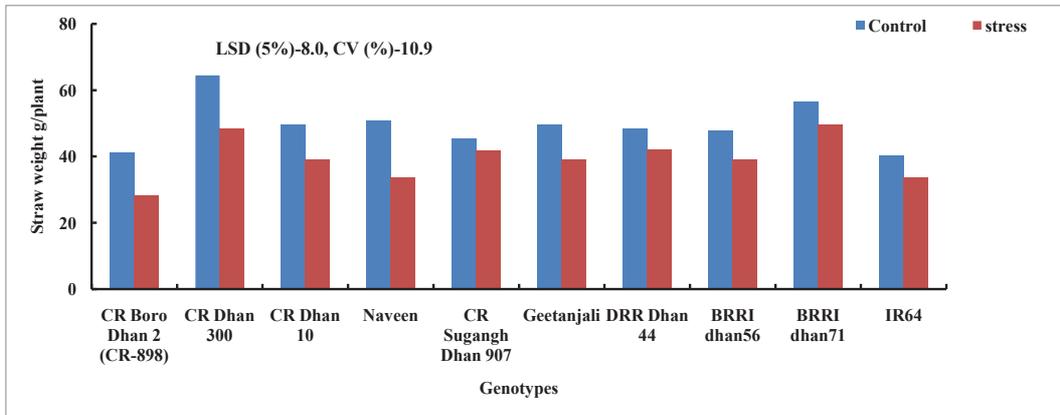
Fig. 5. Straw weight of seven genotypes as affected by water stress at reproductive phase.

Panicle characteristics

Generally, panicle number was reduced in all the genotypes due to water stress but a significant difference was not observed in control and stress conditions (Fig. 6). While a highly significant difference was found regarding panicle exertion percentage. Irrespective of genotypes, under control conditions, the panicle exertion rate was 94.1 to 99.4% but in stress conditions, the exertion rate varied from 68% to 96.4% (Table 1). The highest exertion rate (99.4%) was found in Naveen and DRR Dhan 44 under control conditions. However, under drought conditions, the highest exertion rate was observed in tolerant check BRRI dhan56. Among the tested genotypes, the highest exertion rate was observed in DRR Dhan 44 (93.6%) followed by Sugangh Dhan907 (91.7%). Under the control condition, the last

internode length was higher than the last leaf sheath length or more or less equal, which contributed to the exertion of the panicle fully while under stress condition last internode length was smaller than the last leaf sheath length (Table 1). So that, panicle could not exerted fully in some genotypes. Normally tiller production continues up to the heading but when soil moisture stress was applied at the panicle initiation and booting stage plant could not attain the maximum tillers as well as panicle number was reduced. It might be possible that severe drought impeded panicle exertion or caused the death of some of the panicles eventually reducing the number of panicles per hill (Mamin, 2003). These results conform with the findings of earlier research (BRRI, 2011; 2012; 2014). O'Toole and Namuco (1983) found that panicle exertion rate decreased linearly with a decrease in leaf water potential.
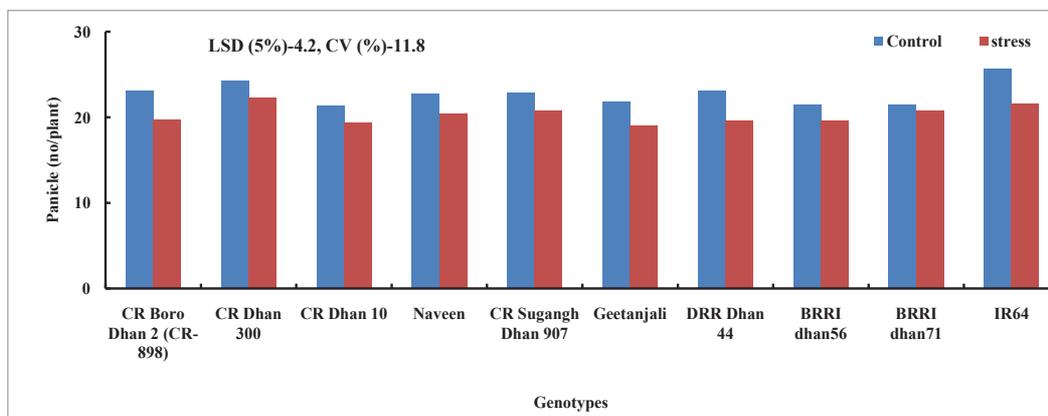
Fig. 6. Panicle number of seven genotypes as affected by water stress at reproductive phase.

Table 1. Panicle length, panicle exertion, last leaf sheath and internode length of tested seven genotypes as affected by water stress at reproductive phase.

Designation	Panicle length (cm)		Panicle exertion (%)		Last leaf sheath length (cm)		Last internode length (cm)	
	Control	Stress	Control	Stress	Control	Stress	Cont-rol	Stress
CR Boro Dhan 2 (CR-898)	24.1	22.4	97.3	79.5	28.8	30.1	29.1	25.7
CR Dhan 300	21.4	20.4	97.6	69.5	28.3	30.4	30.9	26.3
CR Dhan 10	19.5	18.6	95.9	84.7	28.2	26.9	28.9	24.1
Naveen	23.3	22.5	99.4	79.5	32.5	31.5	35.1	26.3
CR Sugangh Dhan 907	18.3	17.2	98.1	91.7	24.5	22.8	26.9	22.5
Geetanjali	23.2	21.8	94.1	68.0	32.4	33.5	32.5	30.2
DRR Dhan 44	20.1	19.4	99.4	93.6	29.2	33.9	32.7	30.2
BRRI dhan56	25.5	23.0	97.2	96.8	34.5	32.7	35.3	29.3
BRRI dhan71	25.5	24.1	96.6	94.4	35.9	36.2	36.9	32.7
IR64	24.1	23.9	98.3	69.3	28.4	29.1	29.1	26.7
LSD (5%)	2.4		6.4		4.3		4.6	
CV (%)	6.6		4.3		8.5		9.4	

Yield and yield component

A significant reduction was found in the grain yield of all the genotypes under stress conditions compared to the control condition (Table 2). The grain yield varied from 31.34 to 47.10 g plant[-1] under control conditions while under stress conditions it varied from 8.33 to 24.98 g plant[-1]. The exotic genotype Geetanjali has greater yield potential at the control condition but under stress conditions, BRRI dhan71 produced the highest grain

yield followed by BRRI dhan56 and the exotic genotype DRR Dhan 44. Among the tested genotypes, the lowest percent yield reduction was found in DRR Dhan 44 (39.0%) followed by CR Sugangh Dhan 907 (44.1%). Regarding filled grain number, the highest number of filled grain was found in CR Sugangh Dhan 907 both under control and stress conditions. The genotype DRR Dhan 44 also produced a statistically similar number of filled grains, which also showed less than 50% sterility. HI was reduced significantly due to water stress. However, the genotype DRR Dhan 44 showed the highest HI (0.32) under drought stress compared to other exotic genotypes. In all the genotypes the filled grain number was decreased concomitant increase of the per cent sterility, which indicates the per cent sterility was very sensitive to reproductive phase water deficit, which is attributed to poor panicle exertion in which anthesis is inhibited in the unexerted portion (O'Toole and Namuco, 1983). In rice, low water potential around the time of anthesis may lead to a failure of anther dehiscence, which leads to male sterility (Saini and Westgate, 2000). Islam and Islam (2010) reported that the yield of T. Aman was reduced by 30 and 55.2% for five days of drought at the reproductive and ripening phases respectively. Yue *et al.* (2006) suggested that the yield loss and harvest index reduction under drought stress in the late season were associated with the reduction of spikelet fertility, biomass and grain weight.

Table 2. Grain yield, filled grain no., % sterility and HI of 7 genotypes as affected by water stress at reproductive phase.

Designation	Grain yield (g plant^{-1})			Grain no. plant^{-1}		% Sterility		HI	
	Control	Stress	% Reduction	Control	Stress	Control	Stress	Control	Stress
CR Boro Dhan 2 (CR-898)	39.87	12.07	69.7	1918.8	682.4	26.0	66.9	0.47	0.23
CR Dhan 300	41.30	10.31	75.0	1812.1	576.5	25.3	74.6	0.36	0.15
CR Dhan 10	33.71	16.57	50.8	1508.2	855.7	32.0	60.2	0.38	0.27
Naveen	31.34	13.22	57.8	1754.7	876.4	34.0	66.1	0.35	0.23
CR Sugangh Dhan 907	33.08	18.48	44.1	1863.6	1262.5	28.5	41.4	0.39	0.27
Geetanjali	47.10	8.33	82.3	2202.5	429.8	32.6	75.1	0.45	0.15
DRR Dhan 44	36.56	22.32	39.0	1737.7	1176.6	26.5	33.4	0.40	0.32
BRRI dhan56	38.21	23.73	37.9	1785.3	1240.8	28.3	35.7	0.41	0.34
BRRI dhan71	41.68	24.98	40.0	1857.8	1230.8	17.7	29.8	0.41	0.31
IR64	42.49	9.08	78.6	1917.7	426.4	25.5	72.4	0.48	0.19
LSD (5%)	11.2			548.6		15.8		0.10	
CV (%)	24.9			24.5		23.0		18.2	

Root characteristics

The deep rooting ability of a genotype is assumed to be related to drought resistance or tolerance of a genotype. Deep root helps plants to utilize sub-surface water for the maintenance of high water potential to maintain normal panicle development and growth. Plants first draw water from the surface layers, and subsequently, the area of water extraction gradually shifts downward through the soil profile (Araki *et al*., 2006; Luo *et al*., 2023). Genotypic variation was observed for all the parameters. All the tested genotypes produced more than 50 cm long roots (Fig.7). The check variety Morich Boti produced the longest root (71.3 cm) followed by BRRI dhan71 and BRRI dhan56. Among the exotic genotypes CR Dhan 10, Geetanjali and DRR Dhan 44 produced more than 60 cm long roots. The sum of the length of roots is called cumulative root length (CRL). The check variety Morich Boti always produced the highest CRL (Table 3). However, among the exotic genotypes CR Dhan 10 had the highest CRL up to 30 cm depth, but below 30 cm soil depth the highest CRL was found in CR Sugangh Dhan907 and DRR Dhan 44. The total CRL was maximum in DRR Dhan 44. The root length density (RLD) is the length of roots per unit volume of soil. The RLD of exotic genotypes CR Dhan 10, CR Sugundh Dhan 907, and DRR Dhan 44 were comparable with the check variety Morich Boti. Root dry weight was also highest in DRR Dhan 44 among the exotic genotypes. Root weight density (RWD) is one of the most important parameters used for the evaluation of roots. Maximum RWD value was observed in deep-rooted check variety Morich Boti (0.49 mg cm^{-3}). Among the tested exotic genotypes the highest RWD value was found in DRR Dhan 44 (0.44 mg cm-3) which was statistically similar with check variety Morich Boti. The other most important character rooting ability is the ratio of root and shoot and it expresses the amount of root (mg) produced per gram of shoot. Among the tested genotypes, the highest amount of root produced by the check variety Morich Boti (693.9 mg/g of shoot) followed by the exotic genotype DRR Dhan 44 (572.7 mg/g of shoot). Genotypic variations in root traits have been reported in rice (Yu *et al*., 1995: Nguyen *et al*., 1997). Under drought conditions, the soil starts drying from the surface but deep soil horizons may remain wet and able to supply water to the plant's roots. Consequently, deep root portions may be more important than shallow root portions when a variety is to be examined for drought tolerance. Abd Allah *et al.* (2010) showed that root depth, root thickness, root volume, and dry root: shoot ratio were associated with drought tolerance. Genotypes or cultivars with deep root development will maintain higher leaf water potential under water limited condition. Well-developed root system will help the plant in maintaining plant water status (Kato *et al*., 2007). The deeper root system would significantly increase the total biomass as well as yield (Mohankumar *et al.*, 2011).
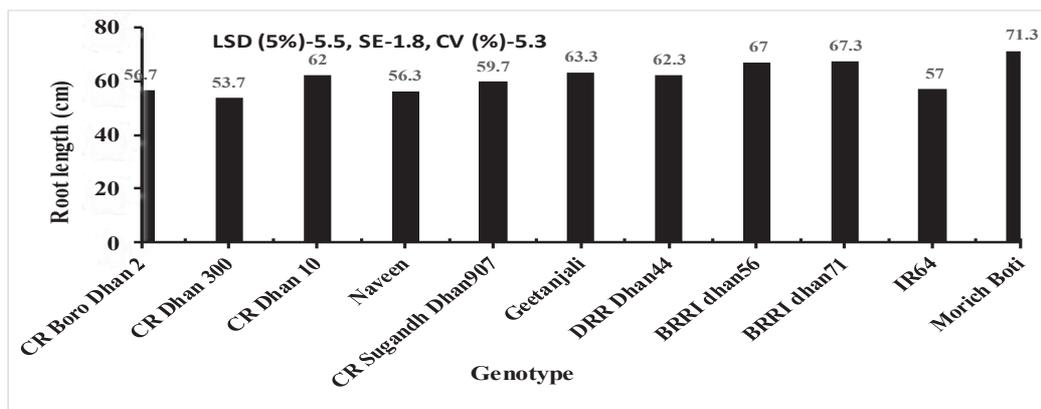
Fig. 7. Root length of seven tested genotypes with check variety Morich Boti.

Table 3. Cumulative root length (CRL), root length density (RLD), root weight, root weight density (RWD) and root shoot ratio of seven tested genotypes with the check variety Morich Boti.

Designation	CRL upto 30 cm depth (cm)	CRL below 30 cm depth (cm)	Total CRL (cm)	RLD (cm cm^{-3})	Root weight (mg)	RWD (mg cm^{-3})	Root shoot ratio (mg/g)
CR Boro Dhan2	2496.7	845.7	3342.3	0.67	1360.0	0.27	323.3
CR Dhan 300	2728.0	459.0	3187.0	0.64	1036.7	0.21	227.3
CR Dhan 10	2772.7	821.7	3594.3	0.72	1550.0	0.31	285.3
Naveen	2622.7	534.3	3157.0	0.64	1173.3	0.24	220.8
CR Sugandh Dhan 907	2532.0	998.0	3530.0	0.71	1393.3	0.28	345.7
Geetanjali	2085.7	521.3	2607.0	0.53	1210.0	0.24	363.0
DRR Dhan 44	2659.7	973.0	3632.7	0.73	2193.3	0.44	572.7
BRRI dhan56	2516.3	746.0	3262.3	0.66	1223.3	0.25	290.1
BRRI dhan71	2350.3	1222.7	3573.0	0.72	1610.0	0.32	341.6
IR 64	2526.7	783.3	3310.0	0.67	1243.3	0.25	294.6
Morich Boti (CK)	2877.3	1033.0	3910.3	0.79	2410.0	0.49	693.9
LSD (5%)	420.1	196.3	564.6	0.11	223.6	0.45	103.4
CV (%)	9.6	14.2	9.8	9.8	8.8	8.8	16.9

CONCLUSION

Among the seven exotic genotypes collected from India DRR Dhan 44 showed better performance under drought conditions followed by CR Sugandh Dhan 907 considering yield reduction, percent sterility and root characteristics, which could be used as donor parent in the hybridization programme.

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Double Transplanting of Dry Season Rice: A Unique Technology to Optimize Yield of Late Transplanted Rice in Northern Bangladesh

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ABSTRACT

In irrigated condition, double transplanting (DT) of dry season rice in Potato-Rice-Rice cropping pattern emerges as a promising technology to reduce yield losses associated with late-planted dry season rice. A consecutive three-year experiment encompassing three planting dates (20, 28 February and 08 March) and four seedling ages (45, 60, 75 days, and with 75-day for double transplanting- 35 days in the seedbed and 40 days in the first transplanted plot) was conducted to assess the performance of double-transplanted dry-season rice in comparison to conventional transplanting methods. Across the years, the grain yield of dry season rice exhibited a gradual decline with the advancement of planting time. However, the higher grain yield was consistently found from double transplanted dry season rice in all planting times. The yield advantage from double transplanting was 17%, 13%, and 16% for planting times on 20 February, 28 February, and 08 March, respectively compared to conventional transplanting. The system productivity of Potato-Double transplanted dry season rice-wet season rice cropping pattern was higher (1-6%) in all planting times the compared to the cropping pattern with traditional transplanting method. Double transplanting technology was found more stable compared to traditional method in late planting situation. The average added net returns with double transplanted dry season rice over traditional transplanted rice was US$139 to US$187 ha^{-1} 20 February, US$67 to US$117 ha^{-1} 28 February and US$68 to US$171 ha^{-1} 08 March planting. These findings highlight the profitability of adopting double transplanting in the Potato-Rice-Rice cropping system.

Key words: Double transplanting, late planting, productivity, net profit

INTRODUCTION

Rice (*Oryza sativa* L.) in the dry season followed by rice in the wet season is the major cropping pattern in irrigated medium highlands of Southeast Asian countries like India, Nepal, Bangladesh and Myanmar. In Bangladesh, Boro is the dry season irrigated rice and transplanted Aman is the wet season rice which is usually transplanted with 25-35 day old seedling from July to August. T. Aman is harvested from early November to middle of December depending on growth duration, transplanting time and photosensitivity of varieties. Between T. Aman harvest and Boro crop establishment, there is a fallow period of 80-90 days. This wet-dry transition period between T. Aman harvest and Boro crop establishment may be a suitable niche for a non-rice crop. Short duration high value Rabi crops like potato, mustard, edible podded pea can be fitted in

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this transition period in some areas of Bangladesh (Elahi *et al.*, 2001; Khan *et al.*, 2004). Introduction of a non-rice crop in between two rice crops may help improve land productivity through a desirable shift in wetland soil ecology in one hand and proper utilization of natural resources to increase system productivity on the other hand. Potato is an important non-rice crop for Asian farmers because of its rich food value and high market price. It contains not only carbohydrate but is also a good source of protein, minerals, vitamin B and vitamin C (Slavin, 2013). It has been established that the total productivity of double rice cropping system could be improved by growing potato in fallow period between two rice (BRRI, 2006). System productivity of Potato-Boro-T. Aman is 29 t/ha whereas the productivity of Boro-Fallow-T. Aman is only 13 t/ha (Khatun *et al.*, 2003). Traditionally, Boro rice cultivation starts with nursery seeding in mid-November to early December. However, farmers intending to grow Boro rice after potatoes typically use older seedlings, which are usually sown in the nursery bed during the last week of December. Seeding of Boro rice in the nursery beds after mid-November produces lower grain yields (Thakur *et al.*, 2003). Boro rice produced higher grain yield upto 25 January transplanting. After 25 January planting, the grain yield declines significantly (BRRI, 1998; Chowdhury and Guha, 2000). The quandary of the productivity of potato and Boro rice may be taken care of by double transplanting of Boro rice. Double transplanting (DT) has been practiced for wet season rice in riverside lands of some Asian countries-India, Bangladesh and Nepal since long time back. It involves growing of seedling in the nursery, followed by transplanting in an intermediate field with closer spacing of 10 × 10 cm using 10-12 seedlings hill[-1]. After 45

days, tillers from the intermediate field are splitted and transplanted in the main field (Rashid *et al.*, 2004). Good prospects of double transplanting technology have also been reported in India (Roy *et al.*, 2007). However, there is a dearth of information regarding the performance of double transplanted dry rice in Potato-Rice-Rice cropping system. Recognizing the magnitude of the above-mentioned cause and the importance of potato and dry season rice in the cropping system, the present study was undertaken to evaluate the performance and economic productivity of double transplanting of dry season rice in Potato-Rice-Rice cropping system.

MATERIALS AND METHODS

Experimental site

The study was conducted in the northern region of Bangladesh at the research field of BRRI Regional Station Rangpur (25°41′N and 89°16′ E), Bangladesh, spanning from the dry season 2008 to wet season 2011. The climate of the area is subtropical and exhibits wide seasonal variations in rainfall, temperature and humidity. According to the weather data collected from a nearby weather station (25°43'N and 89°15'E) of Bangladesh Meteorological Department, the hot season commences early in April and extends through July. The maximum temperature observed was about 32 to 36 °C (90 to 97 °F) during the months of May, June, July and August, whereas, the minimum temperature recorded in January ranged from 6 to 17 °C (43 to 63 °F). The average annual rainfall was 159-185 mm, 75–80% of this precipitation occurred during the monsoon season from June to September. Figure 1 depicted the weather pattern observed throughout the study period.
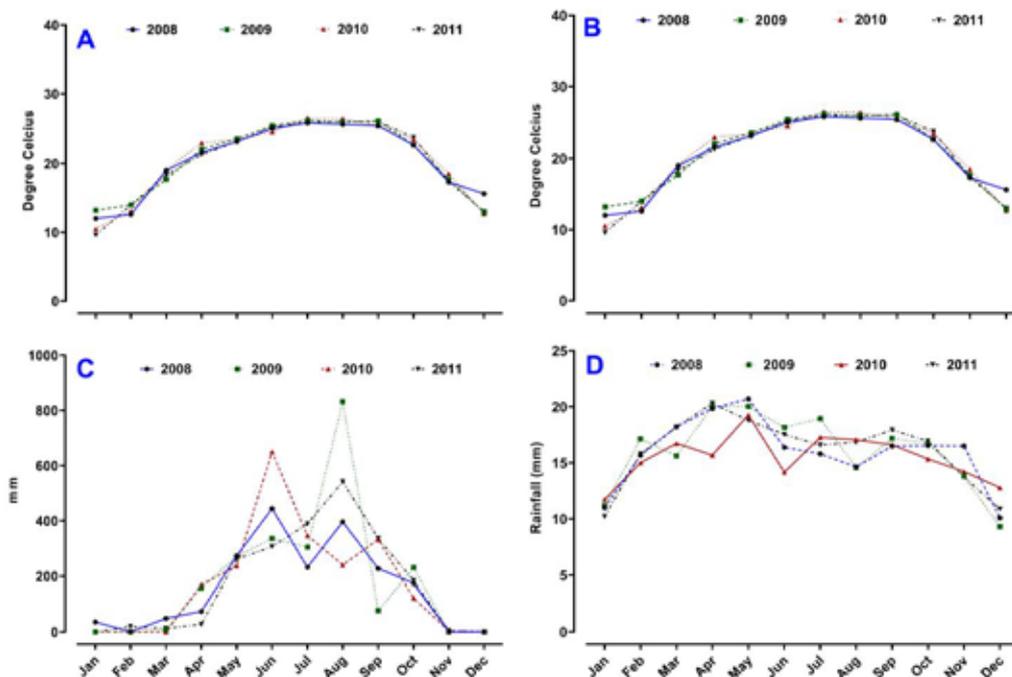
Fig. 1. Monthly average (A) Maximum temperature (B) Minimum temperature (C) Rainfall and (D) Solar radiation at the experimental site, Rangpur, Bangladesh during 2008-2011.

Soil sampling and analysis

The site belongs to Agro-Ecological Region 3 called Tista Meander Floodplain. The soils in this region are rapidly permeable, heavy silt loam or silty clay loam, strongly to slightly acidic, medium in K and CEC content (BARC, 2012). At the commencement of the experiment, soil samples were systematically collected from two distinct depths, i.e., 0 to 15 cm and 15 to 30 cm, using a 5-cm diameter auger. Each sample represented a composite from nine locations within the experimental plot. Subsequently, the freshly collected soil samples were mixed thoroughly, air-dried, crushed to pass through a 2-mm sieve and stored in sealed plastic jars before analysis.

The pH of a 1:5 soil water suspension of the soil samples was determined by a portable pH meter. Soil organic C content was analyzed by the Walkley and Black method (Page *et al.*, 1982). The determination of soil total nitrogen (STN) involved the Kjeldahl digestion method applied to air-dried soil samples (Bremner, 1960). Soil phosphorus (P) (0.5 M NaHCO3 extractable) and ammonium acetate (NH4OAc)-extractable potassium (K) were analyzed following the methods described by Olsen *et al.* (1954) and Page *et al.* (1982), respectively. Plant available sulphate was determined through calcium dihydrogen phosphate extraction method (Page *et al.*, 1982). Table 1 presented The soil chemical properties at different depths of the experimental site.

Table 1. The initial soil status of the experimental plot.

Soil depth (cm)	Soil properties					
	pH	% organic carbon	Total N (%)	Available P (ppm)	Exchangeable K (meq/100g)	Available S (ppm)
0-15	6.65	1.10	0.10	5.67	0.16	5.8
15-30	6.81	0.77	0.07	2.93	0.16	5.2

Experimental design and treatments

The study encompassed twelve treatment combinations, involving three transplanting dates (20 February, 28 February, and 08 March) and four seedling ages (75, 60, 45 days and 75-day double transplanted seedlings) for dry season rice within the potato-dry season rice-wet season rice cropping system. The evaluation spanned three consecutive years: 2008-2009 (year 1), 2009-2010 (year 2), and 2010-2011 (year 3). The experiment was laid out in completely randomized block design (RCBD) with three replications.

In the case of double transplanting (DT) technology, the rice transplanting process involved two stages. Initially, 35-day-old seedlings were transplanted from nursery beds to a small piece of land with a closer spacing of 10 cm × 10 cm, accommodating 6-8 seedlings per hill. Subsequently, 40 days after the first transplant, tillers were uprooted from the first transplanted plot, splited, and transplanted into the main field following the harvest of potatoes at full maturity (80-90 days of growing period). Tillers from the first transplanted rice cover approximately five times higher than the area of the main field under the second transplanting, necessitating about 2000 sqm of land under the first transplanting to cover one hectare of the main field (BRRI, 2007). Figure 2 illustrates the double transplanting system of dry season rice.

Fig. 2. Double transplanting practice of dry season rice.

Crop husbandry

Potato

A high yielding potato cultivar "Diamont" was manually sown at a seed rate of 1500 kg ha^{-1} on three different dates: 05-10 November, 15-20 November, and 25-30 November during the Rabi season from 2008 to 2010, to align with the three transplanting dates of dry season rice. The seeds were

collected from Tuber Crop Research Centre of Bangladesh Agricultural Research Institute (BARI). Each plot received 161 kg N, 44 kg P, 130 kg K, 22 kg S, 5 kg Zn and 2 kg B ha^{-1} for potato cultivation (BARI, 2006). The phosphorus (P) in the form of triple superphosphate, potassium (K) as muriate of potash, sulfur (S) as gypsum, zinc (Zn) as zinc sulfate, and boron (B) as boric acid were applied at the basal level during the final land preparation. Upon land preparation, potatoes were sown with a spacing of 60 cm × 25 cm. Two equal splits of nitrogen (N) as urea were applied at 15 and 30 days after sowing (DAS), just before the earthing-up operation. Surface irrigation was applied immediately after sowing and subsequently as needed by the crop. Hand weeding was performed (one day prior to the application of nitrogen split) at 14 and 29 days after sowing. Other recommended agronomic practices were followed for successful production of potato (BARI, 2006).

Dry season rice

The high-yielding semi-dwarf rice cultivar BRRI dhan29 (160 day seed to seed) was cultivated during the dry seasons from 2009 to 2011. The seeds were collected from Genetic Resources and Seed Division of BRRI. Following the harvest of potato, 75, 60, 45 days old and 75 days DT seedling were transplanted with a spacing of 20 cm × 15 cm on 20 February, 28 February and 08 March, 2009-2011. In the traditional transplanted plots, phosphorus (P), potassium (K), sulphur (S) and Zinc (Zn) were basally applied at the rate of 15-60-15-4 kg ha^{-1} and broadcast prior to the last cultivation. Additionally, 170 kg nitrogen (N) in the form of urea was top dressed in three times. In case of double transplanting plot, 1st transplanted plot received 280 kg N, 15 kg P, 60 kg K, 15 kg S and 4 kg Zn ha^{-1}, while the 2nd transplanted plot received 114 kg N, 15 Kg P, 60 Kg K, 15 Kg S and 4 Kg Zn (BRRI, 2007). The field

was irrigated based on the crop's requirements, and other BRRI recommended agronomic practices were followed to ensure the successful production of rice (BRRI, 2008).

Wet season rice

In the wet seasons from 2009 to 2011, the medium-duration semi-dwarf rice cultivar BRRI dhan49, with a seed-to-seed maturity period of 135 days, was cultivated. The transplanting of 30-35-day-old rice seedlings, with 2-3 seedlings per hill, was carried out on 15-20 July. The spacing used for transplantation was 20 cm × 15 cm. For fertilization, the field received 92 kg N, 12 kg P, 33 kg K, and 10 kg S ha^{-1}. Except for urea, all other fertilizers were applied during the final land preparation. Urea was top-dressed in three equal installments: 7-10 days after transplanting, during the tillering stage, and seven days before panicle initiation. All other agronomic practices were executed according by (BRRI, 2008).

Data collection and analysis

Potato tuber yield was assessed from 6 m^2 harvest area in each plot at harvestable maturity. Grain yields (rough rice) were obtained from 6 m^2 harvest area in each plot at 80% maturity and reported at 0.14 g H$_2$O g^{-1} fresh weight of grain. Human labour used for different management practices and their wage rate were documented. The time required for each field operation was expressed as person-days ha^{-1}, with eight hours considered equivalent to one person-day. The irrigation cost, farm-gate price of potato and rough rice, prices of fertilizer and crop seed were also recorded. Total productivity of Potato-Rice-Rice systems was compared in terms of rice equivalent yield (REY) (Rashid *et al.*, 2004). The REY of potato was computed by the following formula:

$$REY = \frac{\text{potato yield (kg) x potato price (US\$ kg}^{-1})}{\text{Unit price of paddy (US\$ kg}^{-1})}$$

Economic analysis of double transplanting technology was conducted based on added net return relative to traditional transplanting, which is the difference between added gross return and added cost for double transplanting treatment as compared with traditional transplanting. Added gross return equaled additional yield as rough rice (yield of DT treatment - average yield of traditional transplanting) multiplied by the price of yield. Added cost equaled the sum of costs for differences in labour determined as [(labor for 1st and 2nd transplanting, uprooting from 1st and 2nd transplanted plot and weeding of the DT treatment - labour for uprooting, transplanting and weeding of traditional transplanting) × wage rate] and costs for differences in fertilizer and irrigation determined as (fertilizer and irrigation costs of DT treatment - fertilizer and irrigation costs of traditional transplanting). The prices of seeds, fertilizer, irrigation, potato, rough rice, and labour wage were as follows: rice seed = US\$ 0.45 kg^{-1}, potato seed = US\$ 0.32 to 0.36 kg^{-1}, P fertilizer = US\$ 0.28 to 0.51 kg^{-1}, K fertilizer = US\$ 0.19 to 0.45 kg^{-1}, S fertilizer = US\$ 0.06 to 0.08 kg^{-1}, Zn fertilizer = US\$ 1.29 to 1.54 kg^{-1}, B fertilizer = US\$ 1.93 to 2.57 kg^{-1}, urea = US\$ 0.15 to 0.26 kg^{-1}, irrigation cost of double transplanting = US\$ 242.89 to 271.71 ha^{-1}, irrigation cost of traditional transplanting = US\$ 240.10 to 268.91 ha^{-1}, potato = US\$ 0.09 to 0.13 kg^{-1}, rough rice = US\$ 0.22 to 0.23 kg^{-1}, and labour wage = US\$ 1.93 to 2.57 person-day^{-1} (US\$1 = Bangladesh Taka 77.78).

Analysis of variance (ANOVA) of the treatment means were compared using least significant difference (LSD) at the 5% level of probability (Gomez and Gomez, 1984). Descriptive statistics such as means, range, 25% quartile, and 75% quartile were used to determine the variability of parameters. Productivity and stability of the cropping system were analyzed according to Conway, 1987.

RESULTS AND DISCUSSION

Grain yield and yield components of dry season rice

The grain yield exhibited significant variability in respect of planting time ($P \leq$ 0.001), seedling age ($P \leq 0.001$), and year ($P \leq 0.001$), while the interaction effect among these factors was not statistically significant. Notably, the double transplanting treatment consistently yielded the highest grain yield compared to the other treatments across all planting times and years (Table 2). Irrespective of seedling age, grain yield was gradually decreased with the progress of the planting time in all years. On average, rice transplanted on 20 February yielded about 7% and 23% higher grain than those transplanted on 28 February and 08 March, respectively. The findings revealed a decrease in grain yield at a rate of 66 kg^{-1} ha^{-1} day^{-1} from 20 February to 08 March planting. Previous research underscored the importance of completing transplanting for dry season rice by 25 January to avoid a significant decline in grain yield (Chowdhury and Guha, 2000). A gradual rise in both average maximum and minimum temperatures observed as transplanting time advanced in the study area (Fig. 1) could potentially impact rice yield. According to Baker et al. (1992), there was a 7–8% decrease in rice yield for each 1°C increase in daytime maximum/nighttime minimum temperature within the range of 28/21 to 34/27 °C. Among different seedling ages, the 75-day-old double-transplanted seedlings consistently yielded higher grain compared to other age groups across all planting times and years. This result was supported by Roy et al. (2007), who observed higher grain yield with double-transplanted rice compared to

Table 2. Grain yield (t ha^{-1}) of BRRI dhan29 under different planting times and seedling ages in BRRIRS Farm, Rangpur, Bangladesh.

Planting time	Seedling age				Mean for PT
	75 days	60 days	45 days	75 days (DT)	
2008-09					
20 Feb	5.27	5.50	5.01	6.27	5.51
28 Feb	4.98	5.11	4.61	5.36	5.01
08 Mar	3.98	4.00	3.94	4.90	4.21
Mean for SA	4.74	4.87	4.52	5.51	
2009-10					
20 Feb	5.65	5.91	5.04	6.31	5.73
28 Feb	5.37	5.57	5.20	5.96	5.52
08 Mar	4.77	5.10	4.71	5.50	5.02
Mean for SA	5.26	5.53	4.99	5.92	
2010-11					
20 Feb	5.57	5.62	4.92	6.29	5.60
28 Feb	5.05	5.25	4.58	5.86	5.19
08 Mar	4.47	4.53	4.03	4.76	4.45
Mean for SA	5.03	5.13	4.51	5.64	
LSD (5%)					
Planting time (P)					0.20**
Seedling age (S)					0.23**
Year (Y)					0.20**
P×Y					0.35^{ns}
S×Y					0.41^{ns}
P×S					0.41^{ns}
P×S×Y					0.70^{ns}

DT=Double transplanting, SA= Seedling age, PT= Planting time
ns and ** = Not significant, significant at 1% level respectively

traditional transplanting. Traditional transplanting with 60-day-old seedlings resulted in a higher grain yield than both 75-day-old and 45-day-old seedlings. Lower grain yield with 45-day-old seedlings aligns with the findings of Channabasappa *et al.* (1998) who reported better performance of older seedlings compared to younger ones under late-transplanted conditions. Moreover, spikelet sterility and seedling mortality was decreased with transplanting of older seedlings (Murty and Saha, 1979; Rashid *et al.*, 1990). The adoption of double transplanting practices could lead to a yield advantage of 17%, 13%, and 16% compared to traditional transplanting when conducted on 20 February, 28 February, and 08 March, respectively. Across three years, the grain yield with double transplanting practice on 20 February, 28 February and 08 March was higher by 0.90, 0.65, and 0.66 t ha^{-1}, respectively, than that achieved with traditional transplanting. This aligns with reports from other authors who observed higher grain yields in double-transplanted rice from early sown nursery beds in Assam and North Bihar (Singh *et al.* 2003 and Thakur *et al.*, 2003). Additionally, our results are consistent with a study reporting the benefits of adopting double transplanting for PA 6201 hybrid rice, considering its higher grain yield compared to the standard practice of single planting (Rataray, 2006).

All the yield components measured in the present study were significantly affected by planting time ($P \leq 0.001$; except panicle m^{-2} and 1000-grain weight), seedling age ($P \leq 0.001$; except 1000-grain weight), however in-significantly affected by year except panicle m^{-2} ($P \leq 0.05$). Interaction effect of all yield components was non-significant except panicle m^{-2}. The interaction between planting time and seedling age significantly affects the number of panicle m^{-2} ($P \leq 0.05$).

Traditional transplanted rice consistently showed a significantly higher number of panicles m^{-2} compared to double transplanted rice across all the years. Regardless of the year and planting times, 45-day-old seedlings produced significantly more panicles per square meter than seedlings from other age categories. The lower number of panicles m^{-2} in double transplanted rice may be due to insufficient time for split tillers to develop secondary tillers after the second transplanting.

In contrast, the number of spikelets per panicle in double transplanted rice was significantly higher than in the other treatments across all the planting times and years, except for the February 20 treatment in 2008-09. Furthermore, double transplanted rice exhibited significantly higher grain filling percentages than traditional transplanted rice across all years, seedling ages, and planting times, which likely contributed to the higher grain yield of double transplanted rice. However, grain weight remained unaffected by planting time, seedling age, or year (Table 3).

Table 3. Yield components of dry season rice across different treatments and years in BRRI-RS Farm, Rangpur, Bangladesh.

Seedling age	Panicles m^{-2}			Grain panicle^{-1}			1000-grain weight (g)			Grain filling %		
	20 Feb	28 Feb	08 Mar	20 Feb	28 Feb	08 Mar	20 Feb	28 Feb	08 Mar	20 Feb	28 Feb	08 Mar
2008-2009												
75 days	304	282	295	101	116	94	22.0	21.3	21.7	74.5	66.3	66.1
60 days	300	284	301	126	113	85	21.0	21.7	21.3	67	68.9	70.9
45 days	307	315	328	119	106	98	22.0	22.0	21.3	60.7	58.9	55.5
75 days (DT)	275	270	269	121	127	126	22.0	21.3	21.0	79.4	71.1	64.9
2009-2010												
75 days	314	312	303	101	106	107	22.7	22.3	21.6	73.1	69.8	64.4
60 days	305	296	304	122	108	101	22.4	22.9	22.7	69.7	72.6	70.1
45 days	313	322	317	102	104	101	22.4	21.9	22.7	66.5	67.4	60.5
75 days (DT)	274	269	259	140	134	136	21.4	22.3	22.5	74.8	72.4	65.9
2010-2011												
75 days	309	302	295	111	122	107	21.7	22.3	21.7	70.6	58.5	62.6
60 days	305	295	294	110	126	108	22.4	21.6	20.6	72.1	63.9	63.9
45 days	318	315	316	104	145	105	22.6	20.9	21.3	64.2	47.4	55.1
75 days (DT)	270	267	263	127	128	120	22.4	22.3	21.6	74.9	71.6	65
LSD (5%)												
Planting time (P)	4.85^{ns}			7.08**			0.35^{ns}			3.23**		
Seedling age (S)	5.60**			8.18 **			0.41^{ns}			3.73**		
Year (Y)	4.85^{ns}			7.08^{ns}			0.30^{ns}			3.23*		
P×Y	8.40^{ns}			12.27^{ns}			0.61^{ns}			5.60^{ns}		
S×Y	9.70^{ns}			14.17^{ns}			0.71^{ns}			6.47^{ns}		
P×S	9.70*			14.17^{ns}			0.71^{ns}			6.47^{ns}		
P×S×Y	16.80^{ns}			24.55^{ns}			1.23^{ns}			11.20^{ns}		

DT=Double transplanting

ns, * and ** = Not significant, significant at 5% and 1% level respectively

The grain filling percentage exhibited the highest significant positive correlation (r = 0.61, $P \leq 0.01$) with grain yield, followed by spikelets per panicle (r = 0.47; $P \leq 0.05$) (Table 4). This indicated that higher filled grain from higher spikelets panicle[-1] contributes to the higher yields in double transplanting practice. These findings align with previous research, where a higher number of filled grains per panicle was reported in double-transplanted rice compared to the traditional system, leading to an overall enhancement in yield (Roy *et al.*, 2007).

Table 4. Correlation coefficients (*r*) between grain yield and yield components across different treatments and years in double and traditional transplanting.

Trait	Grain yield	Panicle m^{-2}	Spikelet panicle^{-1}	Grain filling %	1000-grain weight
Grain yield	1				
Panicles m^{-2}	0.33^{ns}	1			
Spikelets panicle^{-1}	0.47*	-0.08^{ns}	1		
Grain filling %	0.61**	0.36^{ns}	-0.34^{ns}	1	
1000-grain weight	0.13^{ns}	-0.09^{ns}	0.002^{ns}	-0.13^{ns}	1

ns = Not significant. Number of observations = 27

* Significant difference at $P \leq 0.05$, ** Significant difference at $P \leq 0.01$

Growth and field duration of dry season rice

Figure 3 depicted the growth and primary field duration of dry season rice. Regardless of seedling age, dry season rice physiologically matured earlier with the advancement of planting time over the three years. A previous study also concluded that delayed transplanting of Boro rice results in a shortened growing period (Roy *et al.*, 2007). Regarding different seedling ages, it was observed that 45-day-old seedling-transplanted rice achieved physiological maturity earlier than the thers, while transplanting with 75-day-old seedlings required more time for maturation. Double transplanting with 75-day-old seedlings matured 4-10 days earlier compared to traditional transplanting with the same seedling age. In the case of double transplanting, the crop was likely to obtain additional space for vegetative growth in the intermediate 1st transplanted field, potentially contributing to the earlier maturity of double-transplanted rice compared to traditionally transplanted rice with the same seedling age. BRRI also reported that double-transplanted rice matures 7-10 days earlier than the traditionally transplanted rice with older seedlings in late situations (BRRI, 2015).

The main field duration of crops is crucial not only for introducing a new crop into the existing cropping pattern but also for resilience against biotic and abiotic stresses in certain cases. The main field duration was higher when using 45-day-old seedling-transplanted rice. In all instances, the practice of double transplanting facilitated a reduction in the main field duration. Compared with normal transplanted rice, the field duration decreased with double-transplanted rice, ranging from 4 to 13 days during the dry season. BRRI earlier reported that double transplanting technology minimizes the main field duration of rice (BRRI, 2015).
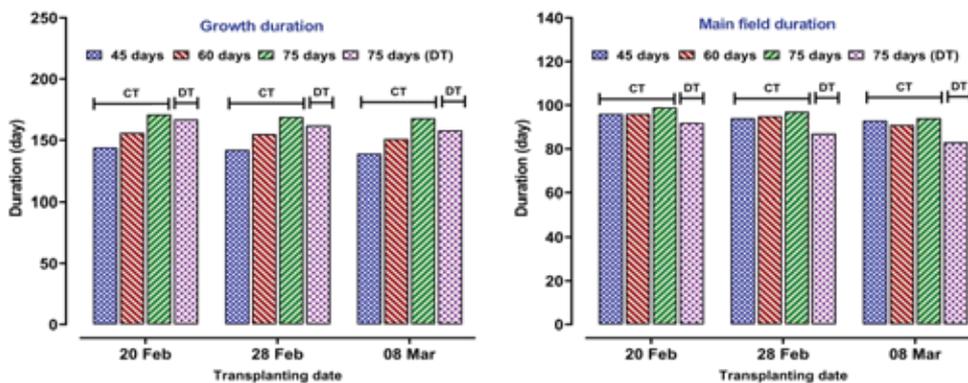
Fig. 3. Growth and main field duration of dry season rice transplanted with varying seedling age on different transplanting date.

CT= Conventional transplanting, DT=Double transplanting

Potato yield

Potato yield remained unaffected by the year, while it exhibited significant variation with planting times ($P \leq 0.001$), with a non-significant interaction effect. Among the treatments, potato yield from 05-10 November sowing was significantly higher than in other treatments across all the years. There was a gradual decrease in potato yield with the progress of planting time. The potato yield planted during November 05-10 was 12% and 41% higher than that planted during 15-20 November and 25-30 November, respectively (Table 5). Previous studies reported higher yields for potato planted on 15 November, showing an increase of 34.29% compared to those planted on 30 November (Haque *et al.*, 2013).

Table 5. Potato tuber yield across different planting time and year in BRRI Farm, Rangpur, Bangladesh.

Planting time	Yield (t ha^{-1})		
	2008-09	2009-10	2010-11
Nov 05-10	22.98	25.42	25.83
Nov 15-20	20.06	22.22	24.27
Novr 25-30	15.98	18.13	18.55
LSD (5%)			
Planting time (P)	2.64**		
Year (Y)	2.63^{ns}		
P×Y	4.56^{ns}		

ns, ** = Not significant, significant at 1% level, respectively

Wet season rice yield

The grain yield of wet season rice was not significantly affected by year. The yield ranged from 4.49 to 4.84 t ha^{-1} across different years (Fig. 4). Biswash *et al.* (2015) also reported similar grain yield of BRRI dhan49 in Northern Bangladesh.
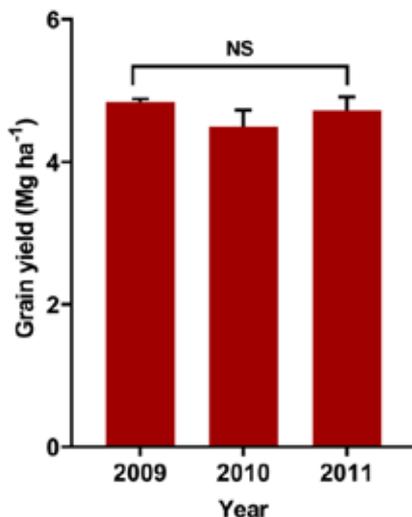

Fig. 4. Year wise grain yield of wet season rice in Northern Bangladesh.

System productivity of Potato-Rice-Rice cropping system

The system productivity of Potato-Dry season rice-Wet season rice cropping system varied significantly among planting times ($P \leq 0.001$), seedling age ($P \leq 0.001$) and years ($P \leq 0.001$), whereas their interaction effect was non-significant expect planting time × year ($P \leq 0.001$). Double transplanting practice consistently turned out the highest system productivity regardless of the planting time, seedling age and years (Table 6). Across different seedling ages, the system productivity of the double transplanting treatment was significantly higher than the other treatments in all the years. This increase in system productivity was attributed to the consistent improvement in grain yield of double-transplanted dry-season rice. System productivity gradually decreased with the progress of planting time, as evidenced by decreased yields of potato and dry-season rice. Additionally, the lower price of potatoes with seasonal progression significantly impacted system productivity. In the year 2008-09, system productivity was notably lower due to the cheap price of potato compared to other years. The introduction of double transplanting for dry-season rice in Potato-Rice-Rice cropping system demonstrated its effectiveness, resulting in higher productivity of the Potato-double transplanted dry-season rice-wet season rice cropping system compared to the traditional one. These findings are in agreement with earlier studies by Roy *et al.* (2007) and Khatun *et al.* (2007).

Table 6. Rice equivalent yield (t ha^{-1}) of Potato-Rice-Rice cropping system across different treatments in BRRI-RS Farm, Rangpur, Bangladesh.

Planting time	Seedling age				Mean for PT
	75 days	60 days	45 days	75 days (DT)	
2008-09					
20 Feb	21.32	21.56	21.06	22.32	21.57
28 Feb	18.48	18.61	18.11	18.86	18.51
08 Mar	15.80	15.82	15.76	16.73	16.03
Mean for SA	18.53	18.66	18.31	19.30	
2009-10					
20 Feb	25.09	25.36	24.49	25.75	25.17
28 Feb	19.01	19.21	18.84	19.60	19.17
08 Mar	16.73	17.05	16.67	17.46	16.98
Mean for SA	20.28	20.54	20.00	20.94	
2010-11					
20 Feb	23.20	23.25	22.55	23.93	23.23
28 Feb	20.55	20.76	20.08	21.37	20.69
08 Mar	16.99	17.05	16.55	17.28	16.97
Mean for SA	20.25	20.35	19.72	20.86	
LSD (5%)					
Planting time (P)					0.20**
Seedling age (S)					0.23**
Year (Y)					0.20**
P×Y					0.35**
S×Y					0.41^{ns}
P×S					0.41^{ns}
P×S×Y					0.70^{ns}

DT=Double transplanting

ns, ** = Not significant, significant at the 1% level, respectively

A comparative analysis was also conducted to assess the advantage of using double transplanting practice over traditional transplanting in terms of productivity and stability. Stability measured by the coefficient of variation in productivity, determined from a time series of productivity measurements (Conway, 1987). The superior productivity with double transplanting practice across all planting times confirmed its benefits over traditional transplanting. Additionally, the higher stability of the double transplanting technology, particularly evident on 08 March, suggests its feasibility in later conditions (Fig. 5).
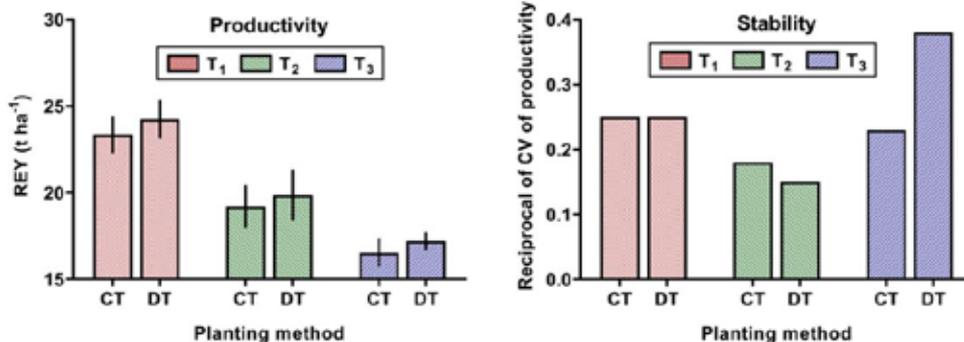
Fig. 5. Productivity and stability of double and conventional transplanted rice in Potato-Rice-Rice cropping systems in Northern Bangladesh.

* Error bar showing confidence interval at 0.05

T_1 = Transplanting at 20 February, T_2 = Transplanting at 28 February, T_3 = Transplanting at 08 March, CT = Conventional transplanting, DT = Double transplanting

Economic analysis

Added costs and net returns associated with double transplanting were analyzed in comparison to traditional transplanting technique to assess the profitability of the double transplanting technique (Table 7). Across the years, the average additional costs for double transplanting practice on 20 February, 28 February, and 08 March ranged from $30 to $34 ha^{-1}, $28 to $34 ha^{-1}, and $28 to $33 ha^{-1} respectively. These added costs were primarily attributed to the extra application of P, K, S, Zn fertilizers, additional land preparation and labour requirements in the first transplanted plot. On the other hand, the average added net returns with double transplanting ranged from US$ 22 to 439 ha^{-1} on 20 February, US$ 17 to 325 ha^{-1} on 28 February and from US$ 25 to 272 ha^{-1} on 08 March across different years. The highest added net return was observed with double transplanting on 20 February compared to other treatments over three years. Overall, the average added net returns were higher with double transplanting practice across all planting times, indicating its profitability compare to traditional transplanting. On average per dollar net return (added net return divided by added cost) was the highest on 20 February transplanting ($ 5.36) followed by 08 March transplanting ($ 3.94) and it was the lowest in 28 February transplanting ($ 3.74). These results suggest that double transplanting of dry season rice was more profitable on 20 February transplanting. Moreover, the positive added net returns with double transplanting practice in all the planting times confirmed that the technology is ready for wide-scale evaluation and promotion in Bangladesh. Previous studies have similarly concluded that, despite the higher cost associated with double-transplanted technology, this system yielded a higher gross margin (net profit) than the conventional approach (Khatun *et al.*, 2007; Roy *et al.*, 2007).

Table 7. Added costs and added net returns of double transplanted dry season rice compared to traditional transplanted rice under different planting time in Northern Bangladesh.

Planting time	Added cost (US$ ha^{-1})	Added net return (US$ ha^{-1})			
		Mean	Range	25% quartile	75% quartile
2008-09					
20 Feb	34	187	15 to 439	89	264
28 Feb	34	67	15 to 228	38	62
08 Mar	33	171	8 to 272	154	202
2009-10					
20 Feb	30	139	22 to 306	54	233
28 Feb	28	98	17 to 213	53	165
08 Mar	28	112	33 to 212	59	175
2010-11					
20 Feb	31	183	15 to 387	95	226
28 Feb	30	179	11 to 325	140	198
08 Mar	28	68	25 to 180	11	103

CONCLUSION

In the study, double transplanting practice demonstrated its superiority over the traditional transplanting system in late situation. This technology has effectively intensified the double rice cropping system by ensuring the harvest of potato after full maturity during the wet-dry transition period between dry and wet season rice. Simultaneously, it minimized the yield loss of dry season rice resulting from late transplanting after potato cultivation. The shorter main field duration of double-transplanted rice can also mitigate the impact of abiotic risks such as hailstorms, unusual rains, and higher temperatures at maturity. Consequently, double-transplanting of dry season rice following potato cultivation emerges as a promising technology for enhancing yield and income. Implementing a comprehensive program one to demonstrate and promote this practice in areas with Rabi crops-Rice-Rice cropping pattern could significantly improve the productivity of the existing system.

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Assessing the Adoption and Adoption Gap of Selected BRRI-Released Boro Rice Varieties in Bangladesh

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ABSTRACT

Improved high-yielding modern rice varieties can reduce hunger and food insecurity in Bangladesh. However, lower adoption and higher adoption gap of modern rice varieties are the main concerns of rice researchers, extension specialists, and legislators. This study attempts to determine the adoption status and adoption gap of 10 selected BRRI-developed *Boro* rice varieties; to assess some selected socio-economic characteristics of the rice farmers; and to explore the contribution of the selected socio-economic characteristics of farmers to their adoption gap of selected BRRI-released *Boro* varieties. Necessary data were collected from 03 September to 31 December 2021 using a well-structured pre-tested interview schedule from 371 randomly selected farmers covering 12 agricultural blocks of four upazilas under Cumilla, Mymensingh, Tangail, and Bogura districts. The study revealed that most (73.05%) of the rice farmers had high and low adoption gap; 23.72% had moderate adoption as well as adoption gap; and the rest 3.23% of the respondents' farmers had low adoption and high adoption gap of BRRI-developed *Boro* rice varieties. Overall adoption and adoption gap of BRRI-released *Boro* rice varieties were 77.02% and 22.98%, respectively. Based on the descending order of the Adoption Index, BRRI dhan29 ranked 1st, followed by BRRI dhan28. The adoption indices of these two top-ranked varieties were 38.84 and 30.43, respectively, which were much higher than the others. Third to ninth ranked varieties were BRRI dhan58, BRRI dhan89, BRRI dhan88, BRRI dhan50, BRRI dhan74, BRRI dhan81, and BRRI dhan63. Reverse-ranked orders were observed based on the descending order of the adoption gap index (AGI). Stepwise multiple regression analysis indicated that 'knowledge on BRRI-released *Boro* rice varieties', 'extension contacts', 'rice farming profitability', 'rice farming experience', and 'satisfaction on BRRI-released *Boro* rice varieties' of the farmers had a significant negative contribution to their adoption gap, i.e., positive contribution to their adoption of BRRI-developed *Boro* rice varieties. The study concluded that policy interventions should be taken to improve farmers' knowledge of BRRI-released *Boro* rice varieties by increasing extension contact to all the low and highly experienced farmers to make them profitable and satisfied to increase adoption and decrease the adoption gap of BRRI- developed *Boro* rice varieties. These issues also urge policy interventions for the rethinking of current dissemination tactics to ensure the widespread adoption of newly released modern *Boro* rice varieties at the farm level.

Key words: Adoption, Adoption Gap, Boro, Rice, BRRI, *Boro* rice varieties, Bangladesh

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INTRODUCTION

Rice and food security are synonymous in Bangladesh (Brolley, 2015). Rice is the main staple food for more than 166.5 million people in Bangladesh (BBS, 2022; FPMU, 2020). Bangladesh ranks fourth among countries globally in rice consumption, with an annual per capita availability of rice of 213.5 kg (FPMU, 2020) and third in world rice production (Al Mamun *et al.,* 2021, FAO, 2022). Rice is Bangladesh's largest crop, occupying about 76% of the total cropped area (15.44 million hectares), of which about 88% was planted to modern varieties in 2019-20, with traditional landrace varieties covering 12% (BBS, 2022). The current rice intake in Bangladesh is about 367g capita-1, day-1, providing approximately 70% of total calories and 65% of total protein for adults (HIES, 2016). Rice is grown on more than 13 million farms on approximately 11.77 million hectares, summed over the winter (dry) and monsoon (wet) seasons (DAE, 2020). The contribution of rice to the value of the crop sub-sector is about 70% (Mottaleb *et al.*, 2016). It is predicted that the population of Bangladesh will be 215.4 million in 2050 and estimated 44.6 million tons (MT) of milled rice will be required to feed the increased population of the country (Kabir *et al.*, 2015).

Bangladesh Rice Research Institute (BRRI) is the center of excellence in terms of research and development of high-yielding rice varieties and production technologies. So far, BRRI has developed and released 111 modern rice varieties (MVs), including eight hybrids suitable for growing in three distinct seasons: *Aus, Aman*, and *Boro* (BRKB, 2022). Among the 111 MVs 50 are released for *Boro* (irrigated rice) season, considering different ecosystems. The foundation of the country's food security has been laid on *Boro* production. It's a major rice growing season alone contributing more than 54% of total food grain and was also the highest (3.44 t/ha) compared to *Aus* rice (1.66 t/ha) and *Aman* rice (1.99 t/ha) per unit production (Parvin, 2009). *Boro* is the most suitable season for rice production, and its production is higher due to proper operational management and weather conditions (Rahman *et al.*, 2020). Because the yield of the contemporary *Boro* varieties is much more responsive to a high level of input use and timely crop management. However, due to various socio-economic constraints faced by farmers and their lack of understanding of approved *Boro* variety cultivation procedures, yields at the farmer level are lower (Islam *et al.*, 2018).

The overall adoption of modern rice varieties remained relatively slow during the seventies and eighties; the coverage of modern varieties speeded up and increased to about 34% during the nineties (Hossain *et al.,* 2006). In the later period (2000 onward), farmers enormously increased the area under MV cultivation, which was triggered to 66% in 2005. According to the available statistics, the average coverage of modern rice varieties has reached to 79% in 2010 (Alam, 2012). After every MV is released for cultivation, the promotion and dissemination of those varieties are designated to other departments or agencies of the government. In most cases, the end-users could not harvest the fullest benefits of new BRRI varieties and matured technologies. Moreover, all those varieties having high potential, inadequate motivation, and slow diffusion are major reasons for lower adoption than traditional or aged MVs. It was reported that BRRI dhan28 and BRRI dhan29 are still popular among rice growers and traders across the country. Even though BRRI dhan58, BRRI dhan81, BRRI dhan88, and BRRI dhan89 are some of the varieties suggested to replace them (BRKB, 2019). There was a significant positive relationship between the knowledge of the farmers and their adoption decision of different modern

rice cultivation practices (Alam, 1997). Like farmers' knowledge, their other socio-economic characteristics may influence their adoption decision of different modern rice varieties, especially BBRI-developed *Boro* rice varieties. By understanding the adoption gap, researchers and policymakers can evaluate how effectively BBRI-developed *Boro* varieties are performing in terms of yield potential, adaptability to local conditions, and other desirable traits. For further research and development of the high-yielding *Boro* rice variety, it is imperative to inquire which variety is most popular and which is not. This information helps in identifying successful varieties and those needing improvement. Considering the above contextualization, this study attempts to address the following objectives to:

- Determine the adoption and adoption gap of selected BBRI-developed *Boro* rice varieties in Bangladesh;

- Assess some selected socio-economic characteristics of the rice farmers in Bangladesh; and

- Determine the contribution of the selected socio-economic characteristics of the farmers to their adoption gap of selected BBRI-developed *Boro* rice varieties in Bangladesh.

METHODO LOGY OF THE STUDY

Study Area

Four districts namely, Cumilla, Mymensingh, Tangail, and Bogura were selected purposively out of 64 districts of Bangladesh. Four upazilas were then randomly selected by taking one from one district. Twelve Agricultural Blocks (AB) were again selected randomly by taking three AB from each Upazila as the study area.
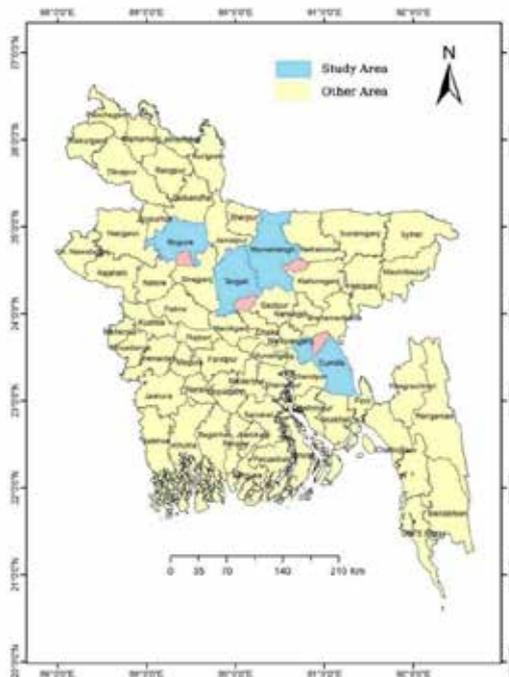

Fig. 1. Map of Bangladesh showing the study areas

Population and sample

There were 10069 *Boro* rice farmers in these selected 12 ABs which constituted the population of the study. Out of this population, by using sample size calculator developed by Creative Research Systems (1984), the sample size was determined as 370 by taking a 95% confidence level. Sample rice farmers were selected proportionately and randomly from the selected 12 ABs. For removing a fractional number of sample size after proportionate random sampling, the sample size was decided as 371 for the study.

Data collection

The researcher interviewed selected farmers face-to-face with the help of a pre-tested interview schedule from 03 September to 31 December 2021 for the collection of data for the study.

Measurement of adoption and adoption gap

Adoption is a decision to use an innovation by an individual and continue to use the innovation (Rogers, 1995). It is a mental process through which a person decides to adopt an innovation after carefully considering its relative advantage, compatibility, complexity, visibility, and adaptability in relation to his/her biophysical and socio-economic environment (Rogers, 1995). Different researchers (Ovwigho, 2013) measured the adoption of innovations in different ways. Dasgupta (1989) and Ray (1998) measured multi-practice behavior by Adoption Quotient. To measure the adoption and adoption gap of 10 selected BBRI-developed *Boro* varieties, the present researchers developed a scale with slight modification of this Adoption Quotient involving time score and land score with the following steps:

Time proportion score (TS): Time proportion score of adoption was measured by calculating the proportion of 'Awareness Period' (time required for awareness since the introduction of a variety) and 'Adoption period' (time required for adoption since the introduction of a variety) by using the following formula:

$$T_S = \frac{\text{Awarness period}}{\text{Adoption period}} = \frac{T2 - T1}{T3 - T1}$$

Where,

TS = Time proportion score

T_1 = Year of the introduction or release of the variety

T_2 = Year of awareness about the variety

T_3 = Year of adoption of the variety

Land proportion score: Land proportion score of adoption was measured by using the following formula:

$$L_S = \frac{La}{Lp}$$

Where,

L_S = Land proportion score

L_a = Land allotted for the variety

L_p = Potential land for *Boro* rice cultivation

Adoption: Adoption (A) of the variety of a farmer was determined by multiplying 'Time proportion score' (T_S) with 'Land proportion score" (L_S) and expressed in percentage in the following way:

A = TS × LS × 100

Where,

A = Adoption of the variety

T_S = Time proportion score of the variety

L_S = Land proportion score of the variety

Finally, a former's adoption of all the ten selected BRRI released *Boro* rice varieties was computed by adding all the adoption scores against all the varieties. Thus, the score of the adoption of 10 selected BRRI-released *Boro* rice varieties of the respondent farmers could range from 0 to 100, where '0' indicates no adoption and '100' indicates the highest adoption.

Adoption gap: The adoption gap of a farmer against all the ten selected BRRI released *Boro* rice varieties was computed by deducting the adoption of that farmer against all the ten selected BRRI released *Boro* rice varieties from 100 in the following way:

Adoption Gap = 100 - Adoption

Thus, the score of the adoption gap of ten selected BRRI-released *Boro* rice varieties of the respondent farmers could range from 0 to 100, where '0' indicates no adoption gap and '100' indicates the highest adoption gap.

Variety-wise adoption index: Variety-wise Adoption Index (AI) of each variety was computed by using the following two alternative formulas (Saka and Lawal, 2009)

$$AI = \frac{\text{Total adoption of the variety by all the respondents}}{\text{No. of sample respondent (n=371)}} \quad \text{.............................(i)}$$

or

$$AI = \frac{\text{Total adoption of the variety by all the respondents}}{\text{The highest possible adoption of the variety by all the respondents (i.e., } 100\times371)} \times 100 \quad \text{.............................(ii)}$$

The highest possible adoption of the variety by all the respondents

(i.e., 100×371)

Actually, each of the above two formulas produces the same result.

Variety-wise adoption gap index (AGI): Each of the 10 selected BRRI-released *Boro* rice varieties had an equal chance of being adopted across the entire study area. For this reason, the variety-wise AGI of each variety was computed in the following way:

AGI of a variety =
{(100/No. of varieties) - AI of that variety}

Empirical assessment of drivers of the adoption or adoption gap of MVs

IBM SPSS software package was used for the analysis of statistical data. Several socio-economic characteristics of the farmers may influence the adoption and adoption gap such as age, education, rice farming area, rice farming income, rice farming experience, rice farming profitability, extension contact, value chain contact, training exposure, decision-making ability, satisfaction on BBRI-developed *Boro* rice varieties, and knowledge on BBRI-developed *Boro* rice varieties were selected for the study after thorough consultation with relevant experts and reviewing literature. Measuring procedures of these socio-economic characteristics of the farmers were stat:

Socio-economic characteristic stat of the farmers	Measuring procedure
Age	One (1) score for one year of age at the time of interview from date of birth
Education	One (1) score for one (1) year of successful schooling, Zero (0) for illiterate
Rice farming area	Rice farm size in hectare(s)
Annual rice farming income	One (1) for 1000 Bangladeshi Taka (BDT.) income from annual rice farming
Rice farming experience	One (1) for one year of rice farming experience
Rice farming profitability	Actual score(s) is the ratio of benefit (or return) and the cost of rice farming.
Extension contact	Scores as 3, 2, 1, and 0 for regular, occasional, rare, and not at all contact for each of the 18 selected extension media contact
Value chain contact	Scores as 0 to 7 as per the degree of contact with each of the six selected value chain actors
Training exposure	One (1) score for each day of training received on rice farming
Decision-making ability	Scores as 1 to 4 as per the degree of decision-making for each of the 10 selected varieties.
Satisfaction with BBRI-developed *Boro* varieties	Scores 1, 2, and 3 for low, moderate, and high satisfaction on each of the 15 selected items of satisfaction on BBRI-developed Boro rice varieties
Knowledge of rice production	Two (2) scores for each of the 20 selected questions on rice production

RESULTS AND DISCUSSION

Adoption and adoption gap in the study areas

The possible range of adoption and adoption gap of BRRI-released *Boro* rice varieties was 0-100, and they were vice-versa. However, the observed range of adoption and adoption gap of BRRI-released *Boro* rice varieties of the farmers was 0 to 92.80. The mean adoption and adoption gap were 77.02 and 22.98 respectively. The standard deviation of adoption and adoption gap were the same as 22.09 because they were vice-versa. Based on adoption and adoption gap, the respondents were classified into three categories as shown in Table 1.

Table 1. Distribution of farmers according to their adoption and adoption gap of BBRI-developed *Boro* rice varieties.

Adoption category	Adoption gap category	Respondent	
		Frequency	Percentage
High adoption (>66.67)	Low adoption gap (up to 33.33)	271	73.05
Moderate adoption (>33.33-66.67)	Moderate adoption gap (>33.33-66.67)	88	23.72
Low adoption (up to 33.33)	High adoption gap (>66.67)	12	3.23
Total		371	100

Note: Mean adoption = 77.02   Mean adoption gap = 22.98 Standard Deviation= 22.09

Findings revealed that most (73.05%) of the rice farmers had high adoption and low adoption gap; 23.72% of them had moderate adoption and adoption gap; and the rest 3.23% of respondent farmers had low adoption and high adoption gap of BRRI released *Boro* rice varieties. These findings were in congruence with the findings of Nguezet *et al.* (2012) and Singh *et al.* (2014). Hossain (2003) found that the majority (67%) of the *Boro* rice farmers had medium adoption, 17% had low adoption and 16% had high adoption of modern *Boro* rice cultivation practices. Haider *et al.* (2001) found four categories of adoption levels of farmers, viz five percent were non-adopters, 62% were low adopters, 24.5% were medium adopters, and 8.5% were high adopters. Razzaque (1977) studied the extent of adoption of HYV rice in three villages of the Bangladesh Agricultural University Extension Project area and observed that among the respondent growers, 6.6% of the farmers had high adoption of HYV rice, 33.3% had medium adoption and 40% had low adoption.

Variety-wise adoption index (AI) and adoption gap index (AGI)

The adoption and adoption gap of all the selected ten BBRI-developed Boro varieties were 77.02% and 22.98% respectively of the respondent farmers of the study area. Based on descending order of variety wise adoption index (AI) and adoption gap index (AGI) of the study area, Rank Orders were made to compare the varieties (Table 2).

Based on descending order of AI, BRRI dhan29 ranked first, followed by BRRI dhan28. AI of these two top-ranked varieties (BRRI dhan29 and BRRI dhan28) were 38.84 and 30.43 respectively, which were much higher than others. Third to ninth ranked varieties were BRRI dhan58, BRRI dhan89, BRRI dhan88, BRRI dhan50, BRRI dhan74, BRRI dhan81, and BRRI dhan63. There was no adoption of BRRI dhan67 in the study area. Salam *et al.*, (2019) also reported that more than 60% of the rice cultivation area of Bangladesh was covered by BRRI dhan29 and BRRI dhan28 varieties during Boro season. After the release of these two (BRRI dhan28 and BRRI dhan29) *Boro* mega varieties in 1994, the second silent green revolution of rice occurred in Bangladesh.

As each of all the ten selected BBRI-developed Boro rice varieties had an equal chance of being adopted across the entire study area, the highest AGI of a variety could be 100/No. of varieties or 100/10, i.e., 10. Based on the descending order of AGI, BRRI dhan67 ranked first (full AGI of 10), followed by BRRI dhan63, BRRI dhan81, BRRI dhan74, BRRI dhan50, BRRI dhan88, BRRI dhan89, BRRI dhan58, BRRI dhan28

and BRRI dhan29. As the AI of BRRI dhan29 and BRRI dhan28 were 38.84 and 30.43 respectively; their AGIs were -28.84 and -20.43 respectively. Negative AGI means these two varieties were cultivated more than the expected area.

Two new *Boro* varieties BRRI dhan88 and BRRI dhan89 released later (in 2018), but their AGI was lower than BRRI dhan50, BRRI dhan74, and BRRI dhan81 which were released earlier. Due to higher yield potentiality BRRI dhan88 and BRRI dhan89 were getting faster popularity than BRRI-released old *Boro* varieties like BRRI dhan50, BRRI dhan74, and BRRI dhan81. Miah (1989) reported that when deciding to introduce a new variety, breeders considered many attributes other than yield, but yield is the still main attribute considered for fast adoption. Fig. 1 shows the adoption and adoption gap of BBRI-developed Boro varietie.

Table 2. Variety-wise adoption index (AI) and adoption gap index (AGI) with rank order.

Name of the Boro variety	Year of introduction *	Yield potential (ton/ha) *	Variety-wise adoption (%) **	Variety-wise adoption index (%)	Rank order (Based on AI)	Variety-wise adoption gap index (AGI)	Rank order (Based on AGI)
BRRI dhan28	1994	6.0	38.46	30.43	2	-20.43	9
BRRI dhan29	1994	7.5	47.59	38.84	1	-28.83	10
BRRI dhan50	2008	6.0	0.96	0.74	6	9.26	5
BRRI dhan58	2012	7.2	05.10	3.78	3	6.22	8
BRRI dhan63	2014	6.5	0.20	0.19	9	9.81	2
BRRI dhan67	2014	6.0	0.00	0.00	10	10.00	1
BRRI dhan74	2015	7.1	0.39	0.3389	7	9.67	4
BRRI dhan81	2017	6.5	0.42	0.3386	8	9.67	3
BRRI dhan88	2018	7.0	0.89	0.79	5	9.21	6
BRRI dhan89	2018	8.0	1.86	1.59	4	8.41	7
Overall adoption			95.87	77.02		22.98	

*Source: *Adhunik Dhaner Chash* (Modern Rice Cultivation), BRRI (2022)

** Adoption is measured by using the traditional method commonly used by different scientists.
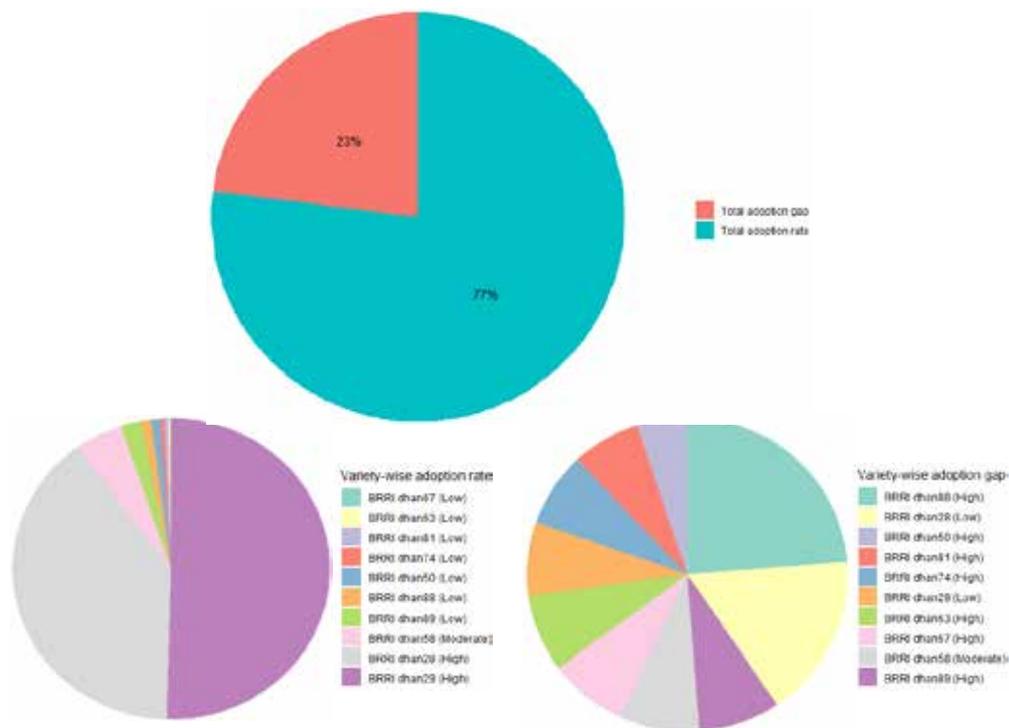
Fig. 1. Comparative adoption and adoption gap of selected 10 BBRI-developed *Boro* rice varieties.

Rahaman *et al*. (2020) reported that 99.2% of the land of Bangladesh was planted with high-yielding rice varieties during the Boro season, of which 67.04% was developed by the Bangladesh Rice Research Institute (BRRI). BRRI dhan28 and BRRI dhan29 were the dominant varieties. The coverage of recently released BRRI varieties was lower compared to the old varieties.

Selected socio-economic characteristics of the rice farmers

Socioeconomic characteristics of the farmers might have a contribution to their adoption gap of BBRI-developed *Boro* rice varieties. For this reason, salient features like possible range, observed range, mean, and standard deviation (SD) of the selected socio-economic characteristics of the 371 sample rice farmers of the study areas were assessed (Table 3).

Table 3. Descriptive statistics of different factors of 10 BRRI released *Boro* rice varieties.

Variable	Possible range	Observed range	Mean	SD
Age (Score)	Unknown	24-80	48.93	11.94
Education (Score)	Unknown	0-16	6.07	4.27
Rice farming area (Score)	Unknown	0.11-6	1.22	0.72
Rice farming income (Score)	Unknown	16-904	193.14	120.64
Rice farming experience (Score)	Unknown	5-55	25.49	9.98
Rice farming profitability (Score)	Unknown	1-2	1.65	0.25
Extension contacts (Score)	0-54	5-38	20.80	7.42
Value chain contact (Score)	0-42	8-39	17.48	5.32
Training exposure (Score)	Unknown	0-28	0.52	2.46
Decision-making ability (Score)	10-40	10-40	28.18	5.60
Satisfaction on BBRI-developed *Boro* rice varieties (Score)	0-45	11-45	30.00	8.48
Knowledge of BRRI-released *Boro* rice varieties (Score)	0-40	8-40	27.26	7.88

Correlation between farmers' socioeconomic characteristics and the adoption gap of selected BBRI-developed *Boro* rice varieties

Before determining the contribution of the selected characteristics of the farmers to their Adoption of BBRI-developed *Boro* rice varieties, initially, Pearson's Product Moment correlation test was initially done to explore the relationship of each of the selected characteristics of the farmers with their adoption gap. Table 4 shows the correlation coefficient of each of the selected characteristics of the respondent farmers with their adoption gap.

Results reveal that out of 12 selected characteristics of the farmers, nine characteristics such as age, education, rice farming experience, rice farming profitability, extension contact, value chain contact, decision-making ability, satisfaction on BBRI-developed *Boro* rice varieties, and knowledge on BBRI-developed *Boro* rice varieties had a significant negative relationship with their adoption gap.

Full model regression analyses were then run by involving all the 12 selected characteristics of the farmers like age (X_1), education (X_2), rice farming area (X_3), annual rice farming income (X_4), rice farming experience (X_5), rice farming profitability (X_6), extension contact (X_7), value chain contact (X_8), rice production training exposure (X_9), decision making ability (X_{10}), satisfaction on BBRI-developed *Boro* rice varieties (X_{11}), and knowledge on BBRI-developed *Boro* rice varieties (X_{12}) as independent variables with their adoption gap of BBRI-developed *Boro* rice varieties as the dependent variable (Y).

Table 4. Correlation coefficients of selected characteristics of the respondent farmers with their adoption gap.

Farmers' characteristic	Correlation co-efficient (r)
Age	-0.421**
Education	-0.207**
Rice farming area	-0.039[NS]
Annual rice farming income	-0.037[NS]
Rice farming experience	-0.438**
Rice farming profitability	-0.516**
Extension contact	-0.574**
Value chain contact	-0.258**
Rice production training exposure	-0.094[NS]
Decision-making ability	-0.456**
Satisfaction on BBRI-developed *Boro* rice varieties	-0.544**
Knowledge on BRRI release *Boro* rice varieties	-0.665**

[NS] Not significant, *Significant at 0.05 level of probability, **Significant at 0.01 level of probability

Table 5 presents the results of full model regression analyses.

The full model regression results revealed that out of 12 selected characteristics of the farmers, seven characteristics such as rice farming area, annual rice farming income, rice farming experience, rice farming profitability, extension contact, satisfaction on BBRI-developed *Boro* rice varieties, and knowledge on BBRI-developed *Boro* rice varieties had a significant contribution to their adoption gap.

James *et al.*, (2013) reported that a Variance Inflation Factor (VIF) 5 or less is not problematic for collinearity in a multivariable (linear or logistic) model. Miles (2014) suggested that generally, a VIF above 4 or tolerance below 0.25 indicates that multicollinearity might exist, and further investigation is required. When VIF is higher than 10 or tolerance is lower than 0.1, there is significant multicollinearity that needs to be corrected. In the full model regression analysis results, it was found that the VIF of

'rice farming area' and 'annual rice farming income' were greater than 10 and their tolerance was less than 0.1. It means that there was significant multi-collinearity among rice farming areas and annual rice farming income.

Keeping these facts in view, linear stepwise multiple regression analysis was used to explore the contribution of the selected characteristics of the farmers to their adoption gap of BBRI-developed *Boro* rice varieties as suggested by Droper and Smith (1981) to insert variables in turn until the regression equation was satisfactory. Therefore, in order to avoid misleading results due to the problem of multi-collinearity and to determine the best explanatory variables, the method of stepwise multiple regression was employed by involving the selected characteristics of the farmers as independent variables with their adoption gap of BBRI-developed *Boro* rice varieties as dependent variable. The objective of the stepwise multiple regression

model was to find out the contribution of the variables, only those were significant. Ali (2009, Moonmoon (2021), and Malek (2021) also followed these procedures in their studies.

Table 5. Results of full model regression analysis showing the contribution of all the 12 independent variables to the adoption gap.

Selected characteristic	Unstandardized coefficient		Standardized coefficient			Collinearity statistics	
	B	Std. Error	Beta	T	Sig.	Tolerance	VIF
Constant	104.244	5.949		17.522	0.000		
Age (X_1)	0.035	0.104	0.019	0.335	0.737	0.366	2.731
Education (X_2)	-0.045	0.194	-0.009	-0.232	0.817	0.820	1.219
Rice farming area (X_3)	-12.686	3.900	-0.412	-3.253	0.001	0.072	13.866
Annual rice farming income (X_4)	0.081	0.023	0.441	3.452	0.001	0.071	14.061
Rice farming experience (X_5)	-0.308	0.125	-0.139	-2.468	0.014	0.364	2.747
Rice farming profitability (X_6)	-14.887	3.924	-0.167	-3.794	0.000	0.602	1.662
Extension contact (X_7)	-0.830	0.127	-0.279	-6.526	0.000	0.634	1.577
Value chain contact (X_8)	0.122	0.153	0.029	0.793	0.428	0.851	1.175
Rice production training exposure (X_9)	-0.177	0.313	-0.020	-0.566	0.572	0.952	1.050
Decision making ability (X_{10})	-0.011	0.178	-0.003	-0.064	0.949	0.571	1.751
Satisfaction on BBRI-developed *Boro* rice varieties (X_{11})	-0.279	0.120	-0.107	-2.330	0.020	0.547	1.829
Knowledge on BBRI-developed *Boro* rice varieties (X_{12})	-0.973	0.145	-0.347	-6.719	0.000	0.434	2.302

R = 0.756, R square = 0.585, Adjusted R square = 0.571

After running stepwise multiple regression, it was found that out of 12 independent variables, five (5) variables namely, knowledge of BBRI-developed *Boro* rice varieties (X_{12}), extension contact (X_7), rice farming profitability (X_6), rice farming experience (X_5), and satisfaction on BRRI released *Boro* rice varieties (X_{11}) were entered into the regression equation. Table 6 presents the results of this stepwise multiple regression analysis.

Table 6. Summary of stepwise multiple regression analysis showing the contribution of the significant variables to the adoption gap.

Variable entered	Standardized partial 'b' coefficient	Value of 't' (with probability level)	Adjusted R^2	Increase in R^2	Variation explained (%)	Collinearity Statistics	
						Tolerance	VIF
Knowledge of BRRI release *Boro* rice varieties (X_{12})	- 0.364	-7.577 (0.000)	0.441	0.441	44.1	0.512	1.955
Extension contacts (X_7)	- 0.251	-6.066 (0.000)	0.525	0.084	8.4	0.689	1.452
Rice farming profitability (X_6)	- 0.127	-3.012 (0.003)	0.545	0.020	2.0	0.660	1.514
Rice farming experience (X_5)	- 0.126	-3.240 (0.001)	0.557	0.012	1.2	0.776	1.289
Satisfaction on BBRI-developed *Boro* rice varieties (X_{11})	- 0.117	-2.571 (0.011)	0.564	0.007	0.7	0.573	1.744
		Total		0.564	56.4		

Multiple R	= 0.755
R-square	= 0.570
Adjusted R-square	= 0.564
F-ratio	= 292.45 significant at 0.000 level
Constant	= 101.27

Table 6 presents the data that indicate the multiple R, R^2, and adjusted R^2 in the stepwise multiple regression analysis were 0.755, 0.570, and 0.564 respectively, and the corresponding F-ratio of 292.45 were significant at 0.000 levels.

The regression equation obtained was as follows:

$$Y = 101.27 - 0.364X_{12} - 0.251X_7 - 0.127X_6 - 0.126X_5 - 0.117X_{11}$$

Stepwise multiple regression analysis revealed that the whole model of 12 independent variables explained 56.4% of the total variation in the adoption gap of BBRI-developed *Boro* rice varieties. However, since the standardized regression coefficient of five variables formed the equation and was significant, it might be assumed that whatever contribution was there, it was due to these five variables.

VIF of the significant variables were 1.955, 1.452, 1.514, 1.289, and 1.744 which were less than 2; again, the tolerance of these variables was 0.512, 0.689, 0.660, 0.776, and 0.573 which were higher than 0.25. It means that multi-collinearity did not exist in these significant variables as suggested by James *et al*. (2013) and Miles (2014).

Results of stepwise multiple regression analysis again indicated that 'Knowledge of

BRRI released *Boro* rice varieties (X_{12})' of the farmers was by far the most important characteristic that strongly and negatively influenced their adoption gap of BRRI-released *Boro* rice varieties. 'Extension contacts (X_7)', 'rice farming profitability (X_6)', 'rice farming experience (X_5)', and 'satisfaction on BBRI-developed *Boro* rice varieties (X_{11}) of the farmers also had remarkable negative influence upon their adoption gap of BRRI-released *Boro* rice varieties. Since the rest seven variables or characteristics of the farmers did not enter into the regression model, it was inferred that these seven characteristics either had a multi-collinearity problem or had a minimum contribution to the total explained variation of 56.4%. On the basis of stepwise regression analysis, contributions of significant five independent variables to the adoption gap of BBRI-developed *Boro* rice varieties are discussed below in order to importance.

Knowledge of BBRI-developed *Boro* rice varieties (X_{12}): From the results of stepwise multiple regression analysis, it was revealed that knowledge of BBRI-developed *Boro* rice varieties of the farmers had a strong negative contribution to their adoption gap. Co-efficient of correlation also showed a significant negative relationship between the knowledge farmers and their adoption gap. It means that farmers' knowledge of BBRI-developed *Boro* rice varieties had a strong positive contribution to their adoption of BBRI-developed *Boro* rice varieties. Knowledge plays an important role in the decision-making process. It is the precursor to the adoption of any innovation. A knowledgeable person could understand the merits and demerits of any technology easily in a short time. Therefore, farmers having high knowledge could easily reduce their adoption gap of BBRI-developed *Boro* rice varieties. This might be the reason for knowledge having a negative influence on the adoption gap. Reddy *et al.* (1987) found a

significant association between knowledge and the use of improved packages of practices in paddy production by participant and non-participant farmers. This was also supported by the studies of Asaduzzaman (2002), Islam (2003) Hamidi (2004), Kumar *et al.* (2010), and Singh (2014).

Extension contacts (X_7): The extension contact of farmers had the 2nd highest significant and negative influence on their adoption gap and it was found to be the second most important contributor. The value of co-efficient of correlation (r) also showed a significant negative relationship between the extension contact of the farmers and their adoption gap. Farmers having greater contact with the extension agents obviously had a lower adoption gap. This might be the reason for extension contact having a negative influence on the adoption gap. Hamidi (2004) also found a significant positive relationship between the farmers extension contact and their adoption of rice cultivation. This result was consistent with earlier findings of Langyintuo and Mungoma, (2008); Kassie *et al.*, 2011; Asfaw *et al.*, (2012); Feleke and Zegeye (2006); Mignouna *et al.*, (2011); and Mariano *et al.*, (2012).

Rice farming profitability (X_6): Rice farming profitability of the farmers was the 3rd important contributor and had a significant and negative influence on their adoption gap of BBRI-developed *Boro* rice varieties. Coefficient of correlation value also supported this relationship between the concerned variables. It was very logical that farmers could adopt profitable innovations in shortest period of time and profit could reduce the adoption of innovations. The result was consistent with earlier findings of Langyintuo and Mungoma, (2008); Kassie *et al.*, 2011; Asfaw *et al.*, (2012); Feleke and Zegeye (2006); Mignouna *et al.*, (2011); and Mariano *et al.*, (2012).

Rice farming experience (X_5): The experience in rice farming of the farmers had a significant and negative influence on their adoption gap and it was found to be the fourth important negative contributor to the adoption gap, i.e. positive contributor to the adoption of BBRI-developed *Boro* rice varieties. Co-efficient of correlation also showed a significant negative relationship between the rice farming experience of the farmers and their adoption gap. Experience in rice farming makes farmers efficient and judicious in their adoption decisions. The present study proved that the farmers who have more experience in rice farming on this matter obviously had a lower adoption gap. Hamidi (2004) found a significant positive relationship between the experience in rice farming of the farmers and the adoption.

Satisfaction on BBRI-developed *Boro* rice varieties (X_{11}): Satisfaction on BBRI-developed *Boro* rice varieties of the respondents was the 5th important contributor and had a significant negative influence on their adoption gap. Co-efficient of correlation also showed a significant negative relationship between the satisfaction of the farmers on BBRI-developed *Boro* rice varieties and their adoption gap. Actually, farmers having more satisfaction on BBRI-developed *Boro* rice varieties had the capacity to take the challenge and buy inputs for new variety adoption which might be the cause for this finding. The result was consistent with earlier findings of Langyintuo and Mungoma 2008; Kassie *et al.* 2011; Asfaw *et al.*, 2012; Feleke and Zegeye, 2006; Mignouna *et al.*, 2011; and Mariano *et al.*, 2012.

CONCLUSION

Most of the rice farmers had high adoption and low adoption gap; 23.72% had moderate adoption and adoption gap; and the rest 3.23% of respondent farmers had low adoption and high adoption gap of BBRI-developed *Boro* rice varieties. The older two varieties BRRI dhan28 and BRRI dhan29 are still more popular than the new varieties. Knowledge on BBRI-developed *Boro* rice varieties, extension contacts, rice farming profitability, rice farming experience, and satisfaction on BBRI-developed *Boro* rice varieties of the farmers had a significant negative contribution to their adoption gap, i.e., positive contribution to their adoption of BBRI-developed *Boro* rice varieties. Full model regression analysis also revealed that the 'rice farming area' and 'annual rice farming income' of the farmers also had significant negative contributions to their adoption gap, i.e., positive contribution to their adoption of BBRI-developed *Boro* rice varieties. Therefore, it may be concluded that to popularize newly released BRRI-*Boro* rice varieties emphasis should be given to increasing the farmers knowledge by increasing extension contact through rapid information dissemination, demonstration, farmers' participatory research, training, etc. for all categories of farmers with low to high experience, low to high rice farming area and having low to high annual rice farming income to make them satisfied and to table to understand the profitability of BBRI-developed *Boro* rice varieties. Planners and decision-makers need to consider these issues for enhancing and promoting the adoption of BBRI-developed *Boro* rice varieties and minimize their adoption gap.

ACKNOWLEDGEMENTS

sample rice farmers of the study area for their direct contribution in cooperating and arranging a time to conduct interviews. The researchers also recognize Niaz Md Farhat Rahman, PSO, BRRI for his valuable suggestions and comments during the analysis of data and writing the manuscript.

CONFLICT OF INTERESTS

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

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Eco-Engineering for Managing Insect Pests in Rice Fields

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ABSTRACT

This study was consisted of eight experiments across Boro and Transplanted Aman seasons in various locations in Bangladesh to explore eco-friendly insect pest control methods in rice fields. The primary objectives were to safeguard natural-enemies through ecological engineering techniques and minimize the use of insecticides in rice farming. Ecological engineering aimed to boost biodiversity in the rice environment, fostering both plant and animal diversity to offer extra support for natural enemies in terms of sustenance and shelter. To fulfill these objectives, nectar-rich flowering plants such as marigold, cosmos, sesame and sunflower were planted strategically in rice bunds ensuring habitats by establishing crucial sources of food and protection for beneficial insects. These beneficial insects, in turn, contribute to biological pest control by establishing an equilibrium between harmful and beneficial insects within the rice ecosystem and consequently reducing the dependency on insecticides. The study consisted of two treatments, T_1: Rice fields with flowering plants on bunds; and T_2: Farmer's practice of prophylactic insecticide use. The study observed a significant increase in the predators and parasitoids abundance in eco-engineering field (T_1) compared to insecticide-treated fields (T_2). Across seasons and locations, T_1 consistently showed higher populations of various beneficial insects such as spiders, damsel flies, dragon flies, ladybird beetles, carabid beetles, staphylinid beetles, green mirid bugs, and parasitic wasps compared to T_2. Notably, despite maintaining insect infestation below the economic threshold level in both T_1 and T_2, T_1 exhibited significantly higher egg parasitism rates of rice hispa, brown planthopper, yellow stem borer, and rice leafroller compared to T_2. Remarkably, on average while achieved statistically similar yields between T_1 and T_2 (5.99 t/ha and 5.93 t/ha, respectively), the study highlights the efficacy of manipulating habitats to enhance biocontrol services in rice fields. By providing nectar sources, alternative prey, and refuges for natural enemies, this approach offers promising prospects for reducing insecticide usage in rice fields by maintaining or potentially increasing rice yield equivalents.

Key words: Eco-engineering, natural enemies, flowering plants, predator and parasitoid.

INTRODUCTION

The global imperative for increased rice production, driven by burgeoning populations worldwide, poses a pressing challenge, particularly in countries like Bangladesh (Kennedy, 2002; Miao *et al*., 2011). Central to this challenge is the prevalence of diverse arthropod pests that ravage rice fields. Bangladesh's rice ecosystems have seen a recorded count of 266 arthropod species and 375 natural enemies (comprising predators and parasitoids) that play crucial roles in these ecosystems (Islam *et al.,* 2003; 2012; Roy *et al.,* 2024). These myriad arthropods perform diverse ecological roles, ranging from herbivory on rice plants to activities such as parasitization, predation, pollination, decomposition, and nutrient cycling. The complex interactions among rice plants, pests, and a wide variety of natural enemy species aim to establish balances that deter

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abnormal pest outbreaks.

However, the pervasive use of synthetic pesticides poses a significant challenge, proving hazardous not only to target pests but also to non-target organisms (Ahmed *et al.,* 2002; 2011). Farmers in Bangladesh resort to chemical pesticides, particularly during the early stages of crop growth when pest populations might not inflict substantial damage (Bari *et al*., 2015). Evidence suggests that refraining from harmful pesticide use during this critical period, approximately 30 to 40 days after rice transplanting allows natural enemy populations to curb abnormal pest outbreaks and prevent significant harm to crops (BRRI, 2016).

Varied management practices prevail among farmers across Bangladesh, and some alternative technologies aim to reduce chemical pesticide reliance in rice production (Bari *et al*., 2015). One such strategy is ecological engineering, which aims to rejuvenate or augment biodiversity in the rice ecosystem, catering to both flora and fauna species. This approach improves vital resources for natural-enemies, such as shelter and food. The application of ecological engineering entails cultural practices, primarily centered around vegetation management, with the objective of reinforcing biological control or the direct impacts on pests known as 'bottom-up' effects (Gurr *et al.,* 2004).

The provision of resources like sap and pollen to the predators fosters bio-control, whereas pesticides diminish natural enemy populations, impairing this biological control (Heong, 2009). Manipulation in insect's habitat to bolster biological control has been explored keenly across various crops (Landis *et al*., 2000). This strategy intends to enhance the activity of natural-enemy by providing enough resources that augment their performance, including

alternative foods specially, when the prey or the hosts are intermittently unavailable (Gurr, 2009).

Several studies underscore the efficacy of ecological engineering. As an example, a field investigation carried out in Vietnam showed that cultivating flowering plants with abundant nectar on the embankments of rice fields substantially elevated the abundance of natural-enemies and had an effect on the incidence of rice planthopper infestation (Lan *et al.,* 2010). This approach encompasses three key ecological policies to heighten suppression of insect pest (Gurr *et al.,* 2012). Firstly, reducing the application of insecticide application at the early cropping stages decreases mortality among beneficial arthropods. Secondly, offering alternative food sources to predators during these stages, coupled with refraining from early-season insecticide use, enhances their efficacy. Finally, habitat manipulation, such as planting flowering plants on the embankment of rice field which contain nectar, bolsters hymenopteran parasitoids.

This ecological engineering approach holds immense promise in cultivating ecosystem services to bolster pest suppression sustainably (Gurr *et al*., 2011). The existence of nectar-rich flowering plants on levees not only aids pest parasitoids by providing nourishment but also serves as a potential communication tool to encourage farmers to reduce insecticide usage, countering the influence of pervasive insecticide commercialization like marketing and advertising to increase public awareness (Escalada and Heong, 2012).

Based on these foundations, this research aimed to preserve natural-enemies through ecological engineering methods, specifically by growing flowering plants rich in nectar on embankments, with the goal of reducing the reliance on insecticides in rice cultivation.

MATERIALS AND METHODS

During the Boro seasons of 2018-19 and 2019-20, a series of experiments were conducted involving different rice varieties. In the Boro 2018-19 season, experiments were carried out at BRRI Gazipur and a farmer's field in Rajshahi, where test varieties were BRRI dhan28 and BRRI dhan63 respectively. Additionally, experiments with BRRI dhan88 were conducted at both BRRI HQ Gazipur (Photo-1) and Charbadna farm at BRRI Regional Station (RS), Barishal, during the Boro 2019-20 season. The experiment was carried out by Complete Randomized Design (CRD) with three replications. The size of each treatments was 400 m^2 and the plot size of each replicated treatment was 133 m^2.

The treatments employed were as follows: T_1 involved cultivating flowering-plants (Marigold, cosmos, and sunflower) at bunds within the rice fields to provide essential food and shelter for various parasitoids. The width of the flowering bunds was 50 cm. T_2 represented the standard farmer's practice, encompassing prophylactic insecticide use. In T_2, different insecticides, viz., carbofuran 5G, chlorpyrifos 20EC, and (chlorantraniliprole + thiamethoxam) 40WG-were applied four times at 10.0kg ha^{-1}, 1.0 L ha^{-1} and 75 g ha^{-1} doses respectively, following a 15-day interval after the first urea fertilizer top dressing (after 20 DAT). Among the three insecticide carbofuran 5G was used first two times followed by other two insecticides one time.

BRRI dhan87 were used in T. Aman 2019 season, at BRRI HQ farm, Gazipur, BRRI RS Rajshahi, and a farmers' field in Alimganj, Paba, Rajshahi. In T. Aman 2020, an experiment was done solely at BRRI, Gazipur (Photo-2). Similar treatments (T_1 and T_2) were implemented across all locations: T_1 involved cultivating sesame and cosmos on rice bunds, while T_2 replicated the farmers' standard practice of prophylactic insecticide use. The same three insecticides utilized during the Boro season were applied three times in T_2. At first granular insecticide (carbofuran 5G) was applied during the first urea fertilizer top dressing (after 20 DAT) following a 15-day interval of other two insecticides. In T. Aman season, 20 days old seedling and in case of Boro season 35-day old seedling were transplanted in both the treatments at a time.

Uniformly across seasons and locations, twenty complete sweeps were conducted from both the treatments at 15-day intervals until the flowering stage. Insect pests and their predators and parasitoids were counted from all the sweeps, meticulously recorded and tallied separately. Additionally, the egg parasitism rates of rice hispa (RH), brown planthopper (BPH), and yellow stem borer (YSB) were determined using the retrieval method. Moreover, larval parasitism of rice leafroller (RLR) from natural infestation was exclusively evaluated at BRRI HQ, Gazipur across various seasons.

Statistical analysis: All data were subjected to statistical analysis separately by using the analysis of variance technique by R software (versions-2024.04.0) using 'doebioresearch' package.

Photo-1. Scenario of eco-engineering maintained plot at BRRI HQ, Gazipur, during Boro 2019-20.

Photo-2. Scenario of eco-engineering maintained plot at BRRI HQ, Gazipur, during T. Aman 2020.

RESULTS

Across seasons and locations, the incidence of insect infestation consistently persisted beneath the economic threshold level (ETL). Notably, insect pest prevalence was comparatively lower during the Boro season than in the T. Aman season.

During Boro 2018-19 season, the highest numbers of grasshoppers (GH) were observed in T_1 (5.50/20 sweep) at BRRI

Gazipur, followed by green leafhoppers (GLH), long-horned grasshoppers (LHG), and rice bugs (RB) at 1.0, 0.75, and 0.75/20 sweep respectively (Fig. 1). Similarly, in the farmer's field at Alimganj, Paba, Rajshahi, the highest GH count was 6.0/20 sweep in T_1, followed by brown planthoppers (BPH) at 3.0/20 sweep (Fig.1). Natural enemies, notably spiders (SPD), showed higher numbers in T_1 compared to T_2 at both BRRI Gazipur and farmer's field, Alimganj, Paba, Rajshahi (Fig. 2).
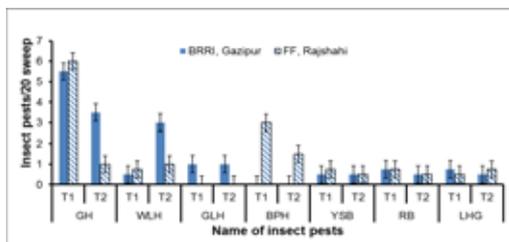

Fig.1. Insect pest population/ 20 sweep in different treatments at BRRI, Gazipur and farmers field, Rajshahi during Boro 2018-19 (T_1=Flowering plants on levee, T_2= Farmers practice/insecticide application)
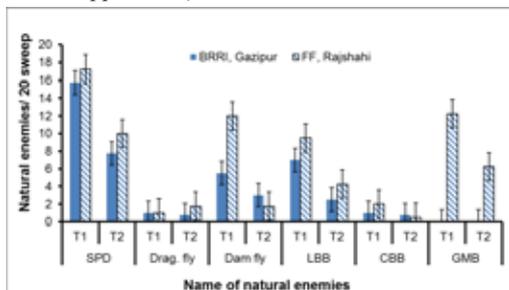

Fig.2. Predator (natural enemies) population/20 sweep in different treatments at BRRI, Gazipur and farmers field, Rajshahi during Boro 2018-19, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice / insecticide application)

Remarkably, in Boro 2018-19 at BRRI Gazipur, despite three applications of insecticides in T_2, comparable yields were observed between T_1 (7.06 t/ha) and T_2 (7.01 t/ha). Additionally, egg parasitism rates for RH, BPH, and YSB were notably higher in T_1 (59.2%, 13.5%, and 24.0% respectively) compared to T_2 (Table 1). In Rajshahi, similar yields were also observed in T_1 (4.55 t/ha) and T_2 (4.57 t/ha).

During Boro 2019-20, the incidence of GH and GLH was the lowest in both T_1 and T_2 at BRRI Gazipur (Fig.3). However, the population of the insect pests was more at Charbadna farm, BRRI RS, Barishal, with the highest GLH and GH counts in T_2 (Fig. 3). Natural enemies showed higher numbers in T_1 at both BRRI, Gazipur and Barishal, with notable exceptions such as staphylinid beetles and parasitic wasps that were absent in T_2 at BRRI, Gazipur (Fig. 4).

Fig.3. Insect pest population/20 sweep in different treatments at Gazipur and BRRI Barishal farm during Boro 2019-20, BRRI, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice /insecticide application)

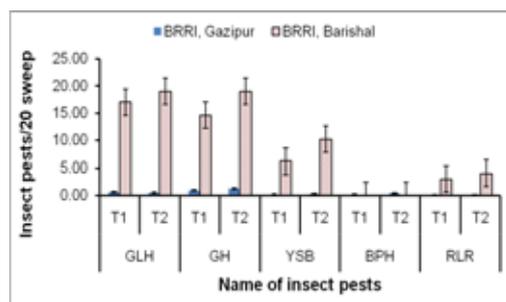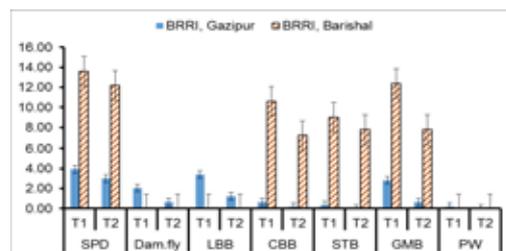Fig.4. Predator (natural enemies) population/20 sweep in different treatments at Gazipur and BRRI Barishal during Boro 2019-20, BRRI, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice i.e., insecticide application)

In T_2 insecticide used three times both in BRRI Gazipur and BRRI RS Barishal. But similar yield was obtained both in T_1 and T_2 (7.82 and 7.85 t/ha respectively at BRRI, Gazipur and 6.71 and 6.72 t/ha respectively at BRRI RS Barishal) (Table 1).

During the T. Aman 2019 season, comparable levels of harmful and beneficial insects were observed across all locations, albeit with a higher incidence in T. Aman season compared to the Boro season. At BRRI Gazipur, T_1 exhibited the highest count of grasshoppers (GH) followed by white leafhoppers (WLH), green leafhoppers (GLH), and rice leaf folders (RLF). Lower pest incidence was noted at BRRI RS Rajshahi and in the farmers' fields of Rajshahi (Fig. 5). Moreover, T_1 consistently showed a higher population of predator, including damsel flies, spiders, ladybird beetles, carabid beetles, and dragon flies compared to T_2 at BRRI farm, Gazipur (Fig. 6). The locations BRRI RS Rajshahi and farmer's fields of Rajshahi displayed the highest count of beneficials and the lowest insect incidence. Across seasons and locations, T_1, consistently harbored more natural enemies. Additionally, T_1 displayed significantly higher egg parasitism rates for brown planthopper (BPH), yellow stem borer (YSB), and larval parasitism for rice leaf rollers (RLR) compared to T_2 at BRRI, Gazipur. Grain yield was similar between T_1 and T_2; however, T_1 additional sesame production substantially increased the rice equivalent yield (REY) to 7.0 t/ha (Table 2). This trend was also observed at BRRI RS Rajshahi and farmer's fields of Rajshahi, where REY was higher in T_1 compared to T_2 (Table 2). Although insecticides were used three- and four-times during T. Aman and Boro seasons in T_2, respectively, the yield remained comparable to that of T_1. However, T_1 generated extra profit due to additional production of crops in bunds without the use of insecticide.
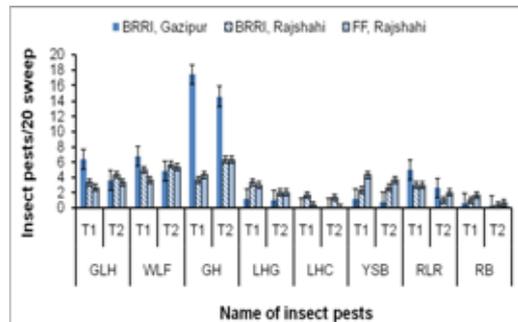
Fig.5. Insect pest population/ 20 sweep in different treatments at BRRI, Gazipur, BRRI Rajshahi and Farmers field, Rajshahi during T. Aman 2019, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice / insecticide application)
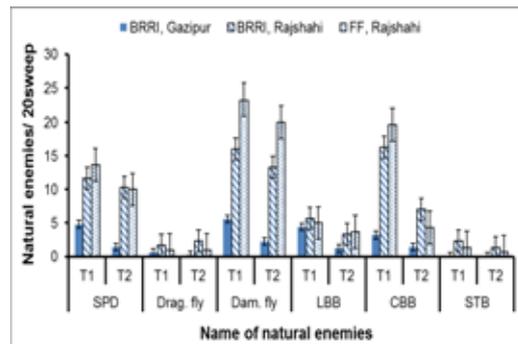
Fig.6. Predator (natural enemies) population/20 sweep in different treatments at BRRI,Gazipur, BRRI, Rajshahi and Farmers field, Rajshahi during T. Aman 2019, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice/insecticide application)

In the T. Aman 2020 season, T_1 at BRRI, Gazipur exhibited the highest count of grasshoppers, followed by rice leaf folders, green leafhoppers, and white leafhoppers (Fig. 7). Conversely, T_2 showed a lower incidence of insect pests. Similarly, T_1 displayed a higher count of predators like spiders, damsel flies, ladybird beetles, carabid beetles, and dragon flies compared to T_2 at BRRI farm, Gazipur (Fig. 7). T_1 also demonstrated higher egg parasitism rates for

YSB and larval parasitism for RLR compared to T_2 at BRRI, Gazipur (Table 2). Grain yield was similar between T_1 and T_2; however, the additional sesame production in T_1 significantly raised the REY to 5.12 t/ha (Table 2). Challenges faced by BRRI dhan87 due to lodging during the soft dough stage of the crop resulting lower yield in both the treatments. Treatment T_2, where insecticides were used four times, yielded similarly to T_1. Yet, T_1 yielded additional profit due to increased sesame production without the use of insecticide.

Fig.7. Insect pest and beneficial insects (natural enemies)/20 sweep in different treatments at BRRI, Gazipur during T. Aman 2020, (T_1=Rice field with flowering plants on bunds, T_2= Farmers practice/insecticide application)

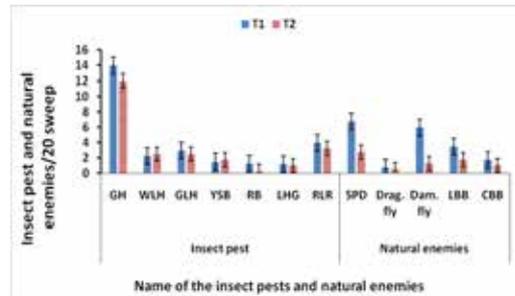**Table 1. Parasitism (%) and yield of different treatments in different locations during boro season.**

Treatment	Boro 2018-19					Boro 2019-20	
	BRRI Gazipur				FF Rajshahi	BRRI Gazipur	BRRI Barishal
	RH PP	BPH PP	YSB PP	GY (t ha^{-1})	GY (t ha^{-1})	GY (t ha^{-1})	GY (t ha^{-1})
T_1	59.20 a	13.5 a	24 a	7.06	4.55	7.82	6.71
T_2	17.83 b	0.0 b	0.00 b	7.01	4.57	7.85	6.70
Levels of significance	***	***	***	ns	ns	ns	ns
LSD (5%)	2.05	1.60	3.21	-	-	-	-
CV	2.35	10.48	11.79	1.35	7.98	2.91	7.58

(Where, T_1=Rice field with flowering plants on bunds, T_2= Farmer'ss practice/insecticide application, RH=Rice Hispa, BPH=Brown Planthopper, YSB=Yellow Stem Borer, GY=Grain Yield, PP=Parasitism Percentage, GY= Grain yield)

Table 2. Percent parasitism and yield of different treatments in different locations during T. Aman season.

Treatment	T. Aman 2019 BRRI Gazipur					T. Aman 2020 BRRI, Gazipur				T. Aman 2019 BRRI Rajshahi		FF Rajshahi	
	BPH PP	RLR PP	YSB PP	GY (t ha^{-1})	REY (t ha^{-1})	RLR PP	YSB PP	GY (t ha^{-1})	REY (t ha^{-1})	GY (t ha^{-1})	REY (t ha^{-1})	GY (t ha^{-1})	REY (t ha^{-1})
T_1	23.67 a	29.23 a	34.35a	5.60	7.0a	19.22a	25.39a	5.60	7.10 a	6.00	7.49a	4.53	6.03 a
T_2	3.67 b	4.40 b	0.0 b	5.65	5.65b	1.25 b	0.0 b	5.65	5.65b	5.70	5.70 b	4.41	4.41 b
Levels of significance	***	***	***	***	ns	***	***	ns	**	Ns	**	ns	***
LSD (5%)	1.60	1.61	1.60	3.21	-	0.42	1.60	-	0.49	-	0.26	-	0.09
CV	5.13	4.23	4.13	11.79	5.15	1.80	5.57	5.06	3.39	4.98	1.13	3.54	0.54

(Where, RLR=Rice Leaf Roller, BPH=Brown Planthopper, YSB=Yellow Stem Borer, GY=Grain Yield, REY= Rice Equivalent Yield, PP=Parasitism Percentage, T_1=Rice field with flowering plants on bunds, T_2= Farmers practice/insecticide application, FF= Farmers field)

DISCUSSION

In rice production, insecticides are frequently employed to manage insect pests and ensure optimal yields. Bangladesh's rice ecosystem harbors 232 detrimental insect species, 183 parasitoids, and 192 predators, among which only 20-33 species pose significant threats, capable of inducing yield losses when present in substantial numbers (Islam *et al*., 2003; 2012). Predators and parasitoids naturally regulate these pests in the field. However, the initiation of the modern rice varieties in the last three decades, driven by the need to feed growing populations in countries like Bangladesh, has led to extensive chemical insecticide use. These pesticides diminish natural enemy populations, impeding biological control and fostering pest outbreaks (Heong, 2015).

Habitat manipulation, aimed at augmenting biological control, has been explored across various crops (Landis *et al*., 2000). Thus, this strategy strives to augment the effectiveness of natural enemies by supplying resources that bolster their performance when prey or hosts are scarce (Gurr, 2009). Materials like nectar have been demonstrated to extend the lifespan, improve foraging efficiency, and increase the actual parasitism of various parasitoid species. (Mitsunaga *et al*., 2006; Shearer and Atanassov, 2004; Zhu *et al*., 2013; Lou *et al*., 2014).

The eco-engineering technique for rice insect control, pioneered by the International Rice Research Institute (IRRI) and was started in countries like China, Vietnam, and Thailand in 2008, has shown promising results. Vietnamese studies demonstrated that cultivating nectar plants alongside rice crops on bunds significantly bolstered the population and effect of beneficials on rice planthopper species (Lan *et al*., 2010).

Our study modified the existing rice ecosystem by implementing ecological engineering techniques, planting flowering—plants carrying nectar such as sunflower, sesame, marigold, and cosmos on bunds around rice fields. These plants provided crucial resources like food, shelter, and nutrients, facilitating the growth and development of biocontrol agents within the rice ecosystem (Photos 1 and 2). Parasitoids frequently consumed nectar from these flowers, improving their fitness (Zhang *et al*., 2017). Our results demonstrated a substantial increase in parasitoids and predators' abundance (Figs 2, 4 and 6), leading to enhanced parasitism rates of rice planthopper, yellow stem borer eggs and rice hispa in rice fields (Table 1).

During the T. Aman season, sesame flowers on bunds served as essential resources for natural enemies, particularly hymenopteran parasitoids. These flowers significantly improved the efficacy of the genus *Anagrus*- an egg parasitoid of planthopper (Gurr *et al.,* 2011). Zhang *et al.* (2017) announced that incorporating nectar containing plants and discontinuing insecticide use increased egg parasitism rates of planthopper significantly and enhanced egg parasitism of lepidopteran insects in rice ecosystem.

The integration of flowering-plants in our study, which contain nectar and stand on rice bunds are primarily beneficial for parasitoids and act as crucial global pest control agents (Macfadyen *et al*., 2015). Numerous parasitoids, effective against pests like *Scirpophaga incertulas*, *Dicladispa armigera*, *Cnaphalocrosis suppressalis*, *C. medinalis* and planthoppers, were identified (Lu *et al*., 2014). The *Anagrus* spp., commonly prevailed in our experiment, have shown effectiveness opposed to planthoppers in various Asian

countries which are rice growing (Gurr *et al*., 2011; Lu *et al*., 2014).

Additionally, rice plots with plants on levees having nectar gave shelter more predators compared to those treated with insecticides. Spiders are highly effective predators globally and in rice fields (Lu *et al*., 2014; Bamberadeniya and Edirisinghe, 2009; Wang *et al*., 2017). Global spider communities have the capacity to eliminate approximately 800 million tons of insect pest species, estimated by Nyffeler and Birkhofer (2017) and (Lu *et al*., 2005) stated that *Tetragnathidae* being the predominant spider taxon in rice ecosystems.

Conversely, the T_2 treatment, which involved the application of broad-spectrum insecticides 3 to 4 times without the presence of flowering plants, exhibited lower parasitism rate and captures of parasitoids for planthopper, coleopteran, lepidopteran eggs and larvae. Insecticide application decreased parasitoid abundance, resulting in reduced parasitism rates various insects like yellow stem borer, planthopper and rice hispa eggs, as well as rice leafroller larvae. Insecticide use is known to negatively impact planthopper natural enemies (Chien and Cuong, 2009; Teo, 2011; Zhang *et al*., 2017), potentially inducing planthopper outbreaks by diminishing parasitoids and predators (Sogawa, 2019).

Evidently, the rice field in close proximity to flowering plants abundant in nectar, without any insecticide treatment, harbored the greatest abundance of beneficials and the least incidence of harmful insects. In contrast, the use of insecticides (T_2 treatment) resulted in the lowest count of beneficials and parasitism rates. This highlights the influence of insecticide application in diminishing parasitoids and the rates of parasitism for the examined eggs of insect pests (Gurr *et al*., 2016).

Insect infestation was beneath the ETL in the T_1 plots. Notably, regular insecticide application in rice fields (T_2) did not boost yields, aligning with findings by (Ali *et al*., 2017), who demonstrated comparable rice yields without insecticide application, emphasizing the reduction in insecticide use and farmers cultivation cost in rice production. Our experiment outcomes emphasize that altering the current rice ecosystem using eco-engineering effectively managed pests without compromising crop yield. The T_1 treatment, in particular, enhances sound environment and faunal biodiversity, simultaneously improving the visual appeal of the rice ecosystem. Introducing nectar rich flowering plants on levee could also serve as supplementary income sources for economically disadvantaged rice farmers. Although sunflower, cosmos, sesame and marigold were utilized in this study- other appropriate crops such as okra and common bean, featuring nectar-rich flowers, could yield more advantages.

CONCLUSION

Sap-rich flowering plants presence on levee resulted in the highest count of beneficials and the greatest percentage of parasitism observed in rice fields, targeting insect pest eggs and larvae. Conversely, rice fields surrounded by flowering plants exhibited no observable decrease in yield in comparison with insecticides. This discovery suggests that farmers have the potential to reduce or eliminate the application of hazardous and toxic insecticides for pest management by incorporating flowering plants along rice bunds which are rich of nectar. This approach holds potential for ecosystem revitalization, contributing to the preservation of natural-enemies. Ultimately, it aids in reducing production expenses and environment pollution mitigating insect outbreak and decreasing the labourer

involved for application of pesticide, thereby increasing overall income.

The utilization of ecological engineering can complement existing Integrated Pest Management (IPM) strategies employed in various agricultural systems, including tropical rice farming. By bolstering the effectiveness of natural enemies and diminishing reliance on pesticides, this technique opens up new avenues for application within the rice landscape. The challenge ahead lies in disseminating this technology among Bangladeshi farmers, necessitating a shift away from indiscriminate insecticide use. Efforts toward widespread adoption of ecological engineering practices hold the key to sustainable pest management in the region.

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Combining Ability Analysis of Hybrid Rice (*Oryza sativa* L.) Parental Lines for Yield, Grain Quality and Grain Zinc Content

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ABSTRACT

Combining ability analysis assists in identifying parents with high general combining ability (GCA) effects and cross combinations with high-specific combining effect (SCA) to exploit heterosis and isolate pure lines from the progenies of heterotic hybrids. An experiment was conducted at the experimental field of the Genetics and Plant Breeding department, Bangabandhu Sheikh Mujibur Rahman Agricultural University during Aman season 2017-2018 using 25 hybrids obtained from 5 x 5, line x tester mating design. Analysis of variance of combining ability showed highly significant differences among the genotypes indicating wider genetic variability among genotypes. Significant General Combining Ability (GCA) and Specific Combining Ability (SCA) effects were obtained for all the characters studied except 50% flowering, panicle length, and grain breadth. Among the lines GAN46A, IR58A and IR62A showed significant GCA effects for grain yield, and most of the yield contributing traits could be used as good general combiner lines for improving the grain yield of rice. IR68A line is good general combiner for Zn and Fe content. Among testers, Hera5R, ACI1R and KataribhoghR testers are good general combiner for Zn and Fe content. Hera5R and ACI1R testers having positive GCA effect with yield (t/ha). IR58A x BU7R, IR58A x BHD1R, IR62A x Hera5R, BRRI1A x Hera5R, BRRI1A x BHD1R, BRRI1A x ACI1R, GAN46A x BU7R, GAN46A x BHD1R, GAN46A x ACI1R crosses are good specific combiner for zinc content with grain yield (t/ha).

Key words: Rice, Hybrid, CMS, Line X Tester, GCA, SCA

INTRODUCTION

Rice is abundantly produced and consumed in South and Southeast Asia and more than half of the global population consume rice as their staple food. However, rice is a poor source of micronutrients and vitamins. Thus, micronutrient deficiency particularly zinc and iron deficiency are acute in the poor people who mostly depend on rice for majority of their micronutrient requirements. In Bangladesh, 86.9% of 6-59-month-old children and 94.6% of Non-Pregnant Non-Lactating women (NPNL) suffer from micronutrient malnutrition; in particular, Zn and Fe insufficiency affect 31% and 15.1% of 6-59-month-old children and 43.4% and 14.1% of NPNL women (ICDDR, B 2022). The process of increasing the nutritional value of food crops using agronomic techniques, conventional or modern plant breeding and biotechnology is known as biofortification. Biofortification of staple food crops for enhanced micronutrient content through genetic manipulation is the best option available to alleviate hidden hunger with little recurring costs (Welch *et*

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al., 2004, Ortiz-Monasterio *et al.*, 2007). Through biofortification, it is attainable to economically combine high yield with the high micronutrient density trait in rice. It has become crucial for breeders to develop rice cultivars that have enhanced grain zinc content and high yield potentiality. In the history of rice improvement, one of the most significant breakthroughs is the development of hybrid rice varieties on a commercial scale utilizing male sterility and fertility restoration systems. The A, B, and R lines are the three breeding lines that form the foundation of the hybridization approach. A line is the cytoplasmic male sterile line where the male sterility is jointly controlled by recessive nuclear gene and sterile cytoplasmic factor. B line is an isogenic line of A line, the only difference in male sterility and fertility. R-line possesses a fertility restoration gene. (Islam *et al.*, 2015).

Combining ability analysis is an effective quantitative genetics tool for measuring ability of the parental lines to produce heterotic progenies for a particular trait either in specific or non-specific (general) combinations. There are two categories for combining ability: general combining ability (GCA) and specific combining ability (SCA). Diallel (Griffing, 1956) and line x tester (Kempthrone, 1956) matting designs are two of the statistical tools that can be used to determine the combining ability and gene action governing different quantitative traits. They offer reliable information about the general and specific combining abilities (GCA and SCA) of parents and their cross combinations, as well as assist in the estimation of various kinds of gene actions. Combining ability estimates play a major role in determining which parental lines are the best for developing hybrids. The combining ability studies are frequently used by plant breeders to evaluate genotypes for their parental usefulness and to assess the gene action involved in various characters to design an efficient breeding plan for further genetic improvement of the existing materials. Therefore, this study was undertaken to determine the combining ability and nature of gene action for grain zinc and iron content, yield and its different components.

MATERIALS AND METHODS

Experimental site and materials list

During Aman season 2018, the experiment was conducted at the research field and laboratory of the Department of Genetics and Plant Breeding, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur. The experimental material comprised of five cytoplasmic male sterile (CMS) lines, hereafter A line and five restorer lines, hereafter R lines of rice with diverse genetic base. Zinc and iron enriched five A and five R lines (Table 1) were collected from department of Genetics and Plant Breeding, BSMRAU.

Table 1. List of experimental materials showing grain zinc and iron content.

A line	Zn content	Fe content	R line	Zn content	Fe content
IR58A	43.20	18.17	Hera5R	38.90	12.28
IR62A	48.27	16.05	BU7R	37.33	14.63
IR68A	43.10	25.43	ACI1R	39.83	14.87
Gan46A	47.50	20.60	BHD1R	35.43	14.40
BRRI1A	39.40	52.80	KataribhoghR	33.33	12.83

Raising of parental materials and hybridization

Sowing of five A lines and five R lines was taken up to synchronize flowering. Crossing was done during Aman 2017. The CMS lines were used as female parents and the R lines were used as male parents. Using five A lines and five R lines as parents, total 25 cross combinations were made following line x tester mating design. Care was taken to obtain a good number of seeds per cross, so that they could be used for evaluation in field and also for evaluating grain zinc content. Also, the A lines were maintained by the corresponding B line in the field trial for generating data.

Evaluation of F1 progenies along with parents

During Aman 2018, the 10 parents along with 25 F1 seeds were evaluated. The experiment was laid out in a randomized complete block design (RCBD) with three replications in the field. At first seeds of each genotype were sown in the pot at laboratory then transplanted to the main field with the spacing of 20 x 20 cm as single seedling/hill.

Data Collection

Ten plants were selected randomly from each entry in each replication to record data on 19 physio-morphological traits. Data were collected on the following parameters: days to first flowering, days to 50% flowering, days to maturity, pollen fertility, plant height (cm), number of productive tillers per hill, panicle length (cm), number of tillers, filled spikelet, unfilled spikelet, straw yield, test weight (g), grain length (mm), grain breadth (mm), biomass content, harvest index, zinc content (ppm), iron content (ppm), grain yield ton per hectare.

Grain Iron and Zinc analysis

Analysis of Iron and Zinc content (ppm) of grain were done at brown condition in XRF (X-Ray Fluorescence Spectrometry) method in Harvest plus Laboratory, Bogura. XRF is a non-destructive analytical technique used to determine the elemental composition of materials. The rice samples were dehusked and kept clean before and after dehulling. Adequate samples were added to the cup (>3g). For sample analysis, Adequate samples were added to the cup (>3g). Before pouring the prepared (dehulled) sample to the plastic cups, the cups were cleaned and A4 μm film was placed over beveled edge of smaller plastic cup and then the larger secondary cup is placed over film. The larger cup is then pushed down and twisted. The samples are then held in plastic cups with plastic inserts. The samples were analyzed using glass standard instead of grain samples as standard. Total analysis time for each sample was around 120 seconds; scans were conducted in sample cups. Thus, from the XRF spectrum it is possible to determine the grain iron and zinc content present in the sample based on the energy of detected photons released.

Statistical Analysis

The GCA and SCA effects were determined using Excel and SAS software (SAS Institute 2008, SAS V9.2). The mean data were subjected to ANOVA and estimates of combing ability and their variances were performed as suggested by Kempthrone (1957).

Mathematical model for combining ability analysis is:

$$Yijk = \mu + gi + gj + sij + rk + eijk$$

Where, Yijk = any measurable character of the cross ixj in the kth replication

μ = population mean effect

gi = general combining ability effect of the female parent

gj = general combining ability effect of the male parent

sij = specific combining ability effect of (ixj)th cross

rk = effect due to Kth replication

eijk = environmental effect on (ijk)th individual

RESULTS AND DISCUSSIONS

Combining Ability

Tables 2 and 3 present the result of ANOVA for combining ability, estimates of GCA and estimates of SCA. The genotypes were found highly significant for all the traits except 50% flowering and grain breadth. Significant mean squares of the genotypes were obtained for the traits namely days to first flowering, days to maturity, plant height, tillers, productive tillers per plant, pollen fertility, panicle length, filled grain, unfilled grain, thousand grain weight, straw yield, grain length, biomass, harvest index, grain yield per plant, grain yield (t/ha), Zn content and Fe content. The ratio of GCA to SCA variances ranged from -0.024 to 0.097, which indicated that SCA values were higher than GCA values and thereby the non-additive gene actions predominated over the additive gene action for all the characters.

Singh *et al.,* (2018) found highly significant genotypic variance in hybrid rice. Parents and parents vs crosses were found highly significant for all the traits except plant height, which indicated that parents and parents vs crosses were significantly differed from each other. Crosses were found highly significant for all the traits except 50% flowering, panicle length, grain breadth, which indicated that crosses were significantly differed from each other. The A lines showed significant mean sum of square for days to maturity, tillers, filled grain, unfilled grain, grain length.

The testers (R lines) exhibited significant mean sum of square for thousand seed weight, grain length. Lines x testers differed significantly due to its significant mean sum of square for all the traits except 50% flowering, tillers, panicle length, filled grain, grain breadth. Significant GCA variance and SCA Variance were obtained for all the characters studied except panicle length, grain breadth indicated both additive and non-additive gene action were involved for these traits. The result is in agreement with Kumar *et al.,* (2007) who observed preponderance of both additive and non-additive gene effects were almost equally important for grain yield per plant, grain length, and grain length: breadth ratio.

General Combining Ability

The fixable GCA effect is described as the inherent genetic value of the parent for an attribute resulting from additive gene effects (Simmonds, 1989). Negative GCA effects are desirable for days to flowering, days to maturity and plant height while positive GCA effects are desirable for other like Zn and Fe content traits included in the study. Table 3 presents GCA effects of the parents. None of the CMS lines was observed to be good general combiner for all the traits studied. GAN46A exhibited significant negative GCA effect for days to first flowering, days to 50% flowering indicated as a good general combiner parent for early flowering. Venkatesan *et al.,* (2008) reported that the line IR 58029-99-3-1-3 and tester BR4828-2-2-1 recorded negative GCA effects for days to 50 percent of flowering. Tiwari *et al.,* (2011) also observed higher GCA effects for this trait of flowering. Line IR62A showed significant negative GCA effect for days to maturity. GAN46A line had significant positive GCA effects for tillers and productive tillers per hill. In this study,

Table 2. Analysis of variance of combining ability of 10 parental lines 25 crosses for yield and its contributing traits of rice.

Source	df	DFF	50% F	DM	PH(cm)	NT	NPT	PF(%)	PL(cm)	FS	UFS	TSW
Replications	2	0.07	0.70	0.37	96.839	14.010	15.80	2.67	6.27	538.695	90.64	1.32
Treatments	34	94.57**	106.02	38.10**	724.623**	82.077**	111.53**	2370.84**	51.91**	2793.237**	1173.91**	49.38**
Parents	9	200.82**	172.91	131.35**	2039.094**	119.541**	45.17**	4346.28**	159.66**	1833.541	344.13*	106.65**
Parents vs Crosses	1	14.41**	1209.65	34.74**	63.149	1114.97**	2819.16**	6234.21**	222.64**	1.524	11573.52**	42.60**
Crosses	24	58.06**	34.96	3.27**	259.258**	24.991**	23.60**	1469.07**	4.40	3269.444**	1051.75**	28.18**
Lines	4	109.41	75.51	6.85*	159.047	69.347**	44.85	1432.62	8.50	7569.767*	2105.49*	30.31
Testers	4	39.31	18.05	4.35	228.080	12.647	8.91	1825.62	2.65	2137.900	1004.55	69.29**
Lines x Testers	16	49.91**	29.05	2.10**	292.105**	16.988	21.96**	1389.05**	3.81	2477.250	800.12**	17.38**
σ²GCA		0.204**	0.148	0.029**	-0.821**	0.20**	0.041**	2.001**	0.015	19.805**	6.291**	0.270**
σ²SCA		16.36**	9.173	0.594**	61.111**	2.048**	4.705**	462.667**	-0.621	480.476**	223.059**	5.375**
σ²GCA/σ²SCA		0.012	0.016	0.048	-0.013	0.097	0.008	0.004	-0.024	0.041	0.028	0.050
Error	68	0.831	1.53	0.32	108.773	10.843	7.85	1.04	5.67	1035.823	130.94	1.25

Source	df	SY (g)	GL(mm)	GB(mm)	BM (g/p)	HI (%)	GY (g/p)	GY (t/ha)	Zn (ppm)	Fe (ppm)
Replications	2	4.03	0.06	3.32	12.93	3.01**	2.76	0.15	0.49	1.02
Treatments	34	263.93**	1.69**	4.61	868.48**	629.74**	492.17**	39.13**	362.32**	220.77**
Parents	9	232.44**	1.93**	0.13	1047.84**	124.25**	723.49**	36.88**	210.85**	452.60**
Parents vs. Crosses	1	342.86**	1.33**	22.32*	402.29**	1916.23**	1193.53**	15.36**	3213.88**	1881.82**
Crosses	24	272.44**	1.62**	5.56	820.65**	765.70**	376.20**	40.97**	300.31**	64.63**
Lines	4	288.00	2.22*	5.48	841.23	187.54	285.48	31.09	112.18	9.70
Testers	4	88.00	4.36**	4.28	677.86	1606.99	731.05	79.61	300.02	105.39
Lines x Testers	16	314.67**	0.78**	5.89	851.20**	699.92**	310.16**	33.78**	347.42**	68.17**
σ²GCA		-1.056**	0.021**	-0.008	1.645**	1.251*	1.651**	0.180**	-1.178**	-0.089**
σ²SCA		104.019**	0.215**	0.618	230.427*	240.241*	102.543**	11.193**	115.218**	22.555**
σ²GCA/ σ²SCA		-0.010	0.097	-0.012	0.007	0.005	0.020	0.020	-0.010	0.003
Error	68	2.61	0.14	4.04	4.64	8.64	2.53	0.20	1.76	0.51

Legend: DFF=Days to first flowering, 50%F=Days to fifty percent flowering, DM=Days to maturity, PF=Pollen fertility, PH=Plant height (cm), NPT=Number of Productive Tillers per hill, PL=Panicle Length(cm), NT=Number of tillers, FS= Filled spikelet, UFS= Unfilled spikelet, SY= straw yield, TSW=Test Weight(g), GL=Grain Length (mm), GB=Grain Breadth (mm), BM= Biomass, HI= Harvest Index, Zn=Zinc Content (ppm), Fe=Iron Content (ppm), GY= Grain Yield ton per hectare.

Table 3. General combining ability (GCA) effects of parents (lines and testers) for yield and its contributing traits of rice.

Parent	Days to first flowering	50% Flowering	Days to maturity	Plant Height	Tillers	Productive tillers	Pollen fertility	Panicle length	Filled grain	Unfilled grain	1000 grain weight	Straw yield	Grain length	Grain breadth	Bio-mass	Harvest Index (%)	Zn content	Fe content	Grain yield/plant	Grain yield (t/ha)
Lines																				
IR58A	-0.15	0.21	-0.11	-0.72	-1.59	-1.39	0.24	0.74	15.33	-6.64	1.15*	-3.47**	0.42**	1.07	-3.66**	5.06**	-0.37	-1.12**	-0.19	-0.06
IR62A	0.39	0.01	-0.77**	-1.59	-1.59	-0.99	11.64**	-0.83	18.93	1.83	0.21	-4.80**	-0.25	-0.25	-9.61**	-2.07	-1.93**	0.43	-4.81**	-1.59**
IR68A	3.85	3.15	1.09**	4.35	-1.32	-1.32	-15.36**	-0.03	-34.2*	19.23**	-2.33**	4.53**	0.23	-0.30	1.32	-3.38**	4.49**	0.83*	-3.22**	-1.06**
GAN46A	-3.7**	-3.19**	-0.11	2.01	3.15*	2.35*	3.24**	-0.66	-11.33	-11.71*	-0.15	-0.80	-0.53**	-0.36	1.22	2.27*	-2.41**	-0.54*	2.02*	0.67**
BRRI1A	-0.35	-0.19	-0.11	-4.05	1.35	1.35	0.24	0.77	11.27	-2.71	1.12*	4.53**	0.13	-0.17	10.74**	-1.88	0.22	0.40	6.20**	2.05**
SE	0.235	0.319	0.147	2.693	0.850	0.723	0.264	0.615	8.310	2.955	0.289	0.417	0.095	0.519	0.556	0.759	0.343	0.184	0.411	0.114
SE(gi-gi)	0.333	0.451	0.207	3.808	1.202	1.023	0.373	0.870	11.52	4.178	0.409	0.590	0.135	0.734	0.787	1.073	0.485	0.260	0.581	0.162
Testers																				
Hera5R	-0.41	-0.25	-0.11	-2.52	1.35	1.08	-3.76**	-0.19	-0.20	4.43	-1.91**	3.20**	0.73**	0.95	7.45**	0.48	2.45**	1.20**	4.25**	1.40**
BU7R	2.45**	1.88**	0.63	-2.85	-0.19	-0.65	-4.76**	-0.49	-9.40	9.63*	0.44	1.87*	-0.08	-0.32	-7.44**	-16.0*	-6.71**	-3.18**	-9.30**	-3.07**
KataribhoghR	0.45	-0.19	0.49*	-3.05	0.35	0.48	8.64**	0.11	-5.87	2.49	0.70	-2.13	0.19	-0.27	-2.80**	7.04**	2.64**	1.27**	-0.66	-0.22
BHD1R	-1.9**	-0.99	-0.51**	5.08	-1.12	-0.72	-13.7**	-0.06	-5.07	-5.77	-2.25*	-0.80	-0.76**	-0.21	-4.01**	-2.25*	-2.41	-2.35**	-3.21**	-1.06**
ACI1R	-0.55	-0.45	-0.51**	3.35	-0.39	-0.19	13.64**	0.64	20.53	-10.77*	3.01**	-2.13**	-0.08	-0.15	6.79**	10.7**	4.03**	3.06**	8.92**	2.94**
SE	0.235	0.319	0.147	2.693	0.850	0.723	0.264	0.615	8.310	2.955	0.289	0.417	0.095	0.519	0.556	0.759	0.343	0.184	0.411	0.114
SE(gi-gi)	0.333	0.451	0.207	3.808	1.202	1.023	0.373	0.870	11.75	4.178	0.409	0.590	0.135	0.734	0.787	1.073	0.485	0.260	0.581	0.162

IR62A and GAN46A lines also exhibited significant positive GCA effects for pollen fertility.

IR58A and BRRI1A lines showed positive GCA effects for thousand grain weight indicating these two lines might be good general combiners for test weight. For biomass content, BRRI1A line exhibited the highest positive significant value indicating to be a good general combiner for the trait. IR68A line showed significant positive GCA effects for Zn and Fe content along with grain yield (t/ha) which indicates that the line is a good general combiner for Zn and Fe content as well as for grain yield (t/ha).

None of the testers was observed to be good general combiner for all the traits studied. BHD1R showed significant negative GCA effects whereas KataribhoghR showed positive GCA effects for days to maturity. So, BHD1R was a useful general combiner for early maturity. The tester line KataribhoghR exhibited significant positive GCA effects for pollen fertility reflecting good general combining ability for this trait. For test weight, ACI1R was good general combiner as it showed significant positive effects. Hera5R and ACI1R showed significant positive GCA effects for biomass content, which indicated that these two testers were good general combiners for biological yield of rice.

Among testers KataribhoghR and ACI1R showed significant positive GCA effects for harvest index % which indicated that it was good general combiner for this trait. For grain length, Hera5R showed significant positive GCA effects indicating a good general combiner for long grain. Tester Hera5R, ACI1R and KataribhoghR showed significant positive GCA effects for Zn and Fe content of grain and grain yield (t/ha) also. So, these lines might be used as good general combiner for Zn and Fe content along with grain yield (t/ha).

Specific Combining Ability

The performance of hybrid combinations is measured by the specific combining ability (SCA), which is a non-additive gene action related to dominance, over dominance, and epistatic effects. (Dianga et al., 2020). Choosing hybrids based on SCA effects would maximize their heterotic effect. Negative SCA effects are desirable for days to flowering, days to maturity and plant height while positive SCA effects are desirable for the other like Zn and Fe content traits. Table 4 presents SCA effects of the hybrids. None of the hybrids was observed to be good specific combiner for the all the traits studied. The cross combinations GAN46A x BU7R, BRRI1A X BU7R, IR58A x KataribhoghR, IR68A x KataribhoghR, BRRI1A x KataribhoghR, IR68A x ACI1R, GAN46A x ACI1R showed significant negative SCA effects for days to first flowering, days to 50% flowering, days to maturity indicating to be good specific combiners for early maturity. Among these cross combinations GAN46A x BU7R showed highest negative SCA effects and was detected as the best specific combiner for these traits. GAN46A x KataribhoghR, BRRI1A x KataribhoghR cross combinations showed the highest significant positive SCA effects for plant height. So, these crosses were the best specific combiners for producing taller plants. IR58A x BHD1R showed the highest significant positive SCA effects for productive tillers per hill and might be considered as the best specific combiner hybrid.

The cross combinations viz. IR58A x Hera5R, BRRI1A x Hera5R, IR58A x BU7R, BRRI1A x BU7R, IR58A x BHD1R, IR62A x BHD1R, IR68A x BHD1R, IR68A x KataribhoghR, GAN46A x ACI1R showed significant positive SCA effects for pollen fertility and might be selected as good specific combiner hybrids. Among these hybrids, IR58A x BHD1R showed highest positive significant value for these traits and could be

considered as the best specific combiner. The cross combinations viz. BRRI1A x BU7R, IR58A x BHD1R, IR58A x KataribhoghR showed significant positive SCA effects for filled grain per panicle and were considered to be good specific combiner hybrids for the trait. In this study, IR58A x Hera5R, IR62A x Hera5R, GAN46A x BU7R, IR58A x BHD1R, IR62A x KataribhoghR, BRRI1A x KataribhoghR, GAN46A x ACI1R crosses are positively significant for Zn content of grain. The significant high SCA effect for Zn content was reported by Pradeep Kumar and Reddy (2009). Again, IR62A x Hera5R, GAN46A x BU7R, BRRI1A x BU7R, IR58A x BHD1R, IR62A x KataribhoghR, BRRI1A x KataribhoghR, GAN46A x ACI1R crosses are positively significant for Fe content which indicates that these crosses are good specific combiners. In another finding, IR58A x BU7R, IR58A x BHD1R, IR62A x Hera5R, GAN46A x BU7R, GAN46A x BHD1R, GAN46A x ACI1R, BRRI1A x BHD1R, BRRI1A x Hera5R, BRRI1A x ACI1R crosses showed good specific combining ability for grain yield (t/ha). The hybrids viz. IR62A x Hera5R, GAN46A x BU7R, GAN46A x ACI1R have been obtained showing best specific combining ability for grain Zn and Fe content and grain yield (t/ha). Both yield and grain Zn are genetically complex traits and are hugely influenced by external environmental factors (Zaw et al. 2019). There was no direct effect of Zn on yield, indicating that combining high yield potential and high grain-Zn content is possible in order to develop successful Zn-biofortifed rice varieties (Calayugan et al. 2021). Rao et., al. reported that germplasm screening for their zinc content in brown and polished rice using ED-XRF revealed wide genetic variability, and evaluation of mapping populations indicated the possibility of favourable recombination of high zinc content and yield. Recently, zinc enriched high yielding rice variety BRRI dhan102 BRRI has developed. The variety has high zinc content 25.5 mg/kg with the average yield of 8.10 t/ha (Kader et., al. 2023).

The crosses between good general combiners may not always give good SCA effects in their cross combinations. Findings of a study on combining ability effects, high specific combiners involved low×low, low ×high, average×low, average×average, high×average and high×high combining parents. In crosses with high×low and low×low general combiners, Jinks (1956) described severe SCA effects caused by over-dominance and epistasis. In crosses involving high vs. low general combiners for yield components, mutual cancellation of heterosis components, especially dominance and its interaction, resulting in unfavorable SCA effects. Crossing two parents with low general combiners produces high performance, attributable to complementary gene activity (Al-Mamun et al., 2022). For example, although the crosses GAN46A x BU7R, BRRI1A x BU7R, IR58A x KataribhoghR, BRRI1A x KataribhoghR, IR68A x ACI1R were made among low x low, low x low, low x high, low x high, high x high general combiner parents for days to first flowering and days to 50% flowering, respectively, their SCA effects were high for these traits. The cross between low x low general combiners (GAN46A x BU7R, BRRI1A x BU7R) exhibited high SCA effects for days to maturity. Also, the crosses BRRI1A x KataribhoghR were made among low x high general combiner parents, showed high SCA effects for plant height. The crosses GAN46A x BU7R, IR58A x BHD1R, BRRI1A x BHD1R were made among low x low general combiners for zinc content, their SCA effects were high for these traits. On the other hand, the crosses between low x high general combiners, (IR62A x KataribhoghR, GAN46A x ACI1R, and BRRI1A x KataribhoghR) exhibited high SCA effects for grain zinc content.

Table 4. Continued

Crosses	TSW	GL(mm)	GB (mm)	BM(g/p)	HI (%)	Zn(ppm)	Fe(ppm)	GY(g/p)	GY(t/ha)
IR58A x Hera5R	2.05**	-0.76**	4.43*	-2.44	-8.06**	3.13**	1.05	-4.58**	-1.51**
IR62A x Hera5R	-0.36	0.45*	-1.30	2.04	14.42**	12.15**	5.26**	5.24**	1.73**
IR68A x Hera5R	-0.42	0.15	-1.11	-11.32**	4.17	0.54	1.34*	-5.46**	-1.80**
GAN46A x Hera5R	1.13	-0.70**	-0.97	-6.36**	-7.00**	-16.17**	-7.14**	-5.83**	-1.92**
BRRI1A x Hera5R	-2.40**	0.85**	-1.04	18.09**	-3.53	0.35	-0.52	10.62**	3.51**
IR58A x BU7R	1.25	0.22	-0.98	9.77**	5.12**	1.05	-1.47**	6.31**	2.08**
IR62A x BU7R	-1.56*	-0.24	0.25	-14.90**	-7.15**	-13.33**	-6.36**	-6.37**	-2.10**
IR68A x BU7R	-0.69	0.39	0.11	3.79*	-1.32	0.83	-0.44	1.66	0.55
GAN46A x BU7R	2.47**	0.01	0.18	11.83**	15.20**	10.11**	5.08**	11.03**	3.64**
BRRI1A x BU7R	-1.47*	-0.38	0.45	-10.49**	-11.86**	1.34	3.20**	-12.62**	-4.17**
IR58A x BHD1R	2.45**	0.28	0.51	31.92**	4.20	4.05**	2.11**	16.46**	5.43**
IR62A x BHD1R	-1.87**	-0.52*	0.36	19.48**	-26.53**	-6.49**	-2.11**	0.01	0.00
IR68A x BHD1R	2.48**	0.18	0.37	-23.21**	11.66**	-3.01*	-2.10**	-9.34**	-3.08**
GAN46A x BHD1R	-1.77*	-0.20	-0.21	4.54*	6.47*	-0.71	0.23	6.41**	2.11**
BRRI1A x BHD1R	2.85**	-0.20	0.59	4.02*	4.55	2.98*	0.79	5.89**	1.94**
IR58A x KataribhoghR	0.60	0.17	-1.23	-5.34*	2.60	-6.21**	-1.40*	0.53	0.17
IR62A x KataribhoghR	-3.65**	-0.10	0.00	-22.86**	8.07**	11.66**	3.51**	-7.66**	-2.53**
IR68A x KataribhoghR	-1.31	-0.07	-1.10	-4.94**	-2.71	2.60*	1.13	-4.41**	-1.46**
GAN46A x KataribhoghR	1.77*	0.82**	0.43	0.67	-23.53**	-17.80**	-7.70**	-9.46**	-3.12**
BRRI1A x KataribhoghR	-1.53*	-0.36	0.30	-4.29*	15.21**	12.93**	5.54**	1.58	0.52
IR58A x ACI1R	-2.59**	0.44*	-1.12	2.95	3.04	-0.57	0.70	2.15	0.71
IR62A x ACI1R	1.00	-0.12	0.25	-14.77**	-26.68**	-15.81**	-6.56**	-16.90**	-5.58**
IR68A x ACI1R	0.14	0.18	0.07	-15.97**	19.12**	2.15	0.42	-2.10	-0.69
GAN46A x ACI1R	-1.71	-0.04	0.37	16.72**	7.26**	12.20**	6.25**	11.92**	3.93**
BRRI1A x ACI1R	3.16**	-0.46*	0.44	11.07**	-2.74	2.03	-0.80	4.93**	1.63**
SE (sij)	0.646	0.213	1.160	1.244	1.697	0.766	0.411	0.918	0.256
SE(sij-skl)	0.914	0.301	1.641	1.759	2.400	1.084	0.581	1.299	0.362

*and** indicate significance at 5% and 1% levels respectively

Legend: DF=Days to flowering, 50%F= Fifty Percent Flowering, DM=Days to Maturity, PF(%)=Pollen Fertility, PH=Plant Height(cm), NT=Number of tillers, PT=Number of Productive Tillers per hill, PL=Panicle Length(cm), FS= Filled Spikelet, UFS= Unfilled spikelet, SY= Straw Yield (g), TSW=Test Weight(g), GL=Grain Length(mm), GB=Grain Breadth(mm), BM= Biomass content (g/p), HI (%)= Harvest Index, Zn=Zinc Content(ppm), Fe=Iron Content(ppm), GY= Grain Yield (t/ha).

Table 4. Specific Combining Ability (SCA) effects of 5 X 5 line-tester progenies for yield and its contributing traits of rice.

Crosses	DF	50%F	DM	PH(cm)	NT	PT	PF (%)	PL(cm)	FS	UFS	SY(g)
IR58A x Hera5R	0.81	0.05	0.11	6.32	-0.15	0.25	25.76**	-0.31	1.53	9.37	2.13*
IR62A x Hera5R	-0.05	-0.08	-0.63	-5.35	0.39	0.65	-38.24**	-0.34	-2.93	7.84	-3.20**
IR68A x Hera5R	-0.05	-0.01	-0.49	-0.81	-1.15	-1.48	-1.64*	-0.11	1.20	-18.69**	-5.87**
GAN46A x Hera5R	-1.05	-0.75	0.51	9.12	1.92	1.85	-6.64**	0.69	20.80	0.24	-0.53
BRRI1A x Hera5R	0.35	0.79	0.51	-9.28	-1.01	-1.28	20.76**	0.06	-20.60	1.24	7.47**
IR58A x BU7R	-0.05	-0.08	0.77**	4.19	0.52	0.19	9.36**	1.43	-10.40	6.57	3.47**
IR62A x BU7R	6.41**	5.45**	0.71**	-3.48	0.39	0.59	-9.64**	-1.27	-35.53	4.71	-8.53**
IR68A x BU7R	3.41**	2.19**	0.17	1.05	-2.15	-2.88	-1.04	0.29	-14.40	20.17**	2.13*
GAN46A x BU7R	-5.59**	-4.55**	-0.83*	4.65	0.25	-0.21	-8.04**	-0.57	17.20	-13.23	0.80
BRRI1A x BU7R	-4.19**	-3.01**	-0.83*	-6.41	0.99	2.32	9.36**	0.13	43.13*	-18.23*	2.13*
IR58A x BHD1R	-1.05	-0.01	1.17**	-0.75	3.79	4.59**	37.36**	2.09	38.60*	9.97	15.47**
IR62A x BHD1R	0.95	2.05**	1.31**	-2.55	-0.75	-0.55	8.96**	-0.84	-17.93	10.77	19.47**
IR68A x BHD1R	4.95**	1.99*	-0.69*	-9.95	-2.35	-2.55	20.96**	0.13	-14.00	-14.96*	-13.87**
GAN46A x BHD1R	4.55**	3.65**	0.51	-5.95	-0.48	0.12	-9.64**	-1.24	-20.20	17.97	-1.87
BRRI1A x BHD1R	-0.45	-0.61	-0.49	-1.88	2.12	3.12	0.36	0.79	10.53	-21.29**	-1.87
IR58A x KataribhoghR	-5.19**	-3.88**	-1.09**	10.25	2.59	2.19	-38.64**	0.29	42.07*	-18.83**	-5.87**
IR62A x KataribhoghR	0.35	-0.15	-0.69*	2.99	-3.28	-3.68*	-28.64**	-1.67	-48.73*	13.04	-15.20**
IR68A x KataribhoghR	-1.59**	-0.55	0.11	-21.75	0.45	0.52	2.76**	-1.07	-24.80	-3.23	-0.53
GAN46A x KataribhoghR	1.95**	1.19	0.51	16.65*	0.25	-0.01	-2.24*	0.79	25.40	18.64**	10.13*
BRRI1A x KataribhoghR	-4.45**	-3.68**	-0.63	12.92*	-2.35	-3.75**	8.76**	0.73	9.07	-12.09	-5.87**
IR58A x ACI1R	6.01**	4.45**	0.11	0.99	-3.41	-3.15	0.76	-0.34	-8.40	6.11	0.80
IR62A x ACI1R	-0.85	-1.68*	-0.63	-3.35	-2.21	-2.08	1.76**	-1.21	-9.20	-10.43	2.13*
IR68A x ACI1R	-3.85**	-3.61**	-0.49	4.19	1.92	1.79	-6.64**	-0.14	20.60	9.04	-13.87**
GAN46A x ACI1R	-2.85	-0.35	0.51	2.12	0.65	0.79	3.36**	0.99	-3.80	9.97	4.80**
BRRI1A x ACI1R	1.55**	1.19	0.51	-3.95	3.05	2.65	0.76	0.69	0.80	-14.69*	6.13**
SE (sij)	0.526	0.714	0.328	6.021	1.901	1.617	0.590	1.375	18.582	6.607	0.933
SE(sij- skl)	0.744	1.009	0.464	8.516	2.689	2.287	0.834	1.945	26.278	9.343	1.319

*and** indicate significance at 5% and 1% levels respectively

CONCLUSIONS

Among the lines, IR58A, IR62A and GAN46A showed significant GCA effects for grain yield, and most of the yield contributing traits, could be used as good general combiner lines for improving the grain yield of rice. IR68A line was found as good general combiner for Zn and Fe content. Among testers, Hera5R, ACI1R and KataribhoghR testers were good general combiner for Zn and Fe content having positive GCA effect with yield (t/ha). The combinations, IR62A x Hera5R, GAN46A x BU7R, BRRI1A x BHD1R, IR62A x KataribhoghR, BRRI1A x KataribhoghR, GAN46A x ACI1R were good specific combiner for Fe content along with grain yield (t/ha). The CMS lines namely GAN46A, IR58A and IR62A might be recommended as good general combiner for improving grain yield in hybrid breeding. Similarly, among the testers, Hera5R, ACI1R and KataribhoghR testers were obtained as good general combiner for Zn and Fe content along with grain yield (t/ha). On the other hand, the hybrids *viz.* IR58A x BHD1R, IR62A x Hera5R, GAN46A x BU7R, GAN6A x ACI1R were found suitable for heterosis breeding for Zn content and grain yield (t/ha). Finally, IR62A x Hera5R, IR62A x KataribhoghR, GAN46A x BU7R, GAN46A x ACI1R, BRRI1A x BHD1R, BRRI1A x KataribhoghR crosses could be recommended as good specific combiners for Fe content and grain yield (t/ha).

AUTHORS' CNTRIBUTION

URS, NAI and MSR formulated the idea; coordinated the research; URS and NAI developed methodology; URS, NAI and MSR provided scientific insights; URS collected data; URS and NAI carried out analysis; URS and NAI did the writings for all version of the manuscript; URS, NAI, MSR and MAK performed critical review and editing; All authors read and approved the final manuscript.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Effect of Spacing on Different Short Duration Rice Varieties in T. Aman and Boro Season

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ABSTRACT

The selection of appropriate plant spacing may contribute to the yield potential of a rice variety. This experiment was conducted at the West Byde of BRRI HQ farm, Gazipur during T. Aman'2017 and Boro' 2017-18 seasons to find out the optimum spacing of different short duration rice varieties. In T. Aman season, the treatments were three rice varieties (V_1 = BRRI dhan71, V_2 = BRRI dhan75 and V_3 = BINA dhan17) and five spacings (S_1 = 15 cm × 15 cm, S_2 = 20 cm × 15 cm, S_3 = 20 cm × 20 cm, S_4 = 25 cm × 20 cm and S_5 = 25 cm × 25 cm). In Boro season the treatments were four rice varieties (V_1 = BRRI dhan81, V_2 = BRRI dhan84, V_3 = BRRI dhan86 and V_4 = BRRI dhan28) and the spacings were same as T. Aman season. In each season, the treatments were arranged in a Split-plot design as variety in the main plots and spacing in the sub plots with three replications. In T. Aman season, irrespective of variety and spacing, the number of tillers per hill increased sharply and reached the maximum at 30 to 45 DAT then gradually decreased. BRRI dhan75 produced the highest grain yield, which was statistically identical with the yield of BRRI dhan71 and BINA dhan17. The spacing 20 cm × 15 cm produced the highest grain yield compared to other spacing. On the other hand, during Boro season the number of tillers per hill increased sharply and reached the maximum at 60 to 80 DAT then gradually decreased. The 20 cm × 20 cm spacing produced the highest grain yield and among the varieties BRRI dhan84 provided the highest grain yield.

Key words: Spacing, short duration, rice, growth and yield

INTRODUCTION

The yield of T. Aman and Boro rice may be increased through introduction of high yielding varieties and improved agronomic manipulations such as proper spacing. Short duration T. Aman rice can also create opportunity to facilitate Mustard, legume, pulses and green manuring crops before late Boro sowing which can contribute significantly to achieve the twin objectives of increasing productivity and improving the sustainability of the cropping system**.** Some short duration T. Aman rice varieties (viz. BRRI dhan71, BRRI dhan75 and BINA dhan17) are not only photo insensitive, but

also drought resistant and short duration Boro varieties (viz. BRRI dhan81, BRRI dhan84 and BRRI dhan86) provide higher yield (BRRI, 2022 and BINA, 2020). Pandey *et al.* (2021) reported that the appropriate plant spacing may influence the yield potential of a rice cultivar through effective utilization of solar radiation, soil moisture and nutrient uptake from the soil. When the planting density exceeds an optimum level, these factors may be deficient and competition among plants becomes severe. Accordingly, the plant growth slows down and the grain yield decreases. Conversely, these factors may

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not be properly utilized at lower planting density. Properly spacing between rows and within rows can result in the maximum advantage from a rice field. Plant density had great influence on the tillering habit and production of grains panicle^{-1} which is responsible for the variation of yield in rice. Alam (2006) found that optimum spacing produced maximum number of total tillers m^{-2}, maximum number of fertile tillers m^{-2} and which was reliant on temperature, moisture and other soil factors. Inappropriate spacing reduces the yield up to 25–30 percent whereas the optimum plant density ensures the plant to grow in their both aerial and underground parts through efficient utilization of solar radiation and nutrients (Salma *et al.*, 2017). In contrast, beyond the optimum level, severe competitions (for light, nutrients, and water) slow down plant growth and decrease grain yield (Bozorgi *et al.,* 2011). Akhter *et al.* (2007) observed that the selection of optimum spacing for transplanting of high yielding cultivars is an important part of high production package. Row transplanting is one of the good agronomic practices being promoted for lowland rice production in Bangladesh. Moro *et al*. (2016) stated that spacing significantly affected tiller production, number of panicles m^{-2} total biomass and grain yield. Both the number of tillers plant^{-1} and number of panicles m^{-2} were significantly reduced under closer spacing than wider spacing. Therefore, the present study was undertaken to find out the effect of spacing on different short duration rice varieties in transplanted Aman and Boro season.

MATERIALS AND METHODS

Study Area

The experiment was performed at the BRRI HQ farm, Gazipur, Bangladesh during T. Aman' 2017 and Boro' 2017-18 seasons to find out the optimum spacing of different short duration rice varieties. The experimental field situated at 23° 59' 33" N latitude and 90° 24' 19" E longitude and at elevation of 8.4 m from the mean sea level (Satter, 1994) and it's characterized by sub-tropical climate. The location was under the agro-ecological zone at Madhupur tract (AEZ 28).

Climatic Condition of the Study Area

The area is situated under subtropical zone, which was characterized by high temperature and high humidity. During the T. Aman season there are sufficient rainfall for growing the crops. However, sometimes where the crops suffered due to lack of rainwater, irrigation was given. Day length, maximum-minimum temperature gradually decreased from early to late in T. Aman season. On the other hand, the temperature increased on the onset of the T. Aman season and it gradually decreased with the advance of Boro season. But the Boro season rainfall was limited and irrigation water was given as and when necessary. The bright sunshine hours were high in the Boro season compared to the T. Aman season.

Treatments and Experimental Design

In T. Aman season the treatments were three rice varieties (V$_1$ = BRRI dhan71, V$_2$ = BRRI dhan75 and V$_3$ = BINA dhan17) and five spacings (S$_1$ = 15 cm × 15 cm, S$_2$ = 20 cm × 15 cm, S$_3$ = 20 cm × 20 cm, S$_4$ = 25 cm × 20 cm and S$_5$ = 25 cm × 25 cm). In Boro season the treatments were four rice varieties (V$_1$ = BRRI dhan81, V$_2$ = BRRI dhan84, V$_3$ = BRRI dhan86 and V$_4$ = BRRI dhan28) and the spacing's were same as T. Aman season. In each season, the treatments were arranged in a Split Plot design as variety in the main plots and spacing in the sub plots with three replications. The unit plot size was 4 m × 4 m. Twenty five and forty day old seedling @

one seedling per hill were transplanted in T. Aman and Boro seasons respectively. Fertilizers were used in BRRI recommended dose. Tiller number per hill from transplanting to maturity with 15 and 20 days interval was recorded in T. Aman and Boro season respectively. All other cultural operations were conducted for proper crop management as and when appropriate. Yield and yield components data were taken.

Statistical Analysis

Using the Crop Stat Analysis package, the collected data were analyzed.

RESULTS AND DISCUSSION

Growth Parameter at Different Growth Stages

Growth parameters like plant height and number of tiller hill^{-1} were significantly influenced by different plant spacing at different growth stages (Figs. 2, 4 and 5).

Plant height: Plant height is a genetic character and it differed significantly by the variety. In T. Aman season, comparing short duration varieties, the tallest plant height was recorded in BRRI dhan71 followed by BRRI dhan75 and the lowest in BINA dhan17 but there was no significant difference between BRRI dhan75 and BINA dhan17 (Fig.1) and in Boro season, comparing short duration varieties, the tallest plant height was recorded in BRRI dhan84 followed by BRRI dhan28, BRRI dhan81 and the lowest in BRRI dhan86 but there was no significant difference among BRRI dhan81, BRRI dhan28 and BRRI dhan86 (Fig. 3). Salam *et al.* (2019) and Tyeb *et al.* (2013) observed such variation in plant height due to varietal differences. Comparing different spacings, it was observed that widest spacing (25 cm × 25 cm) produced the tallest plant and it was decreased with decreasing spacing in both seasons (Figs. 2 and 4). Salam *et al.* (2019), Haque *et al.* (2015) and Moro *et al.* (2016) reported reciprocal result that plant height was significantly influenced by spacing.
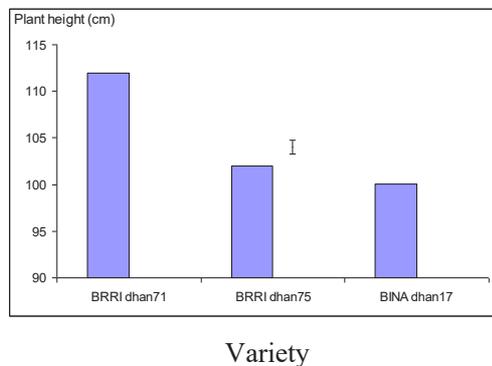

Fig. 1. Plant height at maturity as affected by T. Aman rice varieties (Vertical bar represents the Lsd (0.05) value).
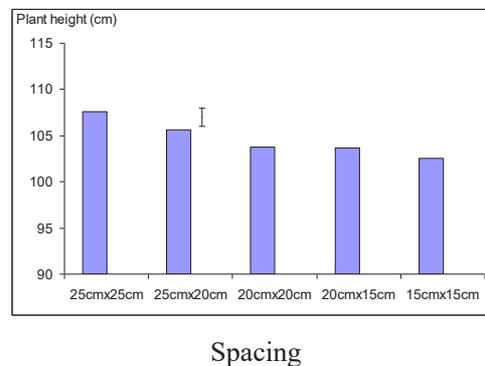

Fig. 2. Plant height at maturity of T. Aman rice varieties as affected by spacing (Vertical bar represents the Lsd (0.05) value).
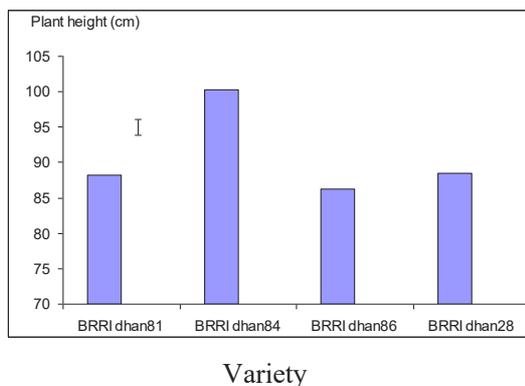
Fig. 3. Plant height at maturity as affected by Boro rice varieties (Vertical bar represents the Lsd (0.05) value).
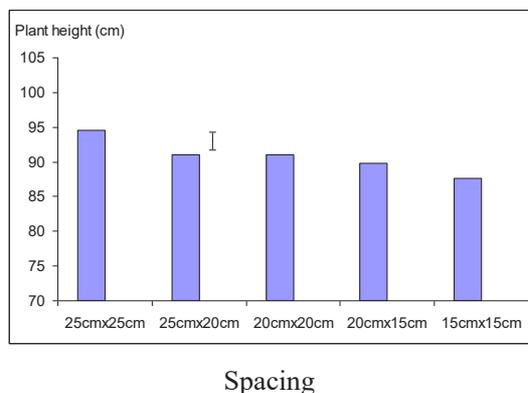
Fig. 4. Plant height at maturity of Boro rice varieties as affected by spacing (Vertical bar represents the Lsd (0.05) value).

Tiller number hill[-1]: Tiller number per hill was recorded from transplanting to maturity with 15 days intervals in T. Aman and 20 days intervals in Boro seasons. Irrespective of variety and spacing, the number of tillers per hill increased sharply and reached the maximum at 30 to 45 DAT in T. Aman and 60 to 80 DAT in Boro seasons then gradually decreased due to dead of some unfertile tillers. Irrespective of spacing in T. Aman, BRRI dhan75 produced the highest number of tiller followed by BINA dhan17 and the lowest in BRRI dhan71. Irrespective of spacing in Boro, BRRI dhan28 produced the highest number of tillers followed by BRRI

dhan86, BRRI dhan84 and the lowest in BRRI dhan81. Regardless of variety, wider spacing produced higher number of tillers per hill than closer spacing in all sampling dates (Fig. 5). The reason might be wide spaced plants received more nutrients, moisture and light thus produced higher number of tillers hill-1. Salam *et al.* (2019) and Mobasser *et al.* (2007) also reported that wider spacing produced maximum number of total tillers than closer spacing.
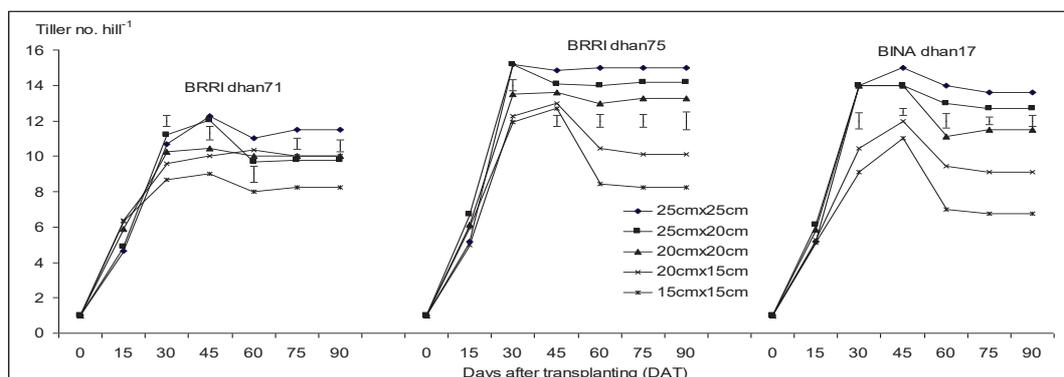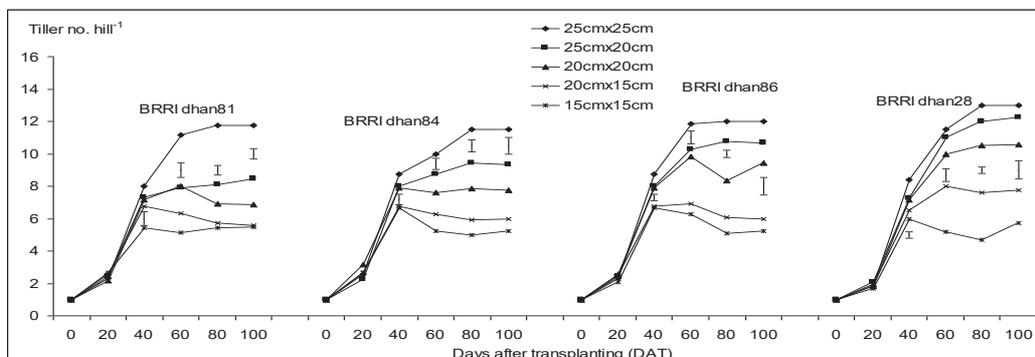
Fig. 5. Tiller number per hill of different short duration T. Aman and Boro rice varieties as affected by spacing (Vertical bars represent the Lsd (0.05) value).

Effect of variety on the yield and yield contributing characters of T. Aman and Boro seasons:

The interaction between variety and spacing was insignificant in all the parameters of yield and yield components. Therefore, only the main effect has been described and discussed below:

Effect of variety: The varietal differences in plant height might be due to heredity of the variety. The difference in the plant may occur due to varietal genetic character; it is similar to Sarkar (2014) variable plant height due to varietal differences. In T. Aman season, the highest number of tiller and panicle m^{-2} was recorded in BRRI dhan75 followed by BINA dhan17 and lowest in BRRI dhan71 (Table 1). In Boro season, BRRI dhan84 produced the highest number of tiller m^{-2} followed by BRRI dhan81 and BRRI dhan86 and; the lowest in BRRI dhan28. BRRI dhan28 gave the highest number of panicle m^{-2} followed by BRRI dhan84 and the lowest in BRRI dhan81 (Table 1). Salam *et al.* (2019) and Hossain *et al.* (2010) found that number of total tillers varied among the varieties and the authors opined that the probable causes of that variation due to varietal differences. Similar findings were observed by Yan

(2002) and Akanda *et al.*, (2020). In T. Aman season, the highest panicle length was observed in BRRI dhan71 followed by BINA dhan17 and the lowest in BRRI dhan75 (Table 1). In Boro season, the highest panicle length was obtained in BRRI dhan84 and the lowest in BRRI dhan81 which was identical with BRRI dhan86 (Table 1). In T. Aman season, filled grain panicle^{-1} was highest in BRRI dhan71 and the lowest in BINA dhan17 whereas, the highest percentage of unfilled grain was recorded in BINA dhan17 and the lowest in BRRI dhan75 (Table 1). In Boro season, the highest number of filled grain panicle^{-1} was recorded in BRRI dhan81 followed by BRRI dhan84, BRRI dhan86 and the lowest in BRRI dhan28 but highest percentage of unfilled grain was observed in BRRI dhan86 which was statistically identical to BRRI dhan84 and the lowest in BRRI dhan28 (Table 2). Variation in grain filling may have occurred due to adopted genetic, environmental, or cultural management practices (Chowhan, 2017). The results showed 1000-grain weight had significant effect due to variety. In T. Aman season, 1000-grain weight was the highest in BRRI dhan71 and the lowest in BRRI dhan75 (Table 1). In Boro season, the highest 1000-grain weight was recorded in BRRI dhan86 followed by BRRI dhan84 and

BRRI dhan28 and; the lowest in BRRI dhan81 (Table 2). This result is in agreement with the finding of Akanda et al., (2020) who stated that weight of 1000-grains differed due to the varietal differences.Variety had no significant effect on grain yield in T. Aman season but significant effect on Boro season (Table 2). BRRI dhan75 produced the highest grain yield followed by BRRI dhan71 and the lowest yield was recorded in BINA dhan17 in T. Aman season (Table 1). In Boro season, BRRI dhan84 produced the highest grain yield. and the lowest grain yield was recorded in BRRI dhan28 which was statistically similar to the yield of BRRI dhan81 and BRRI dhan86 (Table 2). Similar research findings were also reported by Salam et al. (2019) and Akanda et al., (2020) who observed variation in grain yield of rice due to varieties.

Table 1. Yield and yield components of rice cultivars as affected by variety T. Aman 2017 seasons

Variety	Tiller m^{-2}	Panicle m^{-2}	Panicle length (cm)	Grain panicle^{-1}	Unfilled spikelet (%)	1000 grain wt. (gm)	Grain yield (tha^{-1})
BRRI dhan71	218	215	24.39	94	17.05	23.35	5.48
BRRI dhan75	288	277	20.45	89	13.99	19.92	5.55
BINA dhan17	266	260	22.99	79	20.32	21.54	5.13
Lsd at 5%	12.70	12.36	0.77	8.39	4.31	0.72	ns

Table 2. Yield and yield components of rice cultivars as affected by variety Boro 2017-18 seasons

Variety	Tiller m^{-2}	Panicle m^{-2}	Panicle length (cm)	Grain panicle^{-1}	Unfilled spikelet (%)	1000 grain wt. (gm)	Grain yield (tha^{-1})
BRRI dhan81	215	206	21.75	142.00	12.74	20.48	6.07
BRRI dhan84	236	229	25.21	141.94	18.51	21.90	6.32
BRRI dhan86	213	210	23.41	125.92	18.70	23.00	5.97
BRRI dhan28	260	248	21.88	111.46	16.20	21.82	5.95
Lsd at 5%	18.38	17.73	0.84	9.69	1.79	0.43	0.23

Effect of spacing: In T. Aman season, all the parameters except panicle length and 1000 grain weight were significantly affected by spacing. Closest spacing (15 cm × 15 cm) produced the highest number of tiller and panicle m^{-2}; and percent unfilled grain which was gradually decreased with increasing spacing. Closer spacing covers maximum number of hills per unit area consequently produces maximum tillers (Paul et al., 2017; Verma et al., 2002; Saha et al., 2020). The highest grain yield (5.7 tha^{-1}) was observed in closer spacing (20 cm × 15 cm) which was statistically identical with the yield of (15 cm × 15 cm) and (20 cm × 20 cm) spacing. The grain yield gradually decreased with increasing spacing. It was the lowest (4.85 tha^{-1}) in widest (25 cm × 25 cm) spacing which was statistically identical with the yield obtained from (25 cm × 20 cm) and (20 cm × 20 cm) (Table 3) and Boro season, the highest number of tiller and panicle was

observed in closest spacing (15 cm × 15 cm) which was statistically identical to (20 cm × 20 cm) spacing. The tiller and panicle number decreased with increasing spacing. Plants grown as widest (25 cm × 25 cm) spacing produced the longest panicle and the highest number of filled grain panicle[-1] whereas the highest percentage of unfilled grain was recorded in closest (15 cm × 15 cm) spacing. The highest 1000 grain weight was observed in (25 cm × 20 cm) spacing which was insignificant to other spacings except the closest (15 cm × 15 cm) spacing. The plants grown as (20 cm × 20 cm) spacing produced the highest grain yield (6.42 tha[-1]) and closer or wider than (20 cm × 20 cm) spacing decreased yield significantly (Table 4). It might be due to the fact that the closer row spacing provided highest grain yield and straw yield which resulted in the highest biological yield (Paul *et al.,* 2017; Halder *et al.,* 2018; Saha *et al.,*2020).

Table 3. Yield and yield components of rice as affected by spacing T. Aman 2017

Spacing	Tiller m[-2]	Panicle m[-2]	Panicle length (cm)	Grain panicle[-1]	Unfilled spikelet (%)	1000 grain wt. (gm)	Grain yield (tha[-1])
15 cm × 15 cm	312	306	22.48	75	22.74	21.54	5.76
20 cm × 15 cm	266	257	22.83	87	16.74	21.70	5.79
20 cm × 20 cm	255	250	22.57	88	16.30	21.27	5.46
25 cm × 20 cm	232	229	22.43	90	15.90	21.41	5.07
25 cm × 25 cm	221	212	22.75	96	13.93	22.11	4.85
Lsd at 5%	16.40	15.97	ns	10.83	5.57	ns	0.63

Table 4. Yield and yield components of rice as affected by spacing Boro 2017-18 seasons

Spacing	Tiller m[-2]	Panicle m[-2]	Panicle length (cm)	Grain panicle[-1]	Unfilled spikelet (%)	1000 grain wt. (gm)	Grain yield (tha[-1])
15 cm × 15 cm	278	268	22.69	122.79	18.63	21.20	5.91
20 cm × 15 cm	246	238	22.65	128.48	17.63	21.94	6.08
20 cm × 20 cm	230	224	23.06	127.11	16.22	21.97	6.42
25 cm × 20 cm	211	203	23.00	132.42	15.49	21.99	6.04
25 cm × 25 cm	191	184	23.92	140.84	14.73	21.89	5.95
Lsd at 5%	20.65	19.83	0.95	10.83	2.00	0.48	0.26

CONCLUSION

The experimental results concluded that BRRI dhan75 transplanted at 20 cm × 15 cm spacing in T. Aman season and BRRI dhan84 transplanted at 20 cm × 20 cm spacing in Boro season could be a higher grain yield.

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