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Genetic Variability, Correlation and Path Analysis of Floral, Yield and its Component Traits of Maintainer Lines of Rice (*Oryza sativa* L.)

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ABSTRACT

Direct selection based on crop yields is paradox in breeding programmes because of its complex polygenically inherited character, which is influenced by its component traits. A field experiment was conducted to establish the extent of association between yield and yield components and other characters in maintainer lines of rice. Analysis of variance revealed that significant amount of genetic variability was present in the entire characters studied except grain length, grain width and flag leaf breadth. High heritability coupled with high genetic advance as percent of mean was observed for number of tillers per hill, number of panicles per plant, number of grains per panicle, 1000-grain weight (TGW), filled grains per panicle, flag leaf length, stigma breadth, filament length suggesting preponderance of additive gene action in the expression of these characters. The correlation coefficient between grain yield per plant and other quantitative characters attributing to yield showed that grain yield was significantly and positively associated with number of grains per panicle, TGW, spikelet fertility, filament length and pollen fertility at both genotypic and phenotypic levels. Path coefficient at genotypic level revealed that panicle length, number of effective tillers/plant, number of grains per panicle, TGW, filled grains per panicle, spikelet fertility, stigma length, stigma breadth, filament length and pollen fertility had direct positive effect on grain yield indicating importance of these parameters as the main contributors to yield. Thus, a genotype with higher extent of these traits could be selected as parents from existing genotypes for genetic improvement of yield in hybrid rice.

Key words: Rice, variability, heritability, correlation, path analysis.

INTRODUCTION

Rice is the most important staple food crop in the world which is used by more than half of the world population (Kohnaki *et al.* 2013). For growing population, the basic objective of the plant breeders always be towards yield improvement in staple food crops. It is anticipated that the world will have to produce 60% more rice by 2030 than that is produced in 1995 (Babu *et al.* 2012). Hence, an increase in the production of rice plays an important role in the food security and poverty alleviation.

It is known that yield of rice is complex quantitative trait and under pleiotropic gene control at the same time it is highly influenced by environment and contributed by many other traits. Furthermore, selection based on only yield may be misleading in some cases. Evidence on association of characters, direct and indirect effects added by each character towards yield will be more fruitful in aiding the selection process. A defined knowledge of the genotypes and scope of correlated response to selection for yield and yield attributes would be greatly helpful in planning a systematic breeding programme in situation of this kind. High scale of variability in a population provides the opportunity for selection to develop a variety having desirable characters.

The present investigation was undertaken in this context to elucidate information on variability, heritability, genetic advance, character associations and path of these parameters towards yield and

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to identify superior maintainer line in respect of various floral and yield contributing traits.

MATERIALS AND METHODS

Five maintainer lines were grown in a randomized complete block design with three replications at the experimental field of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur located at centre of Madhupur Tract (24º29 N latitude and 90º26 E longitude) having an altitude of 8.2m from the sea level (Anonymous, 1989) during *Aman*, 20018-19.

There are three blocks in the experimental fields. Seedlings of each line were raised in bed and 30-day-old seedlings were transplanted in the experimental plots. Transplanting was done with two to three seedlings per hill maintaining row to row spacing of 20 cm and plant to plant spacing of 15 cm. Proper soil fertility were maintained by applying urea-TSP-MoP-gypsum-$ZnSO_4$ @ 150:100:70:60:10 kg/ha respectively. Entire TSP, MoP, Gypsum and $ZnSO_4$ were applied during final land preparation. The urea was applied in three installments, at 15 days after transplanting (DAT), 30 and 45 DAT. Five sample plants were randomly selected from each plot excluding the border plants for recording traits *viz* Days to 50% flowering, days to maturity, flag leaf length (cm), flag leaf width (cm), plant height (cm), panicle length (cm), number of tillers per plant, number of panicles per plant, number of grains per panicle,1000 grain weight (g), filled grains per panicle, grain length (mm), grain width (mm), yield per hill (g), anther length (µm), anther breadth (µm), stigma length (µm), stigma breath (µm), filament length (µm), pollen sterility%, spikelet fertility%. Anther, stigma and filament length, breadth was measured with microscope using ocular micrometer (level 1) before anthesis. The data on quantitative characters were statistically evaluated on the basis of model designated by Cochran and Cox (1950) for Randomized Complete Block Design. In order to test the significance of treatments critical difference was calculated (Fisher and Yates, 1963). Phenotypic and genotypic coefficients of variation (PCV and GCV) were analyzed according to Burton (1952) and categorized according to Siva Subramanian and Menon (1973). Heritability in broad sense and genetic advance were calculated according to methods specified by Allard (1960) and categorized according to Johnson *et al.* (1955). Correlation coefficients were calculated for all quantitative character combinations at phenotypic, genotypic and environmental level by the formula set by Miller *et al.,* (1958). Path coefficient analysis proposed by Wright (1921) and explained by Dewey and Lu (1959) was used to analyze the direct and indirect impact of various traits to yield.

RESULTS AND DISCUSSION

Tables 1a and 1b furnish the analysis of variance studied for 21 characters. The analysis of variance revealed significant differences for all the characters (except grain length, grain breadth, flag leaf width) indicating the existence of sufficient variation among the genotypes for yield and yield component characters considered in the present investigation and therefore, there is an opportunity for effective selection.

GENETIC VARIABILITY

Tables 2a, 2b and 3 furnish the information on mean, range, PCV, GCV, heritability, and genetic advance in percent of mean for yield and yield component traits. A perusal of these results revealed maximum range of variability for number of panicle per plant followed by number of tiller per hill and yield (Table 3). Higher phenotypic coefficients of variation, compared to Genotypic coefficients of variation were noted for all the character studied in the present investigation,

Table 1a. Analysis of variance for maintainer lines.

Source of variation	d.f	50 % F	DMT	PH (cm)	PL (cm)	NT/H	NP/P	NG/P	GW (mm)	GL (mm)	Filled	Yield/hill (g)
Replication	2	0.0	0.000	8.867	0.569	0.600	2.467	2.467	0.056	4.433	5.267	0.936
Genotype	4	16.5**	179.1**	103.667**	6.148**	94.267**	84.833**	4462.83**	0.112 NS	1.846NS	2826.9**	34.9**
Error	8	0.0	0.000	0.367	0.38	3.267	1.633	1.633	0.040	5.813	0.933	0.783

50% F = Days to 50% flowering, DMT = Days to maturity, PH = Plant height (cm), PL = Panicle length (cm), NT/H = Number of tillers per hill,, NP/P = Number of panicles per plant, NG/P = Number of grains per panicle, GL= Grain length (mm), GW = Grain width (mm), d.f= Degrees of freedom.

Table 1b. Analysis of variance for maintainer lines.

Source of variation	d.f	FLL (cm)	FLW (cm)	TGW (gm)	AL (µm)	AB (µm)	SL (µm)	SB (µm)	FL (µm)	PS (%)	SF (%)
Replication (B)	2	7.945	0.057	2.435	7.117	0.050	0.050	1.190	12.067	0.001	1.403
Genotype (B)	4	49.640**	0.147 NS	12.77**	3658.40**	522.833**	189.542**	573.709**	73679.44**	5.40**	78.52**
Error (B)	8	0.522	0.081	0.622	4.700	4.883	5.342	3.210	15.942	0.001	1.543

FLL = Flag leaf length (cm), FLW = Flag leaf width (cm), TGW = 1000 grain weight (g), A = Anther length (µm), AB = Anther breadth (µm), SL= Stigma length (µm), SB= Stigma breadth (µm), FL= Filament length (µm), PS= Pollen sterility%, SF= Spikelet fertility%, * = Significant at the 5% level, ** = Significant at the 1% level, d.f = Degrees of freedom.

Table 2a. Mean performance of 5 maintainer lines for 30 characters in rice (*Oryza sativa* L.).

Character	1	2	3	4	5	6	7	8	9
Maintainer line (B line)	50% F	DMT	PH	PL	NT/H	NP/P	NG/P	TGW	Filled grains/ panicle
Ghan46B	64.00 d	89.00 c	86.33 a	23.73 a	12.67 b	12.00 c	195.7 a	18.14 a	155.7 a
BRRI 1B	70.00 a	92.00 a	81.33 c	22.36 b	14.67 b	14.67 b	158.3 c	13.67 c	139.0 b
IR 68B	65.00 c	75.00 e	84.00 b	21.42 b	15.33 b	12.33 bc	132.0 d	14.66 bc	100.3 d
IR 62B	66.00 b	78.00 d	72.67 d	22.87 c	26.67 a	24.67 a	94.00 e	15.50 b	79.00 e
IR 58B	65.00 c	89.00 b	87.33 a	22.44 b	14.67 b	13.00 bc	168.3 b	18.23 a	128.3 c
Mean	66.53	85.26	82.33	21.96	16.80	15.33	149.66	16.03	120.46
CV	.47	.37	.73	2.80	10.75	8.33	0.85	4.91	.80
CD (5 %)	.59	.59	1.14	1.16	3.24	2.41	2.41	1.48	1.82
S.E	.18	.18	.34	.35	1.04	.73	.73	.45	.55

50% F = Days to 50% flowering, DMT = Days to maturity, PH= Plant height (cm), PL= Panicle length (cm), NT/H = Number of tillers per hill, NP/P = Number of panicles per plant, NG/P = Number of grains per panicle, TGW = 1000 grain weight (g). Mean values having common letters are not significantly different from each other.

Table 2b. Mean performance of 5 maintainer lines for 30 characters in rice (*Oryza sativa* L.).

Character	10	11	12	13	14	15	16	17	18
Maintainer line (B line)	FLL	AL (µm)	AB (µm)	SL (µm)	SB (µm)	FL (µm)	PS (%)	SF (%)	Yield/hill (gm)
Ghan46B	25.54 c	443.2 a	96.33 b	191.5 ab	84.19 a	667.2 b	98.00 a	79.56 c	34.98 a
BRRI 1B	20.94 d	407.0 c	69.67 d	273.7 c	83.67 a	453.7 d	97.00 b	87.79 a	30.80 c
IR 68B	24.06 b	417.0 b	98.50 ab	192.5 a	65.00 c	363.7 e	95.00 c	76.02 d	26.11 d
IR 62B	22.61 bc	397.7 d	82.33 c	192.0 ab	72.17 b	750.0 a	97.00 b	84.06 b	33.57 ab
IR 58B	35.19 a	407.0 b	100.7 a	187.8 b	51.17 d	526.8 c	95.00 c	76.24 d	32.28 bc
Mean	28.86	402.56	89.50	187.50	71.23	552.26	97.73	80.73	31.54
CV	2.50	.53	2.46	1.23	2.51	0.72	0.45	1.72	2.80
CD (%)	1.36	4.08	4.16	4.35	3.37	7.53	0.84	2.62	1.66
S.E	0.41	1.25	1.27	1.33	1.03	2.30	0.25	.80	.51

FLL = Flag leaf length (cm), AL = Anther length (µm), AB = Anther breadth (µm), SL = Stigma length (µm), SB= Stigma breadth (µm), FL= Filament length (µm), PS = Pollen sterility%, SF = Spikelet fertility% Mean values having common letters are not significantly different from each other.

indicating the influence of environment. Similar findings were stated by Mamta Singh et al. (2007). However, high (>20%) phenotypic co-efficient of variation for number of tillers per hill, number of panicles per plant, number of grains per panicle, filled grains/panicle, filament length and grain yield/hill in the present research was noted to be closely and essentially related with high genotypic co-efficient of variation for the trait, indicating the negligible influence of environment and existence of high genetic variability for the trait in the experimental material. Hence, selection on the basis of phenotype in these genotypes can be effective for improvement of grain yield. Similar results were described earlier by Mishra and Verma (2002) and Hasib et al. (2004). However, moderate (10-20%) genotypic and phenotypic coefficients of variation were recorded in the present study for flag leaf length, anther breadth, stigma breadth and TGW. These results are similar with the findings of Bornane et al. (2014) for TGW. In contrast, low (<10%) estimates of genotypic and phenotypic coefficients of variation were observed in the present study for days to 50% flowering, days to maturity, plant height, panicle length, anther length, stigma length, pollen fertility and spikelet fertility indicating low variability for these characters in the present experimental material and therefore, there is little scope for improvement of these traits. Similar findings were reported earlier by Satish *et al.* (2003) for plant height.

Heritability estimates in broad sense (h2b) were relatively higher (>60%) for almost all the traits studied. Iftekharuddaula *et al.*, (2001) stated similar result in hybrid rice. High heritability evaluations have been found to be helpful in making selection of superior genotypes on the basis of phenotypic performance.

High heritability coupled with high genetic advance as percent meanwas recorded for number of tillers per hill, number of panicles per plant, number of grains per panicle, TGW, filled grains/panicle, flag leaf length, stigma breadth, filament length and grain yield per plant indicating that the high heritability observed is due to additive gene effects and selection may be effective for these characters. Similar findings were observed by Adilakshmi and Girijarani (2012) for TGW and Madhavilatha *et al.* (2005) for yield per plant. On contrary, high heritability coupled with moderate genetic advance in percent of mean was observed for plant height, panicle length, anther length indicating the role of both additive and non-additive gene effects for controlling the characters. The results are similar with the reports of Seyoum *et al.* (2012). Further, information on genetic variation along with heritability and genetic advance assessments has been informed to give a better idea about the efficiency of selection (Burton, 1952). In the present study, high GCV and PCV coupled with high heritability and high genetic advance in percent of mean were observed for number of tillers per hill, number of panicles per plant, number of grains per panicle, grain yield per plant indicating the preponderance of additive gene action and therefore, there is scope for improvement of the trait through selection. Similar results were given earlier by Mohana Krishna *et al.* (2009).

Table 3. Mean, range, genetic variability, heritability (broad sense) and genetic advance as percent of mean for yield and its component traits for five maintainer lines of rice.

Characters	Mean	Range	Coefficient of variation		Heritability	Genetic advance as percent of mean
			PCV(%)	GCV(%)		
Days to 50% flowering	66.53	64.66-70.66	3.60	3.57	98.26	7.30
Days to maturity	85.26	75.66-92.66	8.85	8.84	99.82	18.21
Plant height (cm)	82.33	72.33-87.66	7.16	7.12	98.94	14.60
Panicle length (cm)	21.96	19.87-23.33	6.90	6.31	83.49	11.88
Number of tillers/hill	21.96	12.66-26.66	34.50	32.78	90.27	64.16
Number of panicles /plant	15.33	12-24.66	35.34	34.34	94.43	68.75
Numberof grains/panicle	149.66	94- 195.66	25.77	25.76	99.89	53.04
1000 grain weight (g)	16.03	13.66-18.23	13.47	12.55	86.68	24.07
Filled grains/panicle	120.46	79-155.66	25.49	25.47	90.09	52.45
Flag leaf length (cm)	28.86	23.93-35.19	14.23	14.01	96.91	28.42
Anther length(µm)	402.56	348-443	8.68	8.66	99.61	17.82
Anther breath(µm)	89.50	69.66-100.6	14.88	14.68	97.24	29.82
Stigma length(µm)	187.50	173.66-192	4.35	4.19	91.99	8.25
Stigma breath (µm)	71.23	51.16-84.19	19.52	19.35	98.33	39.54
Filament length	552.26	363.66-750	28.38	28.37	99.93	58.43
Pollen sterility%	97.73	96-99	1.15	1.05	84.21	1.99
Spikelet sterility%	80.33	75.66- 88	6.63	6.40	93.26	12.74
Yield per plant (g)	31.54	26.11-34.98	31.05	30.68	93.53	31.30

CORRELATION COEFFICIENT

Tables 4a and 4b present the genotypic and phenotypic correlations for yield and yield components. These results exposed phenotypic and genotypic correlations to be of parallel direction and significance. However, genotypic correlations had found a higher extent compared to phenotypic correlations indicating the masking effect of environment. Similar results were stated by Madhavilatha *et al.* (2005). Further, grain yield per plant was observed to be positively and significantly associated with number of grains per panicle, TGW, spikelet fertility, filament length and pollen fertility indicating increase of grain yield with increase of these characters. Therefore, priority should be set to these traits, while making selection for yield improvement. The findings are in agreement with the finding of Manikaminnie *et al.* (2013) for reproductive tillers per hill. On the contrary, non-significant positive association was noticed for panicle length, number of panicles per plant, filled grains per panicle, anther length, stigma length and breadth. The findings are in agreement with the reports of Yadav *et al.* (2010).

PATH ANALYSIS

Path coefficient analysis (Tables 5a and 5b) revealed that panicle length, number of effective tillers/plant, number of grains per panicle, thousand grain weight, filled grains per panicle, spikelet fertility, stigma length, stigma breadth, filament length and pollen fertility % possessed the highest positive direct effect on grain yield and therefore direct selection based on these traits would be feasible. Negative direct effect of plant height and days to 50% flowering towards yield indicated short plant with short duration rice hybrids could be developed without sacrificing grain yield. Panicle length showed positive indirect effect with grain yield for most of the characters studied except for plant height, number panicle, filled grain.

Table 4a. Phenotypic (above diagonal) and genotypic (below diagonal) correlations for agronomical and floral characters in maintainer lines of rice (*Oryza sativa* L.).

Character	Days to 50% flowering	Days to maturity	Plant height	Panicle length	Number of tillers /hill	Number of panicles /tiller	Number of grains /panicle	TGW	Filled grains/ panicle	Spikelet fertility	Yield/ plant
Days to 50% flowering	-	.4108	-.2824	-.0714	.0072	.1422	-.0916	-.6610*	.1234	.8058**	-.1263
Days to maturity	.4203	--	.4620	.688**	-.5345*	-.3853	.7550**	.3000	.842**	.3188	.4892
Plant height	-.2863	.4649	-	.808**	-.907**	-.9447**	.8554**	.4899*	-.7289**	-.5949*	-.1418
Panicle length	-.0728	.7517**	.8628**	-	-.873**	-.8091**	.9434**	.4560	.9125**	-.1985	.2098
No. of tillers/hill	.0114	-.5643*	-.945**	-.922**	-	.9657**	-.8653**	-.2533	-.8156**	.3242	.1762
No. of panicles/tiller	.1423	-.3951	-.962**	-.837**	.9855**	-	-.8022**	-.2344	-.7122**	.4845	.3090
No. of grains/panicle	-.0922	.7560**	.858**	1.025**	-.907**	-.8228	-	.5176	.9682**	.1996	.2730*
1000 grain weight	-.7261*	.3256	.5184	.4968	-.2495	-.2751	.5502	-	.3639	.5468	.5535*
Filled grains/panicle	.1252	.8430**	.7347**	1.0094**	-.860**	-.7346	.9699**	.3959	-	.0481	.3263
Spikelet Fertility	.8356*	.3324	-.5989	-.1559	.3229	.4943	.1984	.5561	.0437	-	.3205*
Yield/plant	-.1211	.5029	-.1239	.2723	.1812	.3105	.2883	.6318*	.3336	.2981	-

TGW = 1000 grain weight

Table 4b. Phenotypic (above diagonal) and genotypic (below diagonal) correlations for agronomical and floral characters in maintainer lines of rice (*Oryza sativa* L.).

Character	Flag leaf length	Anther length	Anther breadth	Stigma length	Stigma breadth	Filament length	Pollen fertility	Yield/plant
Flag leaf length	-	-.7289**	.7493**	.4904	-.9071**	.0336	-.4674**	.0434
Anther length	-.7358**	-	-.1393	.1100	.8160**	.0882	.4776**	.0166
Anther breadth	.7635**	-.1376	-	.7532**	-.6075*	-.0800	-.3591	-.1078
Stigma length	.5070	.1249	.7607**	-	-.3584	.3436	-.0267	.0193
Stigma breadth	-.9256**	.8103**	-.6102*	-.3354	-	.2446	.7185**	.3056
Filament length	.0338	.0878	-.0792	.3589	.2469	-	.7836**	.8563**
Pollen fertility	-.4838**	.4975**	-.4080	-.0595	.7620**	.8137**	-	.7790**
Yield /plant	.0373	.0164	-.0873	.0773	.2951	.8872**	.8712**	-

Table 5a. Direct and indirect effects (phenotypic) of agronomical and floral characters on yield in maintainer lines of rice.

Character	Days to 50% flowering	Days to maturity	Plant height	Panicle length	Number of tillers /hill	Number of panicles /tiller	Number of grains /panicle	1000 grain weight	Filled grains/panicle	Spikelet fertility%
Days to 50% flowering	-1.0173	.3968	.2428	.0064	-.0061	.0532	-.3918	-.0148	-.4998	1.1097
Days to maturity	-.4276	.9440	-.3941	-.0657	.2988	-.1477	3.2119	.0066	-3.3645	.4414
Plant height	.2913	.4389	-.8478	-.0754	.5008	-.3596	3.6453	.0106	-2.9323	-.7954
Panicle length	.0740	.7096	-.7315	.0874	.4883	-.3128	4.3581	.0101	-4.0290	-.2070
Number of tillers/hill	-.0116	-.5327	.8019	.0806	-.5295	.3683	-3.854	-.0051	3.4343	.4288
Number of panicles/tiller	-.1447	-.3730	.8158	.0732	-.5218	.3737	-3.495	-.0056	2.9322	.6564
Number of grains/panicle	.0938	.7137	-.7274	-.0897	.4803	-.3075	4.2487	.0112	-3.8711	-.2635
1000 grain weight	.7387	.3074	-.4395	-.0434	.1321	-.1028	2.3377	.0204	-1.5802	-.7385
Filled grains/panicle	-.1274	.7958	-.6229	-.0883	.4556	-.2745	4.1207	.0081	-3.9913	.0580
Spikelet fertility	-.8501	.3138	.5074	.0136	-.1709	.1847	-.8529	-.0113	-.1745	1.3280
Yield/plant	-.1211	.5030	-.1238	.2726	.1810	.3103	.2885	.6319	.3338	.2981

Residue effect = 0.351

Table 5b. Direct and indirect effects (phenotypic) of agronomical and floral characters on yield in maintainer lines of rice.

Character	Flag leaf length	Anther length	Anther breadth	Stigma length	Stigma breadth	Filament length	Pollen fertility
Flag leaf length	.3746	.3216	.5529	-.3168	-1.0245	.0364	.0930
Anther length	-.2757	-.4370	-.0997	-.0781	.9079	.0946	-.0957
Anther breadth	.2860	.0601	.7241	-.4753	-.6754	-.0854	.0785
Stigma length	.1899	-.0546	.5508	-.6248	-.3823	.3868	.0115
Stigma breadth	-.3468	-.3585	-.4418	.2158	1.1069	.2661	-.1465
Filament length	0.0126	-.0384	-.0574	-.2243	.2733	1.0778	-.1565
Pollen fertility	-.1812	-.2174	-.2954	.0372	.8434	.8770	-.1923
Yield/ plant	.0373	.0164	-.0873	.0773	.2951	.8872	.8712

Residue effect = 0.1030

The residual effect for first ten character in Table 5a was 0.351 indicating that 65% of the variability in grain yield was contributed by ten characters studied in the path analysis. The remaining ten characters in Table 5b showed 0.1030, indicating 90% of the variability in grain yield was contributed by these characters. This result gives an impression that few other traits than those involved in the present experiment might also contribute to yield. Correlation and path coefficient reflected that panicle length, number of grains per panicle, thousand grain weight, filled grains/panicle, stigma breadth, filament length, pollen fertility% and spikelet fertility% were the most significant yield components in the studied maintainers of rice hybrids and selection based on these characters would help in exploiting yield potential rice hybrids.

CONCLUSION

Results of the present study on variability, heritability and genetic advance indicated an opportunity for upgrading of grain yield of maintainer lines through selection. The highest mean performance for yield in maintainer (B) lines was found in Ghan 46B followed by IR 62 B. For the development of rice hybrids with earliness and dwarfness IR 62B can be utilized. Most of the studied characters showed significant variation among the genotypes. Studies on character association and path co-efficients revealed the importance of number of reproductive tillers per hill, number of filled grains per panicle, 1000 grain weight, filament length, stigma breadth as selection criteria for effective yield improvement. The study also showed the need of balanced selection in the light of negative association of reproductive tillers per hill with filled grains per panicle and filled grains per panicle with 1000-grain weight in crop yield improvement programmes.

AUTHORS' CONTRIBUTION

MSH, NAI and MSR generated the idea; MSH, NAI, MSR and SM coordinated the experiment/research/project; MSH and NAI developed methodology; MSH, NSI, MSR, MEK and SM provided scientific insights; MSH and SM gathered data; NAI, and MAK carried out analysis and synthesis; MSH and NAI did the writings for all versions of the manuscript;MSH, NAI, MSR, MEK and SM performed critical review and editing; All authors read and approved the final manuscript.

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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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Prevalence and Transmission of *Fusarium moniliforme*: A Seed Borne Pathogen of Rice

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ABSTRACT

Fusarium moniliforme is one of the major seed borne pathogen of rice in Bangladesh that causes significant yield loss. To observe the incidence and transmission of this pathogen, farmers saved seeds and seeds from BADC were collected and detected the pathogen by blotter method. The prevalence of the *F. moniliforme* varied according to locations and seasons. The highest 18% of seed infection was recorded in Boro seeds of Netrakona district and the lowest 2% was in Gazipur district. The Embryonal end of the seed is the most preferable site of the infection. *F. moniliofrme* successfully transmitted from seed to seedling and the transmission is high when pre- sprouted seed sown on the puddled seed bed. The study recommended that before planting season, seeds should be tested and treated when necessary to minimize spread of the pathogen.

Key words: *F. moniliforme,* rice seed, transmission, sporulation, incidence.

INTRODUCTION

Rice, the important cereal crops of Bangladesh, is grown extensively in all over the country. The crop is affected with as many as 32 different diseases in Bangladesh. Of which, 10 documented major diseases and five of them are seed borne (Miah and Shahjahan, 1987). Among the major seed borne pathogens of rice, *F. moniliforme* Sheldon (causal agent of bakanae disease) is quite serious. Under favourable conditions, it causes substantial damage and as high as 95.4% yield loss has been estimated in India and in Bangladesh upto 26.7% yield loss recorded due to bakanae disease (Singh and Sunder, 1997: Latif *et al,* 2006). During the present study, a severe infection of bakanae disease of rice observed in different regions of Bangladesh such as Dinajpur, Habiganj, Cumilla, Netrakona and Gazipur. Infected seed is the main means of such spreading the disease from field to field; because the seed-borne inocula provide initial foci for seedling infection and subsequently infection taken place in the main field (Nath *et al.* 1970; Winter *et al.* 1974). Infected plants in the field that reach heading produce enormous amount of inocula which infect the developing grains results in deep infection on the seed (Kim, 1981). From Bangladesh Mia and Mathur (1983) tested seed health of 75 rice seed sample from different parts and observed more than 90% samples infected with the *F. moniliforme* and the extent of infection of 1.0-20.16% (Hossain, 2002; Momotaz, 2005).

Seed is one of the basic elements for crop production and help to increase agricultural productivity. When seed has good health and physical qualities, farmers have greater prospects of producing a good crop (Miva *et al.,* 2017). The present investigation has been carried out to establish baseline information on quality of farmers saved rice seed in respect of bakanae pathogen, to enhanced strategy of yield improvement. This is important as many farmers use own stored seeds for the next cropping season, though seed borne diseases can be transferred easily and hence other quality attributes may be sub-standard. Proper assessment of the quality of seed, stored by farmers from their previous crop will establish the broad picture of seed quality of locally produced rice as compared to quality declared seed (BADC seed). Therefore, this paper aims to evaluate the incidence of *F. moniliforme* in

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farmers saved rice seeds in some selected districts of Bangladesh and to find its transmission from seeds to seedlings.

MATERIALS AND METHODS

A total of 326 seed samples of farmer's saved seeds in each season (Aus, Aman, Boro) from five locations viz Cumilla, Netrakona, Dinajpur, Gazipur and Habiganj were collected. Samples of BADC were collected from its seed processing centers (SPC) located all over the country. The quantity of each sample was about 500g. Samples were kept in brown paper bag, labeled properly and preserved in a refrigerator at 5-8^{o}C for subsequent use.

The collected samples were tested by blotter method to detect *F. moniliforme* following International Rules for Testing Seed Health (ISTA, 2000). Three layers of filter papers (Whatman No.1) soaked in sterilized water was placed at the bottom of a nine cm diameter plastic petridish. Then 25 seeds were placed on the filter paper in each plate. For each sample 400 seeds were tested. The petridishes containing the seeds were incubated at 25±1^{o}C under alternating cycle of 12/12 hours near NUV light and darkness for seven days. After incubation, the seeds were examined under stereobinocular microscope. A temporary slide was prepared and observed under compound microscope to confirm the pathogen *F. moniliforme* according to Burgess *et al.,* 1994. Number of seeds on which *F. moniliforme* grew was recorded. Data were converted into percentage of seed-borne infection. Seed infection between farmers saved seeds and BADC seeds were compared by using the paired t-test.

Detection of *F. moniliforme* in different seed grade. Bakanae infected rice seeds collected from farmer's field were grouped manually into different categories viz apparently healthy, discoloured filled grain, discoloured unfilled grain and unfilled grain with normal colour. From each category of seeds, 400 seeds were examined for *F. moniliforme* by blotter method and the methods described above. The fungi colony that grew out from the seeds were recorded after seven days of incubation. The data were analyzed and differences among the treatment means were compared following Duncans Multiple Range Test (DMRT).

Site of sporulation of *F. moniliforme* on infected seeds. During detection of *F. moniliforme* on seeds, observations were made on whether the seeds were germinated and infected. Infected seeds were examined. Fungus sporulation was observed in two sites of the seed i.e (a) embryonal end alone and (b) entire seed surface including embryonal end.

Transmission of *F. moniliforme* from seed to seedlings. Naturally infected seed samples of BR1 and BRRI dhan44 were used in this study. One week prior to the start of the seed transmission studies, seed infection percentage was determined. These two samples were stored at 5^{o}C in a refrigerator after seed health testing and used for seed transmission studies.

A total of 48 plastic pots (20 X 12cm) were taken. Twenty-four pots were filled with sterilized soil and another 24 pots were filled with non-sterilized soil. Soil was sterilized following the methods described by Sunder and Satyavir, 1998. Infected seeds of rice variety BR1 and BRRI dhan44 were used. One hundred seeds of each variety were sown in pot by using three different seeding methods and which were a) Dry seed sown on wet pot, b) Sprouted seed sown on wet pot, and c) Dry seed sown under moist soil. Complete covering of seeds was done by 1 to 1.5 cm layer of soil and then compressed by hand. The pots were arranged in a completely randomized block design with four replications for each treatment. The seedlings were examined for the presence of bakanae infected seedlings after seven days until four weeks. The data were analyzed and differences among the treatment means were compared following Duncans Multiple Range Test (DMRT).

RESULTS

Table 1 shows the occurrence of *F. moniliforme* in the seed samples of Aus, Aman and Boro seasons collected from different locations. In case of Aus seeds, 20 samples were tested from Dinajpur, 17 of them were infected with *F. moniliforme*. The pathogen was detected in 31 out of 34 samples of Habiganj. *F. moniliforme* was detected from eight samples of Cumilla. Number of infected samples was three and 10 in Netrakona and Gazipur, respectively. The percentage of infection in different samples of Dinajpur, Habiganj, Cumilla, Netrakona and Gazipur districts was 85, 91, 54, 25 and 47, respectively. During Aman season, about 42 percent of the samples were infected in Dinajpur and 87% in Gazipur. But 100% samples of the Cumilla and 90% samples of Habiganj were infected by *F. moniliforme*. Table 1 also shows the prevalence of *F. moniliforme* in the seed samples of different locations during Boro season. The pathogen was detected from 30 out of 36 samples of Habiganj. Thirty-three samples were tested from Dinajpur, 19 of them were infected with *F. moniliforme*. The pathogens were detected from 11 out of 15 samples of Cumilla. *F. moniliforme* was detected from seven samples of Gazipur. The percentage of sample infection was high 88% in Netrakona followed by 83% in Habiganj. It was 58, 73 and 47% respectively in Dinajpur, Cumilla and Gazipur district.

Figure 1 presents the average infection of *F. moniliforme* in different locations during Aus, Aman and Boro seasons. During Aus season, maximum infection of *F. moniliforme* was found in the seeds collected from Habiganj and Dinajpur district. The minimum (1.91%) infection was recorded in Gazipur district. The infection of the pathogen in the seeds of Cumilla and Netrakona were almost similar. Infection of *F. moniliforme* also influenced by different locations during Aman season. The maximum infection was found in seeds collected from Cumilla. The infection was almost similar in the seeds of Gazipur, Habiganj and Netrakona. The minimum infection was found in seeds collected from Dinajpur. Considering Boro season, the highest infection was recorded in the seeds of Netrokona and Habiganj. The infection in the seeds of Gazipur and Cumilla were 8.93, 4.06% respectively. The lowest infection was found in the seeds of Dinajpur district.

Table 1. Incidence of *F. moniliforme* in the collected seed samples of Aus, Aman and Boro season.

	Aus			Aman			Boro		
Location	No. of sample	No. of sample infected	% sample infected	No. of sample	No. of sample infected	% sample infected	No. of sample	No. of sample infected	% sample infected
Dinajpur	20	17	85	24	17	42	33	19	58
Habiganj	34	31	91	29	26	90	36	30	83
Cumilla	15	8	54	22	22	100	15	11	73
Netrakona	12	3	25	15	7	47	24	21	88
Gazipur	17	10	47	15	13	87	15	7	47

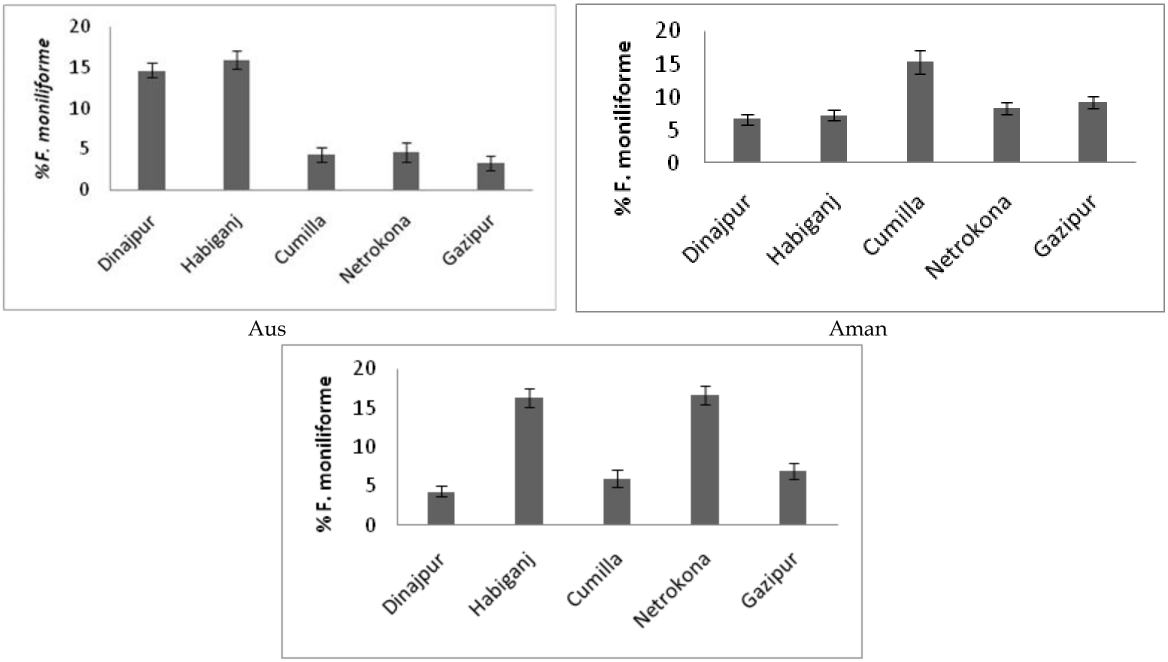

Fig. 1. Seed-borne infection of *F. moniliforme* in different locations during Aus, Aman and Boro seasons.

Table 2 shows the occurrence of *F. moniliforme* in rice seeds of different seed sources. Irrespective of growing season, seed infection was significantly higher in farmers' seeds compared to BADC seeds. The highest 7.61% infection was found in farmers seeds and it was 3.74% in BADC seeds during Aus season. During Aman and Boro season the seed infection of *F. moniliforme* was 8.75% and 9.01% in case of farmer's seeds, respectively. It was 5.42% and 2.72% in BADC seeds.

It is evident from Figure 2 that the maximum infection in farmer's seeds was found in Habiganj and minimum in Gazipur. There was 8.20% seed infection in Netrakona. The incidence of *F. moniliforme* in Dinajpur and Cumilla was comparable. Incidence of *F. moniliforme* in BADC seeds was low in Gazipur but high in Habiganj. The incidence of pathogen in BADC seeds collected from Dinajpur, Netrakona and Gazipur was almost similar.

Table 2. Percentage of seed-borne infection of *F. moniliforme* in different seed sources.

Seed source	Percent infection			Mean
	Aus	Aman	Boro	
Farmers' seed	7.61	8.75	9.01	8.46
BADC seed	3.74	5.42	2.72	3.96
Significance	*	*	*	

* Significance at the 5% level by paired t-test.

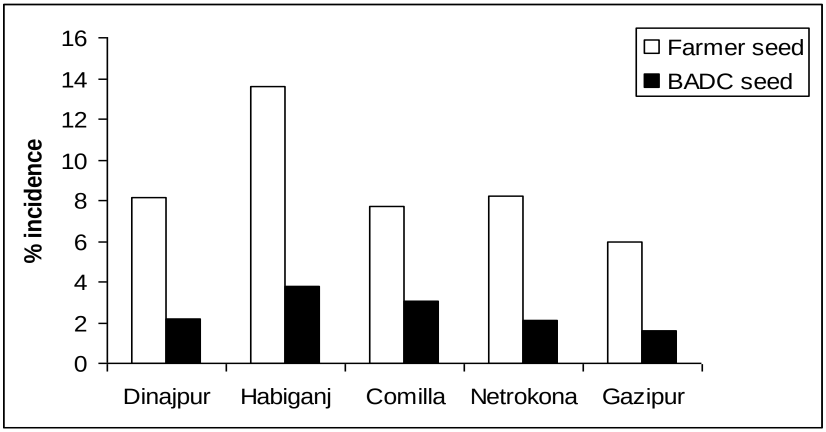

Fig. 2. Prevalence of *F. moniliforme* in the BADC and farmers' seeds of different locations.

Detection of *F. moniliforme* in different category of seeds. Table 3 presents seed-borne infection of *F. moniliforme* and other pathogens in different categories of seeds. The highest 74.75% incidence of *F. moniliforme* was present in discoloured unfilled grains. The lowest 17.50% incidence was found in apparently healthy seeds and the difference varies significantly. The pathogen was detected from 30.50% unfilled grains (without discolouration) and which was 31.50% from discoloured filled grains. The difference was insignificant. The highest incidence (10.08%) of other pathogen was found in discoloured filled grain. Seed infection was 9.50% in discoloured unfilled grains. The lowest 6% incidence was found in apparently healthy looking seed. The incidence of other pathogen in unfilled grain (normal) was 7.42% (Table 3).

Site of sporulation of *F. moniliforme* in rice seeds. *F. moniliforme* produced sporophores (sporulation) on the embryonal end of 12-16% of non-germinated seeds and 66-76% of germinated seeds. Conidiophores (sporulation) of the pathogen covered all over the upper surface of the 84-88% of the non-germinated and 25-34% of germinated seeds (Table 4). The mean sporulation of *F. moniliforme* was on the upper surface of 86% in non-germinated seeds in comparison to 14% in embryonal end. In case of germinated seeds, embryonal end and upper surface had 71% and 30% sporulation, respectively.

Table 3. Detection of *F. moniliforme* and other fungi associated with different categories of seed (Var. BR1).

Seed grade	*F. moniliforme* (%)	Other fungus* (%)
Apparently healthy	17.50 c	6.00 c
Discolored filled grain	31.50 b	10.08 a
Discolored unfilled grain	74.75 a	9.50 ab
Unfilled grain (normal)	30.50 b	7.42 bc

Means followed by the same letter(s), in a column, did not differ at the 5% level of significance by LSD. *Trichoconis padwikki, Curvularia* spp. and *Alternaria* sp.

Table 4. Percent seeds having sporulation of *F. moniliforme* on germinating and non-germinating filled rice seeds.

Variety	Embryonal end		Upper surface	
	Non-germinated seeds (%)	Germinated seeds (%)	Non-germinated seeds (%)	Germinated seeds (%)
BR1	16	76	84	25
BRRI dhan44	12	66	88	34
Mean	14	71	86	30

Based on 100 non-germinating seeds and 400 germinating seeds with *F. moniliforme* of each variety.

Seed to seedling transmission of *Fusarium moniliforme.* Table 5 presents the transmission of *F. moniliforme* from seed to seedlings. Percent transmission was higher in sterilized soil than in non sterilized soil for both the varieties. In case of BR1, the highest 37.14% transmission was observed when pre-sprouted seeds were sown on puddled soil. The lowest 8.57% transmission was recorded when dry seeds sown in the moist soil. Dry seeds sown on puddled soil had 24.76% transmission of *F. moniliforme*. Similarly, for non-sterilized soil, transmission rate was 26.66% when pre sprouted seeds were sown on puddled soil. It was 17.14% and 6.72% for dry seeds sown on puddled soil and dry seeds sown under the moist soil, respectively. Similar trends of rate of transmission of *F. moniliforme* from seeds to seedlings was observed in case of BRRI dhan44. The % transmission of *F. moniliforme* was more in sterilized soil than that of non-sterilized one. The transmission of *F. moniliforme* in sterilized and non-sterilized soil was 23.49% and 16.85% respectively in BR1. It was 26.01% and 18.96% in sterilized and non-sterilized soil of BRRI dhan44.

Table 5. Transmission of *F. moniliforme* from seed to seedlings in different seeding methods.

Seeding method	Transmission (%)				Mean
	BR1		BRRI dhan44		
	Sterilized soil	Non-sterilized soil	Sterilized soil	Non-sterilized soil	
Dry seed on puddled soil	24.76 b	17.14 b	28.32 b	19.51 b	22.43
Sprouted seed on puddled soil	37.14 a	26.66 a	39.96 a	31.71 a	33.86
Dry seed under moist soil	8.57 c	6.72 c	9.75 c	5.68 c	7.68
Mean	23.49	16.84	26.10	18.96	

Means followed by same letter, in a column, did not differ at the 5% level of significance by LSD.

DISCUSSION

Fusarium moniliforme Sheld (bakanae pathogen) occurs in almost all rice growing countries of the world including Bangladesh. Fungal contamination of rice seed samples with this pathogen is a major problem for farmers, in many developing countries. It is proved to be primarily seed-borne and high level of incidence has been found in rice seed samples (Singh and Sunder, 1997).

The findings of the present study confirmed the occurrence of *F. moniliforme* associated with rice seed samples in Bangladesh. This is in accordance with the findings of Fakir *et al.* (1990). They reported *F. moniliforme* was more prevalent in 58 and 59 seed samples, out of 60 samples of two rice varieties. Mia and Mathur (1983) tested seed health of 75 seed samples from different parts of Bangladesh and observed more than 90% samples infected. Present study reveals that the average infections in three different seasons were 15.35, 14.77 and 17.68%, respectively. Earlier reports from Bangladesh are in accordance with the present findings (Rahman, 2002, Uddin, 2003, Momotaz, 2005). According to Uddin (2003) *F. moniliforme* was found in seed at a range of 0.6-5.2%. Incidence of *F. moniliforme* varied with respect to the source of seeds. Farmers' saved seeds showed higher seed infection than those from BADC seeds. This situation prevailing in the country may be due to ignorance of farmers' about seed borne diseases and their poor storage condition. Previously, Islam *et al.* (1994) and Chowdhury *et al.* (2013) mention that percent seed infection in farmers' seeds was higher than BADC seeds. From the results of the present study it appeared that location has little influence on the infection of *F. moniliforme* for BADC seeds. Sporulation of the pathogen occurred either from the embryonal end alone or from the entire seed surface of both germinating and non-germinating seeds. Sporulation of *F. moniliforme* on embryonal end was much higher in germinating seed than that of the non-germinating seeds. The result is supported by the observation of Agarwal *et al.* (1989). They stated that *F. moniliforme* mainly harbored in the embryo. Another important observation made by Chung and Lee (1983) is that sporulation of *Pyricularia oryzae* was confined to the embryonal end of rice seeds. It is well known that the embryonal end of rice seeds has high protein content and this may possibly enhance the sporulation of *F. moniliforme* (Manandhar *et al.*, 1998). When the seeds are dead, the fungus can utilize the whole seeds as a substrate, as suggested by Limonard (1968), who observed abundant sporulation of *Fusarium, Helminthosporium* and *Septoria* on dead seeds of different cereals. The embryonal end of rice seeds as a preferred site for *F. moniliforme* is important in nature since the fungus gets easy and quick access to the shoot coming out from the seed (Manandhar *et al.,* 1998). Our investigation reveals that high rate of seed transmission of *F. moniliforme* occurs in pre-sprouted seed. During soaking of infected seeds, the spore released into water and again infect another seed, as a result the incidence of *F. moniliforme* increased in pre sprouted seed (Karov *et al.* 2008; Martin 2008). Low rate of transmission was found when the seeds were sown in the soil. From these results, it seems that the fungus needs aerobic condition to survive, sporulations and infect the seedlings. The results are in consistent with the observation made by Martin (2008). He stated that bakanae pathogen reproduced rapidly in the presence of oxygen. Similarly, Manandhar *et al.* (1998) reported that transmission of *Pyricularia oryzae* rarely occurred when the seeds were completely covered with the soil. The transmission was lower when seed sown in non-sterilized soil than seeds sown in sterilized soil. The reason is that the presence of antagonistic soil micro-organism might have restricted seed transmission of pathogen.

CONCLUSION

The results of the present study reveal that seed borne *F. moniliforme* was present in all of the seed samples collected from different locations and sources in a varied level and infection was found high in the farmers saved seed. Although test to find out the percent of infection of this pathogen in other varieties were not conducted. While in certain instance it occurred in trace level but under suitable environmental condition it may create the disease in epidemic form. Furthermore, results also reveal that the pathogen successfully transmitted from seed to seedlings. Most of the farmers in Bangladesh used their own saved seeds. Therefore, as a seeding material, the seed health status of farmers saved seeds need to be improved.

AUTHORS CONTRIBUTION

MSH, MAA and MAIK generated idea; coordinated the experiment; developed methodology; provided scientific insights, gathered data; carried out analysis and synthesis and did the writings for all versions of the manuscript. SM carried out some analysis and synthesis; All authors read and approved the final manuscript.

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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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Assessment of Genetic Variability and Correlation of Yield Components of Elite Rice Genotypes (*Oryza sativa* L.)

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ABSTRACT

The study was conducted to evaluate the extent of variability among the elite rice (*Oryza sativa* L.) genotypes for yield and yield components. Sixteen elite rice genotypes were evaluated for yield and yield contributing characters in Bangladesh Rice Research Institute, Regional Station, Satkhira. Highest grain yield (t ha^{-1}) was observed in BR(Bio)8333-BC5-2-16, which was followed by BR16, BRRI dhan28, BRRI dhan58 and BRRI dhan29. BR7671-37-2-2-37-3-P3 had the highest number of grains per panicle with minimum thousand grain weight. Correlation analysis revealed that the number of panicles per plant (0.301), days to 50% flowering (0.606) and grain yield per plant (0.393) had the significantly positive contribution to grain yield. After evaluation of yield components, four genotypes namely BR(Bio)8333-BC5-1-20, BR(Bio)8333-BC5-2-16, BR(Bio)8333-BC5-2-22 and BR(Bio)8333-BC5-3-10 were selected as outstanding genotypes, which can be used as potential breeding materials for variety development or in the crossing program to enrich the rice gene pool in Bangladesh.

Key words: Variability, correlation, yield components, elite rice genotypes.

INTRODUCTION

Rice *(Oryza sativa* L.) is one of the pivotal staple cereal crops feeding more than half of the world population. In view of the growing population, the basic objective of the plant breeders would always be towards yield improvement of staple food crops. Sufficient rice production is the key to ensure food security in Bangladesh. In fact, 'Rice security' is synonymous to 'Food security' in Bangladesh as in many other rice growing countries (Brolley, 2015). Rice security is not just an economic issue but also an important parameter for determining social and political stability (Nath, 2015). More food will be required in future because of increasing population. Population of Bangladesh will reach 215.4 million in 2050, when 44.6 MT of clean rice will be needed (Kabir *et al.*, 2015). Theoretically, rice still has great yield potential to be tapped and there are many ways to raise rice yield, such as building of irrigation works, improvement of soil conditions, agronomic management techniques and breeding of high yielding varieties. The knowledge on the nature and magnitude of genetic variation in respect of quantitative characters like yield and its components is essential for effective crop improvement. Selection of high yielding varieties based only on grain yield will not be much effective unless adequate information on genetic parameters and association between them are available to formulate hybridization and selection program for further improvement, because the estimate of the mean serves as a basis for eliminating the undesirable genotypes.

Information on correlations of characters, direct and indirect effects contributed by each character towards yield will be an added advantage in aiding the selection process. Correlation establishes the extent of association between yield and its components and also brings out relative importance of their effects, thus giving an obvious understanding of their association with grain yield.

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Ultimately, this kind of analysis could help the breeder to design his selection strategies to improve grain yield. Therefore, the present investigation is carried out with the objective of studying the analysis and character associations in rice genotypes for yield improvement.

MATERIALS AND METHODS

Sixteen elite rice genotypes including five standard check varieties namely, BR16, BRRI dhan28, BRRI dhan58 and BRRI dhan29 were grown at Bangladesh Rice Research Institute, Regional Station, Satkhira, Bangladesh during Boro season 2016-17. The experiment was laid out in a Randomized Complete Block Design with three replications. Seeding was done on 09 December 2016 and 35 days old seedlings were transplanted. Twenty cm distance was maintained between the rows and 15 cm between the plants. Single seedling was used for transplanting and unit plot size was 10.2 m^2. TSP and MOP were applied at the rate of 100 kg/ha and 120 kg/ha, respectively during final land preparation. Urea was applied at the rate of 260 kg/ha in three splits at 10 and 30 days after transplanting and 5 days before panicle initiation. A hand weeding was done at 25 days after transplanting. Others intercultural operations and pest control measures were done as and when necessary.

Table 1. Genotypes with passport data are used for this study.

Code	Genotype	Parentage	Source
GEN1	BR(Bio)8333-BC5-1-1	BRRI dhan29/IRBB60	BRRI
GEN2	BR(Bio)8333-BC5-1-20	BRRI dhan29/IRBB60	BRRI
GEN3	BR(Bio)8333-BC5-2-16	BRRI dhan29/IRBB60	BRRI
GEN4	BR(Bio)8333-BC5-2-22	BRRI dhan29/IRBB60	BRRI
GEN5	BR(Bio)8333-BC5-3-10	BRRI dhan29/IRBB60	BRRI
GEN6	BRC266-5-1-1-1	BR16/90060-TR1252-8-2-1	BRRI
GEN7	BRC266-5-1-2-1	BR16/90060-TR1252-8-2-1	BRRI
GEN8	BR8523-36-2-2-6	IR 77512-128-2-1-2 / BR 6817-25-2-2	BRRI
GEN9	BR16 (Ck.)	IR1416-131-5/IR1364-37-3-1//IR1544A-E666	BRRI
GEN10	BR7671-37-2-2-37-3-P3	BRRI dhan29/ IR68144	BRRI
GEN11	BR8626-19-5-1-2	BR7166-5B-6/ SHEW WAR TUN// BRRI dhan47	BRRI
GEN12	BR8626-10-5-1	BR7166-5B-6/ SHEW WAR TUN// BRRI dhan47	BRRI
GEN13	BR8109-29-2-2-3	BM9821/Parija	BRRI
GEN14	BRRI dhan28 (Ck.)	BR6 (IR28)/Purbachi	BRRI
GEN15	BRRI dhan58 (Ck.)	Somaclonal line of BRRI dhan29	BRRI
GEN16	BRRI dhan29 (Ck.)	BG90-2/BR51-46-5	BRRI

Source: BRRI (2013) and BRRI (2019).

Data collection of agronomic traits

Data were collected at days to 50% flowering, plant height (cm), number of tillers per plant, number of panicles per plant, grains per panicle, grain yield per plant, panicle length (cm), thousand-grain weight (g), fertility (%) and yield (t ha^{-1}). Days to flowering has been recorded as soon as 50% of the panicles appeared. Five plants were randomly selected excluding the border rows and avoiding the missing hills around for recording data on plant height in centimeter. Numbers of tillers were recorded in maximum tillering stage. The plant height was measured from ground level to tip of the tallest panicle excluding awns. Panicles were harvested from each individual plant at maturity, properly labelled and placed in net bags separately and air-dried at room temperature for one week. Percentages of spikelet fertility, thousand grain-weight and grain yield per plot were estimated by given formula:

$$\text{Spikelet fertility (\%)} = \frac{\text{Number of filled grains}}{\text{Number of filled grains} + \text{number of unfilled grains}} \times 100$$

$$\text{Yield (t/ha)} = \frac{100 - \text{Grains moisture content (\%)}}{100 - 14} \times \text{Plot yield}$$

Statistical Analysis

Genotypic variance, mean comparisons of different traits, coefficient of variation (CV) was measured by STAR software (version 2.0.1) and PB Tools software (version 1.3). Analysis of variance was used to test the significance of variance sources, while Tukey's Honest Significant Difference (HSD) test ($p = 0.05$) was employed to compare the differences among treatment means. The correlation coefficient analysis was conducted to find the relationship of different traits.

RESULTS

Genetic variability

The analysis of variance shows highly significant genetic variations ($P \leq 0.01$) among the genotypes for days to 50 % flowering, plant height, number of tillers per plant, number of panicles per plant, number of grains per panicle, grain yield per plant, panicle length, thousand-grain weight, grain fertility and grain yield (Table 2). Coefficient of variation (CV) for days to 50 % flowering, plant height, number of tillers per plant, number of panicles per plant, number of grains per panicle, grain yield per plant, panicle length, thousand-grain weight, grain fertility and grain yield were 0.92, 2.42, 7.11, 14.07, 12.93, 5.33, 4.40, 12.92, 6.75 and 4.35% respectively (Table 2).

It was observed that mean values for the studied traits ranged from 105 to 120 days for days to 50 % flowering, 88.6 to 116.3 cm for plant height, 8 to 14.3 for number of tillers per plant, 8.4 to 15.4 for number of panicles per plant, 158.6 to 299 for number of grains per panicle, 19.7 to 27.7 g for grain yield per plant, 21.3 to 25.6 cm for panicle length, 16.1 g to 24.7 g for thousand grain weight, 69.4 to 85.7 for grain fertility and 5.18 to 7.58 t ha^{-1} for grain yield (Table 3). The highest and the lowest yield was observed in GEN1 (BR (Bio) 8333-BC5-1-1) and GEN8 (BR8523-36-2-2-6), respectively. On the other hand, the longest days to 50% flowering was found in GEN1 (BR(Bio)8333-BC5-1-1) (120 days) and the earlier days to 50% flowering was found in GEN8 (BR8523-36-2-2-6) that was 105 days. Figure 1 shows comparison between days to 50% flowering and yield (t ha^{-1}) of four selected outstanding genotypes along with the check varieties. Among the genotypes, GEN2 (BR(Bio)8333-BC5-1-20), GEN3 (BR(Bio)8333-BC5-2-16), GEN4 (BR(Bio)8333-BC5-2-22) and GEN5 (BR(Bio)8333-BC5-3-10) produced 0.84 to 1.67 t ha^{-1}, 0.92 to 1.75 t ha^{-1}, 0.82 to 1.65 t ha^{-1} and 0.79 to 1.62 t ha^{-1} higher compared to the check varieties BR16 (6.56 t ha^{-1}), BRRI dhan28 (5.83 t ha^{-1}), BBRI dhan58 (6.66 t ha^{-1}) and BRRI dhan29 (6.21 t ha^{-1}), respectively (Fig. 1).

Table 2. Genotypic variations of the yield contributing traits in 16 rice genotypes.

Source of variation	DF	50F	PH	TILL	PP	GP	GYP	PL	TGW	F (%)	Yd
Genotype	15	60.2**	129.6**	12.1**	12.7**	6596.6**	19.2**	4.4**	13.9**	87.7**	1.67**
Rep	2	0.3^{NS}	16.6^{NS}	2.1^{NS}	1.5^{NS}	1234.8^{NS}	0.5^{NS}	1.8^{NS}	25.5^{NS}	18.6^{NS}	0.1^{NS}
Error	30	1.1	6.1	0.6	2.8	908.2	1.6	1.1	6.7	28.5	0.1
Mean		114.0	102.3	11.0	11.8	233.2	23.4	23.6	20.1	79.2	6.7
CV%		0.92	2.42	7.11	14.07	12.93	5.33	4.40	12.92	6.75	4.35

** indicate significantly different at 1%, NS= Non significance. CV denote co-efficient of variation. Indicators: 50F= days to 50% flowering, PH= plant height (cm), TILL= number of tillers per plant, PP= number of panicles per plant, GP= grains per panicle, GYP= grain yield per plant (g), PL= panicle length (cm), TGW= thousand grain weight (g), F (%) = fertility (%) and Yd= yield (t ha^{-1}).

Table 3. Mean comparison of different traits of the genotypes through Tukey's Honest Significant Difference (HSD).

Code	50F	PH	TILL	PP	GP	GYP	PL	TGW	F (%)	Yd
GEN1	120a	102.3ce	9.6gh	11.8a-d	225.6a-f	20.8ef	22.9a-d	18.7ab	83.0ab	7.10a-c
GEN2	117ab	104.3b-d	9.3g-i	11.1a-d	215.0b-f	21.8d-f	23.3a-d	20.1ab	83.5ab	7.50ab
GEN3	116bc	102.0c-e	9.3g-i	11.8a-d	204.3c-f	22.0d-f	23.0a-d	20.5ab	83.1ab	7.58a
GEN4	118ab	106.3bc	8.0i	13.2a-d	227.0a-f	22.1d-f	23.6a-d	21.2ab	81.9ab	7.48ab
GEN5	117ab	111.0ab	9.3g-i	15.1ab	271.0a-e	21.9d-f	23.7a-d	18.8ab	81.6ab	7.45ab
GEN6	110de	104.6bd	12.6b-d	8.4d	158.6f	25.2a-d	25.6a	21.5ab	70.2ab	6.51c-e
GEN7	112d	95.6e-g	14.0ab	10.2b-d	186.6e-f	23.8b-e	24.6a-c	18.1ab	76.3ab	6.40c-e
GEN8	105g	116.3a	8.6hi	10.2b-d	195.6d-f	19.7f	24.6a-c	19.9ab	74.7ab	5.18g
GEN9	118ab	92.3fg	14.3a	8.9cd	171.3f	24.7a-d	23.5a-d	24.7a	78.2ab	6.58ce
GEN10	113cd	102.6c-e	12.0c-e	13.1a-d	299.0ab	20.5ef	23.5a-d	16.1b	77.3a-d	5.40fg
GEN11	112de	98.6d-f	11.3d-f	13.8a-c	287.0a-d	27.2ab	23.9a-d	20.5ab	85.5a	7.10a-c
GEN12	116bc	88.6g	10.6e-g	10.6a-d	219.3b-f	26.8a-c	21.3d	23.0ab	77.6a-d	7.06a-d
GEN13	113cd	104.6b-d	13.3a-c	15.4a	288.0a-c	27.7a	24.1a-d	16.9ab	72.5cd	7.19a-c
GEN14	106fg	102.3c-e	10.3fg	10.2b-d	225.3a-f	21.5d-f	21.6cd	20.8ab	85.7a	5.83e-g
GEN15	109ef	102.0c-e	10.3fg	13.3a-d	315.6a	26.0a-c	22.4b-d	20.0ab	85.3a	6.66b-e
GEN16	118ab	103.3cd	13.3a-c	11.4a-d	240.6a-f	23.3c-f	25.4ab	20.0ab	69.4d	6.21d-f
Maxi.	120	116.3	14.3	15.4	299.0	27.7	25.6	24.7	85.7	7.58
Mini.	105	88.6	8.0	8.4	158.6	19.7	21.3	16.1	69.4	5.18
$LSD_{0.05}$	1.64	3.96	1.25	2.63	48.76	1.96	1.66	4.15	8.45	0.46

Mean with the same letter in a column are not significantly different each other at 0.05 % probability level. GEN=Genotypes, Maxi.=Maximum, Mini.=Minimum and LSD=Least Significant Difference . Indicators: 50F= days to 50% flowering, PH= plant height (cm), TILL= number of tillers per plant, PP= number of panicles per plant, GP= grains per panicle, GYP= grain yield per plant (g), PL= panicle length (cm), TGW= thousand grain weight (g), F (%) = fertility (%), and Yd= yield (t ha^{-1}).

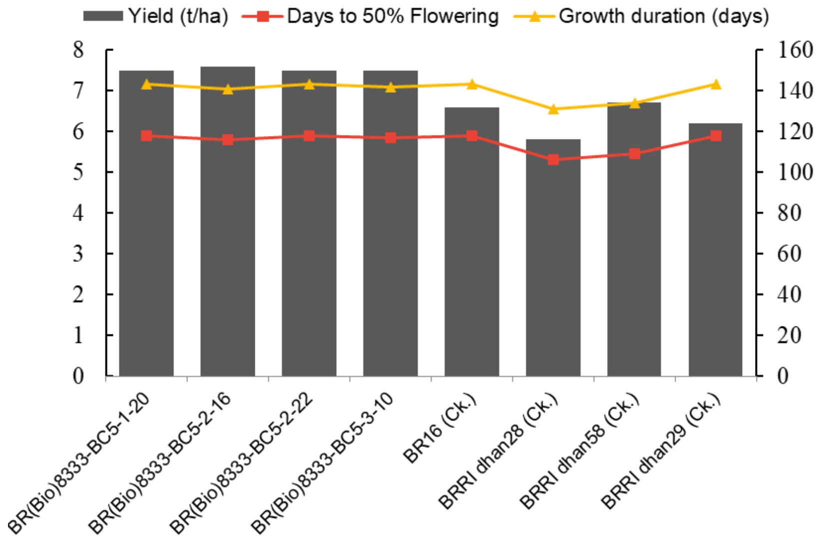

Fig. 1. Comparison between days to 50% flowering and yield (t ha^{-1}) of four selected outstanding genotypes along with four checks.

Correlation analysis

Out of ten characters, only three viz. days to 50% flowering, number of panicles per plant and grain yield per plant showed significantly positive correlations with the grain yield (Table 4).

Table 4. Pearson correlation coefficients among the yield contributing traits using genotypes means

Particulars	50F	PH	GYP	TILL	PP	GP	PL	TGW	F (%)
PH	-0.283	1							
GYP	-0.005	-0.431**	1						
TILL	0.011	-0.437**	0.438**	1					
PP	0.124	0.191	0.098	-0.217	1				
GP	-0.037	0.118	0.138	-0.115	0.692**	1			
PL	-0.013	0.262	-0.093	0.317*	-0.065	-0.165	1		
TGW	0.075	-0.227	0.129	0.061	-0.582**	-0.371**	-0.026	1	
F (%)	0.012	-0.058	-0.125	-0.425**	0.301*	0.202	-0.444**	0.008	1
Yd	0.606**	-0.124	0.393**	-0.242	0.301*	0.041	-0.212	0.071	0.232

** and * indicate significantly different at 1% and 5% respectively, NS: Non-significance Indicators: 50F= days to 50% flowering, PH= plant height (cm), TILL= number of tillers per plant, PP= number of panicles per plant, GP= grains per panicle, GYP= grain yield per plant (g), PL= panicle length (cm), TGW= thousand grain weight (g), F (%) = fertility (%) and Yd= yield (t ha^{-1}).

Correlation coefficients between different agronomic traits and grain yield have shown explicitly in Fig 2. Plant height and panicle length had shown negative and non-significant correlation with grain yield. However, grains per panicle, thousand-grain weight and spikelet fertility percentages showed non-significant but positive correlation with grain yield. Days to 50 % flowering exhibited negative and non-significant correlations with plant height. Number of tillers per plant showed positive and significant correlation with grain yield per plant and panicle length. Number of panicles per plant exhibited positive and significant correlation with grains per panicle and percent spikelet fertility. Significantly positive correlation was observed between number of panicles per plant and percent spikelet grain fertility.

DISCUSSION

Genetic variability

Highly significant genetic variations ($P \leq 0.01$) suggested that the studied genotypes had considerable variability for effective selection. The minimum days to 50 % flowering was (105 days) observed in GEN8 (BR8523-36-2-2-6), while the maximum value (120 days) was recorded in GEN1 (BR(Bio)8333-BC5-1-1). Among the tested entries, GEN1 (BR(Bio)8333-BC5-1-1) showed significant difference from the checks BRRI dhan28 and BRRI dhan58. Weiya *et al.,* (2008) also observed variations in heading days among several genotypes and they identified a regulatory gene responsible for this variation. Therefore, it is suggested that these lines should be further studied to confirm their consistent performance. The minimum plant height (88.6 cm) was recorded in GEN12 (BR8626-10-5-1), while maximum plant height (116.3 cm) was observed in GEN8 (BR8523-36-2-2-6). Hussain *et al.,* (2005) reported that transplantation time, water and soil condition, planting and sowing method affect plant height in rice. In case of delayed planting in photosensitive rice, plant height is also influenced by different sets of planting time (Biswas *et al.,* 2019).

The minimum tillers per plant (8.0) were produced by rice genotype GEN4 (BR (Bio)8333-BC5-2-22). The GEN9 (Check BR16) produced maximum (14.3) number of tillers per plant. This observation was supported by Zahid *et al.,* (2005), who studied twelve genotypes of coarse rice to check their yield performance and reported highly significant variation for different traits including the number of productive tillers per plant, which is an important yield component in rice.

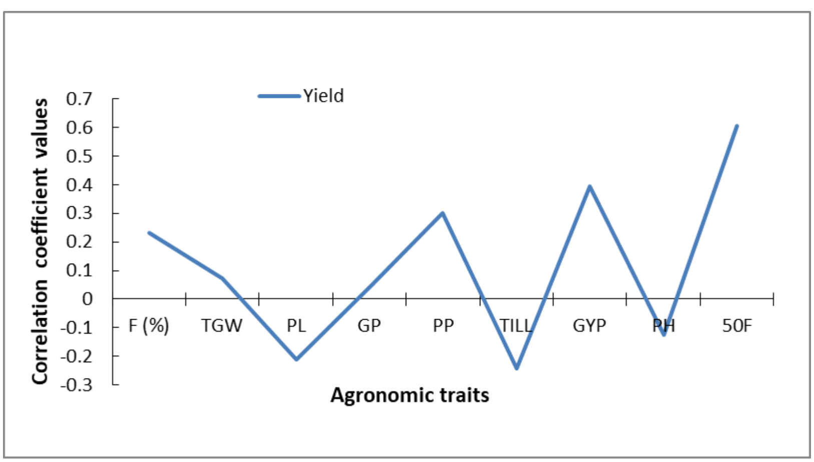

Fig. 2. Correlation coefficients between different agronomic traits and grain yield.

Minimum number of panicles was found in GEN13 (BR8109-29-2-2-3) and maximum in GEN6 (BRC266-5-1-1-1). The least number of filled grains per panicle was observed in the genotype GEN6 (BRC266-5-1-1-1), while the maximum was in GEN10 (BR7671-37-2-2-37-3-P3). Tahir *et al.*, (2002) reported highly significant variation for the grains per panicle for different genotypes.

Minimum grain yield per plant (19.7 g) was recorded in GEN8 (BR8523-36-2-2-6) and maximum (27.7 g) was recorded in GEN13 (BR8109-29-2-2-3). The shortest panicle length (21.3 cm) was recorded in GEN12 (BR8626-10-5-1) while the longest panicle length (25.6 cm) in GEN6 (BRC266-5-1-1-1). Ifftikhar *et al.*, (2009) studied genetic variability for various traits and found that this trait is under the genetic control and could be used in the selection process of some desirable traits.

Minimum thousand grain weight (16.1 g) was recorded by GEN10 (BR7671-37-2-2-37-3-P3), while maximum (24.7 g) were recorded by GEN9 (check BR16). The findings are in with Tahir *et al.*, (2002), who reported highly significant variation among different traits and observed that these traits are under the control of genotypic difference among the genotypes.

Minimum (69.4) and maximum (85.7) grain fertility percentage were recorded in GEN16 (BRRI dhan29) and in GEN14 (BRRI dhan28), respectively. The highest grain yield (7.58 t ha^{-1}) was recorded by GEN3 (BR(Bio)8333-BC5-2-16), while the lowest (5.18 t ha-1) was recorded by GEN8 (BR8523-36-2-2-6). The same variability was reported by Zahid *et al.*, (2005), who studied twelve genotypes of coarse rice to check their yield performance and reported highly significant variation for different traits. This variation in the grain yield might be due to the environment (Mahapatra, 1993) or the correlation of grain yield per plant with various yield contributing characteristics like; fertility of soil, flag leaf area, number of grains per panicle and grain weight.

Days to 50% flowering of selected four genotypes were 10-12 and 7-9 days longer than the check varieties BRRI dhan28 and BRRI dhan58, respectively, but similar in days to 50% flowering with the check varieties BR16 and BRRI dhan29 (Fig 1).

Correlation analysis

The association between days to 50% flowering and yield was significant and positive, which means that the late maturing variety produced higher yield. Positive relation of grain yield with panicles per plant was reported by Zahid *et al.,* (2005) and Golam *et al.,* (2011). Zahid *et al.,* (2005) studied 14 genotypes of basmati rice and reported that plant height has negative correlation with yield. Golam *et al.,* (2011) and Kim *et al.,* (1999) reported positive contribution of grains per panicle towards grain yield, which is agreement with the present findings. Eidi-kohnaki *et al.,* (2013), Haider *et al.,* (2012), Kiani and Nematzadeh (2012), Seyoum *et al.,* (2012), Akinwale *et al.,* (2011) reported the positive association of grain yield with filled grains per panicle. Prasad *et al.,* (2001) observed that a day to 50 % flowering was negatively correlated with plant height, which supported the present study. It was observed that plant height showed significantly negative correlation with grain yield per plant and productive tillers per plant which was supported by Prasad *et al*., (2001). Rasheed *et al.,* (2002) reported a positive association between fertility percentage and grain yield per plant.

CONCLUSION

In this study, sixteen Boro rice genotypes showed extensive variability for yield and yield related traits. Correlation analysis revealed that three agronomic traits such as number of panicles per plant (0.301), 50% flowering (0.606) and grain yield per plant (0.393) had the significantly positive contribution to grain yield. The number of panicles per plant showed significantly positive correlation with grains per panicle and spikelet fertility percentages. Though the growth duration of GEN2 (BR(Bio)8333-BC5-1-20), GEN3 (BR(Bio)8333-BC5-2-16), GEN4 (BR(Bio)8333-BC5-2-22) and GEN5 (BR(Bio) 8333-BC5-3-10) genotypes were longer but possessed 0.79 to 1.75 t ha^{-1} higher grain yield than the check varieties (BR16, BRRI dhan28, BRRI dhan29 and BRRI dhan58). Therefore, these genotypes were identified as high yielders among all genotypes. The gathered information can be useful for rice research and the selected rice genotypes can be used as potential breeding materials for variety development or use in the breeding program as parents after further evaluations in multi-locations in Bangladesh.

AUTHORS' CONTRIBUTION

SKD and RFD generated idea; SKD, MI and RFD coordinated the experiment/research/ project; SKD, MI, and RFD developed methodology; SKD, MK and MMEA provided scientific insights; SKD and RFD gathered data; SKD and MMEA carried out analysis and synthesis; SKD, MK, and MMEA did the writings all versions of the manuscript; SKD, MK, MMEA and TLA performed critical review and editing; All authors read and approved the final manuscript

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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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Assessing the Effectiveness of Rice Procurement Programme and Farmers' Profitability in some Selected Areas of Bangladesh

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ABSTRACT

Using cross-sectional data obtained through carrying out a sample survey conducted during 2018, we examined the perception of farmers and millers about the paddy and rice procurement system and its feasibility. A probit model was employed to ascertain the factors influencing the likelihood of participating in the procurement system by farmers from two districts of Bangladesh. The results showed that the government procurement system has significant impacts on both the participant farmers and millers. The farmers and millers' net profit was TK 4,205 and TK 3,930 by selling a ton of paddy and cleaned rice, respectively, to the procurement center rather than in the local market. The probit regression analysis revealed nine different factors that significantly influenced farmers' participation in the paddy procurement programme. Results further implied that educated farmers had procurement cards with sufficient system knowledge, residing near the hub with improved road access, and association with political parties get preference in participating in the programme. The findings also indicate that lucrative prices, programme scheduling and good conduct of procurement employees inspire farmers to participate in the programme. The government procurement programme has several drawbacks such as anomalies in selecting farmers, taking extra paddy by the employees, corruption, unsuitable payment system, and procurement capacity. Therefore, the government would be vigilant to ensure that the procurement system will provide farmers with price support. A well-functioning procurement system is crucial for guaranteeing the country's food security by ensuring a fair price for the producers. Finally, the study proposed some policy guidelines based on the findings to establish a sound paddy and/or rice procurement system in Bangladesh.

Key words: Food security, procurement, factors affecting, profitability, probit model

INTRODUCTION

Bangladesh is on the verge of commercial agriculture and, in the face of rapid population growth. It is urgently trying to increase agricultural production where food security and livelihood depend heavily on agriculture and agricultural products. Therefore, the Bangladesh government is steadily pursuing agricultural policies to sustain food self-sufficiency and enhance the farmers' financial condition towards achieving the target of sustainable development goals (SDG). In Bangladesh, rice production dominates the agricultural sector by covering about 75 percent area and contributing in the national economy about 4.5 percent of total gross domestic product (BBS, 2018; BER, 2018). During 2018-19, about 77 percent of the total cropped area was covered by rice when the entire production reached 36.39 million tons, which enabled a surplus of 4.2 million tons (BBS, 2019; MoA, 2019). As rice is synonymous with food in the country, sustaining its production will lead the country to achieve food security.

On the other hand, with the increased rice production, there are wider price fluctuations at the harvesting and immediately after the harvesting period, making the price level of the food market unstable and volatile. Besides, the price hike of rice at the downstream part of the supply chain has imperative implications on consumption and nutritional intake, especially on low-income consumers of Bangladesh. As a

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whole, this group of the population spend their large share of the budget on food purposes. Furthermore, it's a major challenge of the government to balance the interest of producers and consumers. To tackle this problem, the government of Bangladesh formulated a food procurement policy to ensure an encouraging price for the producer, maintain food security, and continue supply in the government food distribution system.

The foodgrain procurement system in Bangladesh has a long history. After the introduction of the public food marketing system, the government's food department running the rice procurement campaign to procure rice from the producer. In the sixties, large farmers were involved in the irregular supply of rice at a fixed price normally set by the then government (Ahmed, 1989). In the nineties, the Food Ministry relied on millers for the procurement of paddy and rice. The millers imposed a fixed commission on paddy purchasing from the farmers at the government price and milling the paddy. For a long time, the procurement programme's primary goal was to ensure adequate foodgrains for the public food distribution system (PFDS). From the nineties and onwards, PFDS and price support have become essential for the procurement programme.

The price support worked to ensure a floor price that was declared just before the harvest season, but recently, the scheme has been structured to guarantee farmers an incentive price. The procurement price is now solely related to food grain production costs and declared during the planting season. The current procurement process is said to be inefficient in providing opportunities to the farmers (Rahman *et al.,* 2020). Earlier studies such as Dorosh and Shahabuddin (2002) investigated procurement prices in four years, three of which experienced extremely high procurement rates in *Boro* season. This resulted in higher government costs and windfall income for those who were fortunate enough to sell at the procurement centers. There are also claims that procurement centers often refuse to buy from farmers and collude with millers and intermediaries (Shahabuddin and Islam 1999; Shahabuddin *et al*. 2009). Reza (2001) also assessed the government's *Boro* procurement programme and showed the efficiency of the *Boro* procurement scheme, compared *Boro* paddy market price and procurement price for several years, analyzed the factors involved in the farmers, millers and trader's involvement in the *Boro* procurement programme. In cases between selling rice to procurement centers and selling rice on the market, the study found substantial differences in net returns for farmers and millers. Deb (2008), in his study, showed that there is a fair balance between producer and customer interest in the government procurement programme. Shahabuddin *et al.* (2009) evaluated the efficacy of the domestic procurement system, primarily in terms of farmers' involvement in both the paddy and rice procurement process. Sattar (2011) analyzed the structure and functions of Bangladesh's public food operations, showing the efficiency of the paddy and rice procurement systems. Alam *et al.* (2015) found rising annual household income from the farmers who participated in the programme and noted that government stock and market prices were negatively associated with rice procurement. Alam *et al.* (2017) also examined the effectiveness of *Boro* rice procurement in the Jamalpur district and showed that small and medium-sized farmers' participation was negligible and largely dominated by the politicians. A recent study (Alam *et al.,* 2020) evaluated farm-level stock of rice and the effectiveness of the procurement system. The findings indicated that stocks at the farm level differ positively with growth, and the government stock was negatively correlated with domestic procurement, but the expected delivery was positively correlated with that.

This also indicates that the farmer's annual income has risen due to participating in the procurement programme.

Even though many previous studies focused on the same issue in various locations, they are reviewed to have many sorts of limitations and implemented in different manners. To consider the requirement of policymakers, the present study is a pragmatic attempt to assess the effectiveness of the procurement programme with clear objectives of analyzing the farmers and miller's profitability in *Boro* season; farmer's and miller's perception of the procurement system; perceived constraints related to the procurement programme and the drivers responsible for the farmers participation of the government procurement programme. This research would be useful in deciding if the farmers are pleased or unhappy with the *Boro* paddy procurement of government. If the farmers are satisfied with the paddy procurement programme, in that case, the present analysis will help evaluate the procurement system's efficacy and figuring out the problems, at least in the study region. The study findings would also be helpful for producers, traders, millers and procurement officials, and policymakers in upgrading the government procurement mechanism.

METHODOLOGY

Study area

This study was carried out in two districts of Bangladesh, namely Naogaon and Mymensingh. The study locations were selected purposively based on the surplus in rice production and intensity of well-developed rice mills in the areas. For this study, primary data were collected through carrying out a farm-level survey during May-August 2018.

Sampling procedure and method of data collection

A questionnaire was designed to include open-ended and closed-ended questions for exploring quantitative and qualitative information. A random sampling technique was applied to draw representative samples for this study. The participant farmers and millers were selected from the procurement participants list of Local Storage Depot (LSD) of respected upazila. Non-participant farmers were selected from a comprehensive farmers list collected from the upazila Agriculture Office of concerned upazila. Finally, 250 respondents, out of which 20 millers, 50 participant farmers, and 55 non-participant farmers, were drawn from each district using the random sampling technique (Table 1).

Pre-testing has been performed prior to the final data collection to ensure a sound and effective interview programme. Several inaccuracies were found, and subsequently, some adjustments were made to improve the questionnaire. The researchers reviewed inconsistencies and expressions of undue interest in the findings were reviewed. For analysis, the variables and their forms have been labelled appropriately.

Table 1. Sampling frame.

District	Upazila	Sample category and size			Total sample
		Millers	Participant farmers	Non-participant farmers	
Naogaon	Mohadebpur and Sadar	20	50	55	125
Mymensingh	Muktagacha and Sadar	20	50	55	125
	Total	40	100	110	250

Data analysis and model specifications

Both descriptive and inferential statistics were used in analyzing the data. Average, percentage and differences were the primary descriptive statistical tools employed to show the results comprehensively. The Likert type five scale was used to assess farmers' and millers' perceptions about the paddy and rice procurement system. The collected data were analyzed using Microsoft Excel 2016 and STATA 16.

We aimed to determine socio-economic and demographic variables influencing farmers' willingness to participate in the rice procurement programme through this research. A qualitative response model is appropriate for the farmers' dichotomous nature because the response model relates the probability of an event to various independent variables. The model is also helpful when determining the respondents' characteristics associated with their decisions (Uzunoz and Akcay, 2012). To provide a detailed analysis of the government procurement programme's participation decision, we applied a discrete choice probit model for binary responses (yes, no). Probit analysis is based on the cumulative normal probability distribution. The binary dependent variable takes on the values of zero and one (Aldrich and Nelson 1984). Therefore, the probit analysis can provide statistically significant results to identify the factors influencing the probability of participation in the rice procurement programme.

In the binary probit model, farmers who participated in the procurement programme was taken as 1, while not participated as 0. The $i'th$ farmers are presumed to achieve maximum profit, i.e. preference to enrol in the procurement programme rather than not to participate in the programme. The probability p_i of choosing any alternative over not choosing it can be expressed as in (1), where ϕ represents the cumulative distribution of a standard normal random variable (Greene, 2011):

$$p_i = prob[Y_i = 1|X] = \int_{-\infty}^{x_i'\beta} (2\pi)^{-\frac{1}{2}} \exp\left(-\frac{t^2}{2}\right) dt \text{ .... (1)}$$

$$= \Phi\ (x_{i'}\ \beta) \text{ .... (2)}$$

The relationship between a specific variable and the probability outcome is interpreted employing the marginal effect, which accounts for the partial change in the probability. The marginal effect associated with continuous explanatory variables Xk on the probability $P(Yi = 1 \mid X)$, holding the other variables constant, can be derived as follows (Greene, 2011):

$$\frac{\partial Pi}{\partial x_{ik}} = \phi(x_i'\beta)\beta_k \text{ .... (3)}$$

where ϕ represents the probability density function of a standard normal variable. The marginal effect on dummy variables should be estimated differently from continuous variables. Discrete changes in the predicted probabilities constitute an alternative to the marginal effect when evaluating a dummy variable's influence. Such an effect can be derived from the following (Greene, 2011):

$$\Delta = \Phi(\bar{x}\beta, d = 1) - \Phi\ (\bar{x}\beta, d = 0) \text{ .... (4)}$$

The marginal effects provide insights into how the explanatory variables shift the probability of participation in the procurement programme. Using the econometric software, marginal effects were calculated for each variable.

Factors influencing farmers' attitudes towards participation in the procurement programme may include procurement structure, price, and farmers' social demographic and possible interaction between these factors (Alam *et al.*, 2015). In this paper, we assume that the farmers' socioeconomic and demographic characteristics affected their participation in the procurement programme. The characteristics such as farmers' age, education, knowledge about procurement, their marketed surplus, distance from home to the local market, distance from home to procurement center, communication system (nature of the road), procurement price, having procurement card, appropriate procurement time, manner of officials in the procurement center, presence of corruption, and political affiliation were handled as explanatory variables. Therefore, we treated the variables in the model, which were considered to be statistically significant. Data in Table 2 show the definition of variables and their mean values.

RESULTS AND DISCUSSION

Procurement system

The procurement programme is the only and well-known system for the government or official food grain stock in Bangladesh. Through this system the government, (a) provides humanitarian help during natural disasters, (b) ensures food security by the distribution of food to low-income families, and (c) sustains steady market prices when necessary. The process of collecting, storing, and supplying food grains is costly (Shahabuddin and Shahana, 2014). The ministry of food (MoF) decides the procurement price and the period of procurement. Government procurement centers situated in the country's different areas purchase paddy directly from the farmers and rice from the mill (Rahman *et al.*, 2020). According to the internal food grain collecting policy, all types of farmers have the opportunity to sell paddy at the procurement center, following the government's strict grain standard, and a farmer can sell 120 kg to 3 tons of paddy in a season based on the size of the farm (MoF, 2017). On the other side, millers supplied a set amount of rice, as determined by the government based on their milling ability. The procurement personnel provide weight, price, and stock certificates (WPSC) depending on the characteristics and

Table 2. Summary of the variables used in executing the probit regression analysis.

Variable	Definition	Mean value
Dependent variable		
Farmer's participation in the procurement programme	Dummy: 1= If participant, 0=otherwise	0.48
Independent variable		
Farmer's age	Years	48.71
Education	Years of schooling	4.15
Knowledge about the procurement system	Scored (between 1 - 5)	2.52
Marketed surplus	Amount of paddy in Kilogram (kg)	4836
Procurement price	Dummy of the idea about price: 1= if more, 0= otherwise	0.57
Procurement card	Dummy: 1= having a procurement card, 0= otherwise	0.69
Procurement time	Dummy: 1= for the appropriate time of procurement, 0= otherwise	0.29
Distance to local market	Kilometer (km)	7.35
Distance to procurement center	Kilometer (km)	15.93
Communication system	Dummy: 1= for good connectivity, 0= otherwise	0.55
Political affiliation	Dummy: 1= political affiliation influences selling paddy, 0= otherwise	0.71
Manner of officials	Dummy: 1= if well, 0= otherwise	0.60
Corruption in the system	Dummy: 1= if presence, 0= otherwise	0.49

Source: Analyzed and prepared by the authors' based on the data from the field survey.

make payments to the farmers and millers through banking transactions.

The government aims to reach the procurement target each year, but it has been procuring less than the target for a long time. In Boro season, only 52 and 91 percent of the targeted procurement paddy and rice were met during 1996-2010 (Alam *et al.*, 2015; Sattar, 2011). A disappointing scenario has been observed in Aman procurement, while in the case of Boro procurement, the status is much better. The success of the procurement programme is the achievement of its target (to what extent the new procurement mechanism helps the government to obtain sufficient supplies for its distribution needs); it has been observed that a total of 71 percent of the country's rice procurement has been off-taken domestically (Alam *et al.*, 2015). There are also variations in the rate at which paddy and rice procurement targets are achieved in terms of the goal and real fulfillment of procurement amounts. The cause for this gap could be the lack of knowledge and information, the communication between procurement officials and farmers or millers, the lack of accountability of procurement officers, etc.

Socio-economic and demographic characteristics of rice farmers and millers

Table 3 depicts the socio-economic and demographic profiles of sampled millers and farmers. The average age was found 50 years for millers and 48 years for both participants and non-participants farmers. Approximately 55.00, 54.00, and 57.27 percent of millers, participants and non-participants farmers respectively, were between 21 and 50 years of age, while 45.00, 46.00 and 42.73 percent of the millers, participants, and non-participants farmers respectively were older than 51 years of age. Farmers age plays a crucial function in farming, management practices, and the adoption of modern methods. Many researchers suggest older farmers are more veteran and more familiar with farming processes, capable of handling their inputs more effectively and risk-averting than their younger counterparts. Some researchers claim younger farmers are adopting modern procurement programmes quicker than their older peers, but we haven't seen any substantial gap.

The average household sizes were 4.58, 5.00, and 5.25 for the millers, participants, and non-participant farmers, respectively, which is a bit higher than the average household size (4.50 people) of Bangladesh (HIES, 2016). Farmers' education is also a significant consideration responsible for the success of the government procurement programme. A qualified farmer is capable of collecting up-to-date market information and allows to make a smarter participation decision, which has a positive effect on the procurement programme. Educational attainment was classified into five categories. About 22.00 and 45.45 percent of the participant and non-participant farmers were illiterate. Most of the participants (77 percent) and non-participant (51.82 percent) farmers were primary to higher secondary level educated. On the other side, 75 percent and 25 percent millers were primary to higher secondary level and graduate-level educated, respectively.

The surveyed participant farmers and non-participant farmers had an average farm size of 3.87 acres and 2.01 acres, respectively. About 24, 67, and 9 percent of participants were small, medium and large farmers, respectively. Whereas about 72.73, 21.82 and 5.45 percent of the non-participants were small, medium and large farmers, respectively. Farming is the primary occupation of the 73 percent participant farmers and 81 percent non-participants farmers.

About 15, 72, and 13 percent participant farmers' household annual earning were TK. 50000-100000, TK 100001-250000, and TK 250001

Table 3. Socio-economic and demographic features of the respondents.

Particular	Miller	Participant farmer	Non-participant farmer
Age (%)			
21-30 years	7.50	4.00	3.64
31-40 years	17.50	25.00	25.45
41-50 years	30.00	21.00	28.18
51 and above	45.00	46.00	42.73
Family size (%)			
1-3 person	12.50	7.00	6.00
4-5 person	62.50	59.00	57.00
6 and above person	25.50	34.00	37.00
Education (%)			
Illiterate (0)	-	22.00	45.45
Primary(i-v)	12.50	36.00	36.36
Secondary(vi-x)	25.00	26.00	9.09
Higher secondary(xi-xii)	37.50	12.00	6.37
Graduate and above	25.00	4.00	2.73
Farm classification (%)			
Small	-	24.00	72.73
Medium	-	67.00	21.82
Large	-	9.00	5.45
Occupation (%)			
Farming as primary	-	73.00	80.91
Farming as secondary	57.50	27.00	19.09
Average annual income (%)			
50000-100000 BDT	-	15.00	27.27
1000001-250000 BDT	-	72.00	67.28
250001 and above BDT	100.00	13.00	5.45
Average distance from home/mill to nearby market (km)	2.50	5.91	8.65
Average distance from home/mill to the procurement center (km)	3.70	14.04	17.62
Average quantity of paddy produced by farmers and purchased by millers in Boro season (kg)	2354600.00	9290.00	4835.00
Quantity of paddy/rice supplied to the procurement center in Boro season (kg)	202725.00	2084.00	-
Quantity of paddy/rice sold to the market in Boro season (kg)	1374852.00	4606.00	3152.00
Affiliate of any social organization (%)	73.00	70.0	16.36
Affiliate of any political organization (%)	79.00	67.0	31.81

Note: Small farm (0.05-2.19 acre), medium farm (2.50-7.49 acre), and large farm (7.50 to above). This farm's classification has been obtained from BBS, 2018.

and above, respectively. On the other hand, 27.00, 67.28, and 5.45 percent non-participant farmers were earning TK 50000-100000, TK 100001-250000, and TK 250001 and above, respectively. Whereas the average annual income was above TK 250001 for the millers.

The average distance from home/mill to the local market of the millers, participants, and non-participant farmers were 2.50, 5.90 and 8.65 kilometers, while the procurement center was 3.70, 14.04 and 17.62 kilometers away, respectively. The distance of the procurement center is more from the non-participant farmers' home than the local market. Therefore, distance of the procurement center can be a reason for not participating in the procurement programme. The millers are urban-centered to where they are not far from the market and procurement hub. Participants and non-participating farmers produced an average of 9.29 tons and 4.85 tons of paddy during the Boro season while millers purchased 2354.6 tons of paddy. Millers and participant farmers supplied at the government procurement center on average 202.73 and 2.0 tons of rice and paddy, respectively. In the Boro season, millers supplied 1374.85 tons of rice, and participant and non-participant farmers supplied 4.06 and 3.15 tons of paddy, respectively to the market. Non-participating farmers did not sell their paddy to the procurement hub because they had no procurement card, fewer details, and less expertise. A significant difference has been seen since farmers kept paddy for their family consumption and sold quantities among farmers. On the other side, millers process rice from the purchased paddy and usually obtained 25-28 kg rice from 40 kg paddy.

In general, respondents of this study were engaged as members of various social organizations, such as mosque committees, school boards, cooperative societies, farmer's field schools, professional associations, etc. There are several political parties in Bangladesh, but four or five have been very prominent, getting certain kinds of sub-organizations formed by various types of professionals such as teachers, students, service holders, farmers, businessmen, workers, bankers, and many others. In this study, the definition of the political organization's member is, in certain instances, the follower of governing or rulling political parties. About 79.0, 67.0 and 31.31 percent of the millers, participating farmers and non-participating farmers respectively, were members of different political groups.

Farmers' and millers' perception

Table 4 illustrated the farmers' view of the procurement system. About 56 percent of the participant and non-participant farmers agreed on the procurement price of *Boro* paddy (TK 24/kg) to be reasonable during the survey. The procurement price was considered very low by the other 25 percent of respondents. About 52 percent said the volume of paddy fixed to procure from each farmer was sufficient. Almost a half of the farmers (48 percent) were happy with the scheduling of procurement. The majority of the respondents (48-63 percent) opined that the position of the procurement center and transportation to there are unpleasant to them. Very unfortunately, 58 percent of the respondents expressed that the procurement method is not corruption free. The respondents expressed that they had to pay unlawfully in cash and/or in kind for every quintal of paddy at the procurement centre. Nonetheless, 52 percent of farmers were not fully happy with the payment system for the procurement, whereas 44 percent of the respondents reported that the attitude of the officials was not nice towards the farmer. Approximately 65 percent farmers thought the procurement programme was inconvenient and had a chance to refuse to seller supply paddy at the procurement center.

Table 4. Farmers' perception of government procurement programme.

Selected parameter	Level of perception				
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Paddy procurement price was reasonable	4%	21%	19%	25%	31%
Quantity of paddy procured was reasonable	11%	29%	8%	42%	10%
Timing of paddy procurement was appropriate	11%	18%	23%	32%	16%
Procurement centers located at convenient distance	14%	32%	25%	17%	12%
Transportation to procurement center is easy	24%	39%	16%	18%	3%
Procurement system is convenient	21%	52%	7%	20%	
Mode of payment is appropriate	13%	39%	3%	45%	
Behaviour of labour/officials with farmers is good	5%	39%	8%	48%	
No undue dealings at the procurement center	18%	40%	18%	24%	
Not rejected paddy at procurement center unfairly	11%	54%	7%	20%	8%

Source: Prepared by authors using data from field survey 2018.

Table 5 summarizes millers perceptions regarding the rice procurement system. About 60 percent of the millers said that the procurement price (TK 34/kg) of husked rice was relatively lower in 2018. Most of the millers (79 percent) expressed their satisfaction with the position and transportation to the procurement center as the mills were based on urban areas. Many millers (55 percent) were not happy with the procurement system while some of them (40 percent) acknowledged the system as reasonable. Almost 90 percent of millers said procurement system was not corruption-free and 75 percent expreseed that the behaviour of the procurement officials was not satisfying. On the other hand, Miller (57 percent) claims that when the rice was taken to the procurement center for selling, it was refused to take it without any reason.

Table 5. Miller's perception of the government procurement programme.

Selected parameter	Level of perception				
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Rice procurement price was reasonable	10%	50%		28%	12%
Quantity of rice procured was reasonable	10%	47%	3%	33%	7%
Timing of rice procurement was appropriate	5%	42%	5%	38%	10%
Procurement centers located at convenient distance	10%	13%		48%	29%
Transportation to procurement center is easy	8%	8%	5%	47%	32%
Procurement system is convenient	10%	45%	5%	33%	7%
Mode of payment is appropriate	10%	20%		50%	20%
Behavior of labour/officials with millers is good	35%	40%		20%	5%
No undue dealings at the procurement center	50%	40%	3%	5%	2%
Unfairly rejected rice at procurement center	10%	28%	5%	55%	2%

Source: Prepared by authors using data from field survey 2018.

Production cost and procurement price of *Boro* paddy and rice

Figure 1 presents the cost of production and the procurement price of paddy and rice per kg over the last 12 years. Despite a significant year to year fluctuation, both the cost of production and the procurement prices of paddy and rice have shown increasing trends. This implies a disparity between the rate of increase in the cost of production and the procurement price. The gap between the procurement price and the cost of production for rice in 2009 and paddy in 2013 decreased to the lowest, which suggests that millers and farmers earned lower returns. On the other hand, the price margin for rice in 2008 and paddy in 2015 rose to the highest, implying the higher returns for millers and farmers.

Farmer's costs and returns

How much current procurement programme supports the paddy price and income of farmers in achieving the target of this scheme, the evaluations needed were done, and Table 6 represent the relevant data. The findings indicate that farmers charged the marginally higher cost of selling paddy at the procurement center (Tk 295/ton) than the local market as they had to pay some money to the procurement scruples employees and higher transporting cost to the procurement center. Nevertheless, Tk 4,205 was the net profit of sales per ton of paddy at the procurement center and was far higher than the additional expense. This means that the participant farmers get a 22.16 percent higher return than the non-participant farmers by selling paddy at the procurement center.

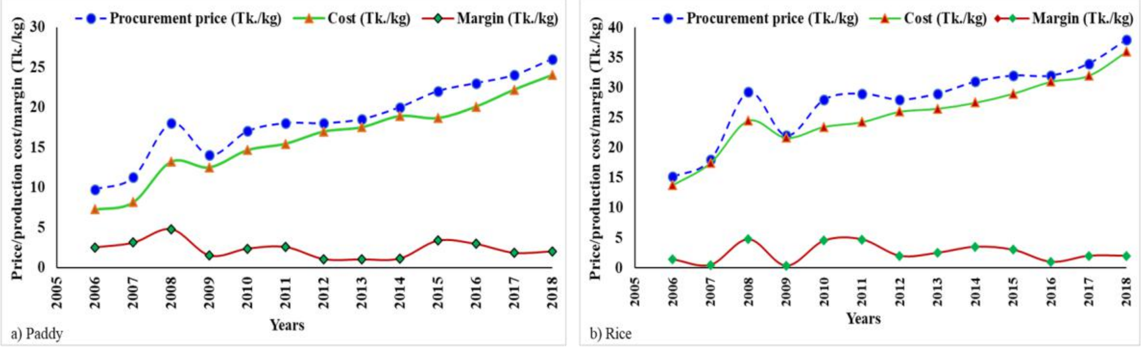

Fig. 1. Procurement price, production cost and margin of paddy and rice in *Boro* season. Source: Prepared by authors using data from field survey, Ministry of Food and Agricultural Economics Division, BRRI.

Table 6. Costs and return of supplying paddy to the procurement center and local market by farmers in 2018.

Particular	Farmers paddy selling point	
	Procurement center	Market
Paddy sold (ton/farm)	2.08	2.08
Gross return (Tk/ton)	24,000.0	19,500.0
Gross return (Tk/farm)	49,920.0	40,560.0
Cost of selling paddy (Tk/ton)	8,20.0	5,25.0
Total cost of selling (Tk/farm)	1,705.6	1,092.0
Net margin (Tk/farm)	48,214.4	39,468.0
Incremental margin of selling paddy (Tk/farm)	8,746.4	-
Incremental margin of selling paddy (Tk/ton)	4,205.0	-

Source: Analyzed and prepared by authors based on data from field survey.

Costs and returns at the millers' level

Millers purchase paddy from farmers and traders, then mill it into rice and ultimately sell rice to the procurement center as per their fixed amount allotted. They are also engaged in crushing the paddy from procurement. The major cost items of supplying husked rice to the procurement center were the transportation of paddy from farm to mills and the processing. Besides, some undue payment to procurement staff was notable. Generally, clean rice can get up to 65 percent after paddy processing, with 35 percent by-products and waste (Singh *et al.* 2014). After processing, the survey millers get a total of 67 percent clean rice. At the miller's level net profit per ton of rice was Tk 3,930 (Table 7).

Factors affecting farmers' participation in the paddy procurement programme

Table 8 represents the results of the estimated binary probit model using the maximum likelihood method. The factors responsible for affecting the farmers' participation at the procurement center for selling paddy were analyzed, and the estimated coefficients and standard errors are depicted in the table. The results of the model indicate that some of the variables had significant effects on the probability of participating in the procurement programme and were in agreement with some of the findings of previous studies.

The empirical result showed that education is an important factor for the farmer in participating in the procurement programme. The marginal effect reveals the likelihood of the farmer's willingness to participate in the procurement programme increased by one percent with the increase of the level of farmers' schooling years. This indicated that the more educated the farmer is, the more willing they are to enroll in the government procurement programme, presumably because the educated farmers can handle information quicker than the others.

Table 7. Costs of and return for supplying rice to the procurement center at the miller's level in 2018.

Item	Taka (BDT.)
Paddy purchasing cost	
Purchasing paddy from market (ton)	19500.0
Cost of bagging and loading of paddy (ton)	330.0
Carrying cost of paddy to mill (ton)	205.0
Paddy processing cost	
Milling and bagging(ton)	1185.0
Transportation cost to procurement center(ton)	150.0
Miscellaneous cost(ton)	50.0
Total cost (ton)	21420.0
Gains from by-product (ton)	2570.0
Price received from the procurement center (ton)	22780.0
Total return (ton)	25350.0
Net profit (ton)	3930.0

Note: Millers get 670 kg rice from 1ton paddy. Paddy was purchased @19.5 TK/kg, and the price of cleaned rice at the procurement center was 34 TK/kg. Source: Analyzed and prepared by authors using data from field survey.

Table 8. Maximum likelihood estimates and marginal probability for the explanatory variables in the probit model (n=210).

Variable	Coefficient	Robust standard error	Marginal effect
Constant	-1.43	1.79	-
Farmer's age	-0.01	0.01	-0.001
Education	0.17***	0.04	0.01***
Knowledge about procurement	0.79***	0.18	0.07***
Marketed surplus	0.00001	0.00003	0.0000001
Procurement price	1.40***	0.40	0.12***
Procurement card	1.15***	0.41	0.10***
Procurement time	1.28***	0.43	0.11***
Distance local market	-0.09	0.14	-0.01
Distance from procurement center	-0.29**	0.13	-0.02**
Communication system	1.06***	0.38	0.09***
Political affiliation	0.81**	0.41	0.07**
Well manner of officials	1.69***	0.41	0.14***
Corruption in the system	-0.26	0.35	-0.02
Log pseudolikelihood		-32.51	
Wald chi^2		103.90	
Prob>chi^2		0.0000	
Pseudo R^2		0.78	

Note: (***), (**) denote significance at the 1%, and 5% levels, respectively. Analyzed and prepared by authors based on data from field survey.

To determine the effects of knowledge about the procurement system on the likelihood of taking part in the procurement programme, the model included the knowledge level of farmers about the procurement system. As expected, the knowledge about the system has a positive and significant effect on participation in the procurement programme. The marginal effect estimation indicates that the probability of participation in the procurement programme would be increased by 7.0 percent in the study areas as knowledge grew. This result is consistent with the findings of the study by Alam *et al.* (2017).

The procurement price is one of the key factors that affect the participation decisions of farmers on the programme. The positive and significant coefficient for procurement price implies that the higher price attracted farmers to sell paddy at the procurement center instead of selling in the market. The marginal effect revealed that the probability of enrolment in the government procurement programme would increase by 12 percent if the procurement price were higher than the price that exists in the local market.

The farmers must need a procurement card to sell paddy at the procurement programme. The coefficient for having/ obtaining a procurement card was positive and significant which implies that the higher the chance of getting a procurement card, the greater the probability of the farmers selling paddy to the procurement programme. According to the model result, marginal effect estimation of the variable indicates that a one percent increase in having/obtaining the farmers' procurement card would increase the probability of participating in the procurement programme by 10%.

Appropriate timing is also a significant consideration for the farmer's participation in the procurement system and shows a positive and significant coefficient. The results of the marginal effect also indicate that a one percent increase in the duration of procurement time would increase the participation of the farmers in the procurement programme by 11 percent in the surveyed areas.

Distance from home to the procurement center also an essential factor to attract farmers in the procurement programme. A negative and significant coefficient of marginal effects indicates that a one percent increasing in the distance from home to the procurement center would decrease the likelihood of farmers becoming interested in the participation of the procurement programme by two percent. A similar explanation has been drawn by Sabur *et al.* (2003).

In addition to distance, better communication facility plays a vital role to fetch the farmers in the procurement programme. The marginal effect of the communication system depicted that one percent increase in good connectivity between farmers home to the procurement center will increase the probability of being farmers' participation in the procurement programme by nine percent. Due to good connectivity farmers' have to incur lower transportation costs, which encourages them to sell paddy even in the long-distance procurement hubs.

Farmers who support a political party usually get the favour of selling paddy at the procurement center. The marginal effect estimation model results indicate that one percent increase in the affiliation with the political party will increase the probability of selling paddy at the government procurement programme by seven percent, which is similar to the findings of Alam *et al.* (2017).

The behaviour of the procurement center officials has a positive effect on farmers' participation in the procurement programme. Marginal effects show that one percent increase in good behaviour of the officials will increase the probability of farmers participating in the procurement programme by 14 percent in the respected study areas.

Farmers perceived constraints of procurements systems

An attempt was made to identify the reasons for not selling paddy by farmers to the procurement center. The major bottleneck of not selling paddy at the procurement center are as follows:

- Despite keeping the grain quality, most farmers are unable to sell paddy at the procurement center, as they are not meeting any unscrupulous undue demand of the officials at procurement center official. Farmers are therefore selling paddy at a cheaper price on the local market. However, the same quality paddy was purchased by the procurement center from local traders, as the traders give a certain percentage of the price as commission to the procurement workers.
- Usually, the paddy price on the day of purchase is not paid to the farmers. Therefore, farmers lose confidence in selling paddy at the procurement center, because they require money to satisfy their immediate needs.

- Both the participant and non-participant farmers reported that the cost of transportation to carry the paddy to the procurement center is too high. This is due to the distance between the homes of the farmers and the procurement center.
- Farmers also stated that procurement workers are strongly biased in providing procurement card among the farmers. They mentioned that elite farmers and those who are politically aligned are given high priority to be enlisted as farmers in procurement. In fact, certain political or elite farmers sell a significant quantity of paddy at procurement centers by sanctioning procurement card named as neighbouring local farmers.
- The list of farmers in the procurement field is not frequently revised. The same farmers, therefore, take advantage of selling paddy at the procurement center.
- Access to sell paddy by tenant farmers at the procurement center is very restricted, as they were unable to display the land registration certificate. This is because the landlords usually do not supply a valid copy of the land registry to the tenants.
- The capacity of government procurement is very limited in Bangladesh. The government is procuring only 5-7 percent of the domestically produced paddy at a reasonable farmgate price (Rahman *et al.* 2020). The rest of the paddy is being purchased, processed and controlled by the private traders. Therefore, one of the procurement's main objectives is that ensuring a fair price for the producers' is not being achieved.

CONCLUSION AND POLICY RECOMMENDATIONS

This study focused on socio-economic and demographic factors affecting farmers' participation in the government procurement programme in the Nagaon and Mymensingh district of Bangladesh. We employed the binary probit model to examine the social and demographic variables. This research showed that the government procurement programme in Boro season has positive impacts on participant farmers and millers. The government paddy purchases as price support, and the demand from other agents push market prices up to favour the rice growers, who usually sell at a lower price during harvest. Through this scenario, the profit comes not just to the participating farmers but also to all growers. Aside from the farmers, millers also get profit by selling husked rice at the procurement center at a rate of Tk 3,930 per ton.

The findings of this research also showed the socio-economic features of the farmers influenced the decision to participate in the procurement programme. The results from the binomial probit model, education, knowledge about procurement, price, procurement card, procurement time, the distance of procurement center, communication system, political affiliation and good behaviour of the officials significantly influenced the participation in the procurement programme. Inadequate quota, anomalies of procurement staff, the undue expectation of scruples procurement staff, strict regulation about quality of paddy and husked rice and payment system, recognized as the drawback of procurement systems.

A well-functioning government paddy procurement system is critical for ensuring the country's food security and increasing farmers' income. The procurement policy implicitly benefits farmers by way of a market mechanism because market prices and procurement prices are positively related. Based on the findings, we outlined some specific recommendations for the improvement of the procurement programme-

- Almost all non-participating farmers indicated that they were not well informed about the public paddy/rice procurement programme's rules and regulations. Therefore, an awareness-raising campaign to build knowledge among farmers would increase their bargaining power, which could increase the involvement of farmers in the programme.

- To ensure the easy participation of farmers in the scheme, a community representative should be selected from village groups of farmers. This will help to have access to the procurement cards and adequate paddy share to sell at the procurement center regardless of the type and political affiliation.
- Forming a triangle link marketing system consisting of farmers, millers and government may ensure fare paddy price for the farmers. In this system, the government procurement price of paddy will be transferred directly to the farmers' 10 Taka bank account. Then, millers will collect the prescribed amount of paddy from the jurisdiction of the farmers. After that, millers will process rice through milling and supply clean rice to the government procurement center. The government will pay the milled rice price (considering the costs of parboiling and transportation) to millers directly. In this regard, a monitoring team can be formed at the upazila level for managing this programme efficiently.
- The capacity of the government procurement should be enlarged so that the system can procure a substantial amount of paddy that can influence the rice market to maintain a reasonable farmgate price of the paddy. In this way, the government procurement programme can make rice production profitable to increase the income of rice farmers.
- Besides, it is necessary to start procuring paddy/rice as early as possible after starting the harvest season. It will influence and increase the participation of the farmers in the procurement programme. It would also push market prices for the support of poor farmers, who normally sell paddy at a lower price during harvesting time.

If this is materialized, the country's rice production will boost up to sustain food security and farmers' income towards achieving the target of SDG.

AUTHORS’ CONTRIBUTION

MSR planned and conceptualized the research, collected data, analyzed data and drafted the manuscript; MARS gave technical guidance, checked the research methods and provided an in-depth manuscript review; MJK provided guidance and comprehensive manuscript review; LD collected data and organized the field activities; MCR offered professional advice on the correct methodology and provided in depth manuscript review; MAI engaged in data analyzing; MABS provided considerable insight into the manuscript. All authors’ perused and accepted the final manuscript.

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DECLARATION OF INTERESTS

Every author accepts and consents to the publishing of the manuscript. The authors declare having no conflicting interests.

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Biological Control of Rice Sheath Blight Disease (*Rhizoctonia solani*) Using Bio-pesticides and Bio-control Agents

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ABSTRACT

A series of experiments were conducted in Plant Pathology Laboratory at Bangladesh Rice Research Institute (BRRI), Gazipur to know the efficacy of four bio-pesticides Recharge, Microtech1, Agroplus and Chitin and two bio-control agents (*Trichoderma harzianum* and *Bacillus subtilis*) on the major rice disease sheath blight (ShB) caused by *Rhizoctonia solani* in *in-vitro* and field condition. One fungicide Nativo (Tebuconazole 50% + Trifloxystrobin 25%) and one disease control (without any treatments) were also included as treatment for comparison. Radial mycelia growth of *R. solani* was mostly inhibited by a Bangladesh *Trichoderma harzianum* (BT1), Recharge and chemical fungicide Nativo 75 G at 48 hours of dual contact of *R. solani* and tested bio-pesticides or bio-control agents in *in-vitro*. The other bio-pesticides along with *B. subtilis* didn't show any inhibition effect on the mycelia growth of *R. solani* which was similar to control (only water) treatment. Fungal inhibition 87.5% and 86.3% of *Rhizoctonia solani* was obtained by Recharge and *Trichoderma harzianum* (BT1), respectively which was nearly similar to the chemical treatment Nativo (96.3%) in *in-vitro* dual culture method compared to control treatment. In net house condition, 74% sheath blight disease was inhibited by soil application of Recharge (0.3 g/m^2 with 50 ml water) for two times at the time of transplanting and 30 days after transplanting (DAT), whereas similar soil application of *B. subtilis* (OD_{600}=0.3) was not found effective to control the ShB disease (< 30% disease reduction). The highest ShB disease was reduced by the chemical control Nativo 75 G (94.2%) followed by BT1 (89%), bio-pesticide Recharge (70.8%), Microtech1 (37.4%) and Chitin (61.3%) compared with the disease control when the tested materials were sprayed for two times (3 days before and 4 days after inoculation).

Key words: Efficacy, bio-pesticide, fungal inhibition, *Rhizoctonia solani*.

INTRODUCTION

Bio-pesticides offer powerful tools to create a new generation of sustainable agriculture products. They are the most likely alternatives to some of the most problematic chemical pesticides currently in use. Bio-pesticides offer solutions to concerns such as pest resistance, traditional chemical pesticides and public concern about side effects of pesticides on the surrounding environment and ultimately on human health. Bio-pesticides are the rich combination of beneficial microorganisms which are vital to soil health as well as pathogen inhibition (Mishra *et al.*, 2015; Sindhu *et al.*, 2016; Islam *et al.*, 2019; Naeimi *et al.*, 2019; Raj *et al.*, 2019).

There are several constraints of rice production and its low yield in Bangladesh. A total of 79 diseases of rice was recorded world-wide (Ou, 1985) and 20 rice diseases was found in Bangladesh and sheath blight was found one of the major diseases of rice (Mian et al. 1983). Among the major rice diseases sheath blight (ShB) caused by the fungal pathogen *Rhizoctonia solani* (*R. solani*) is one of the most economically important diseases in Bangladesh and the world. It is a global rice production constraint incurring economic loss to an extent of 4% annually (Zhong *et al.*, 2007). Sheath blight is becoming as an increasing problem for rice cultivation in Bangladesh for all the three seasons Aus, Aman and Boro (Miah *et al.*, 1985; BRRI, 2018). Sheath blight of rice takes place in all rice growing areas of the world (Ou, 1985; Savary *et al.*, 2006) and may cause up to a 50% decrease in the rice yield under favourable conditions around the world

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(Zheng *et al.*, 2013). Sheath blight caused 14-17% yield loss in different varieties during Aus, Aman and Boro seasons in Bangladesh (Shahjahan *et al.*, 1986). High temperature and relative humidity during crop growth favor development of sheath blight disease, high tillering, short stature and high nitrogen responsive varieties are comparatively more susceptible as the micro climates inside the rice canopy is more favorable than those of the traditional ones of tall plant type with low tillering ability (Miah *et al.*, 1985). Application of fungicides is the major measure for controlling sheath blight of rice for over three decades in Asian countries (Zheng *et al.*, 2013).

Fungal bio-pesticides can be used to control insects, bacteria, nematodes, fungi and weeds (Manoharachary *et al.*, 2014). Mechanism of bio-control varies and depends on both the pesticidal fungus and the target pest. *Trichoderma* secretes enzymes such as chitinolytic enzymes, glucanases, cellulases, and proteases that help in the biological control of plant diseases (Mishra *et al.*, 2015). However, extensive and continuous use of a single chemical may lead to undesirable effects such as residual toxicity and environmental pollution, and also increases the risk of resistance development (Brent and Hollomon, 1998). Therefore, it is necessary to develop environmentally friendly, low residual and effective alternative methods for the management of sheath blight (ShB) disease.

Cultural practices, chemical and biological control, disease forecasting, host genetic resistance, typically major gene resistance are commonly used for controlling ShB. But cultural practices are not found effective in all locations and its efficacy mainly depends on disease incidence records. Agrochemicals and their behaviour of natural degradation harm the environment, causing major ecological and health problems. An eco-friendly and sustainable crop production in agriculture is possible by using bio-pesticides, a formulated product using bio-control agents. The use of biological agents has not widely popular for controlling ShB even though biological control is an environmentally friendly and cost-effective substitute to chemical. Now-a-days, the use of antagonistic bacteria as biological control is considered as the best alternative way to reduce the application of chemicals in field (Yang *et al.*, 2007; Misk and Franco, 2011; Raj *et al.*, 2019).

The extensive use of synthetic organic chemicals in the past decades has led to a number of long-term environmental problems (Arora *et al.*, 2012). Chemical fertilizers and pesticides are continuously accumulating in the environment, harming the ecosystem, causing pollution, and inflicting diseases at alarming levels (Gerhardson, 2002; Arora *et al.*, 2010). The heavy use of pesticides has already caused grave damage to health, ecosystems, and groundwater. Therefore, this study was undertaken to know the efficacy of environment friendly bio-pesticides along with bio-control agents against one of the major rice disease sheath blight.

MATERIALS AND METHODS

The experiments were conducted at Plant Pathology Division, Bangladesh Rice Research Institute (BRRI) during 2016-17. Three bio-pesticides namely Recharge (Russel IPM, UK), Microtech (*B. subtilis*) and Chitin; two bio-control agents *Trichoderma harzianum* (BT1) and *Bacillus subtilis*; one chemical Nativo were tested in the experiments.

Recharge is a rich combination of beneficial soil microorganisms (*Glomus* spp, *Bacillus* spp. *Trichoderma* spp.) which are vital to soil health. The application of Recharge vitalizes the soil and restores its ability to function properly by providing vital background protection to the crop from invasive pests and diseases. Recharge only puts back what the soil has already lost due to excessive pesticide applications. Recharge is a new product came from Russel IPM, UK for field evaluation in Bangladesh. The other three bio-pesticides Microtech1 (*Bacillus subtilis*), Agroplus and Chitin were supplied by different pesticide companies of Bangladesh.

Two bio-control agents *Trichoderma harzianum* (BT1) isolated from rhizosphere of rice plant and *Bacillus subtilis* was derived from *Datura metel* seed extract (Wang *et al.*, 2018). A commonly used effective fungicide Nativo 75 G (Tebuconazole +Trifloxystrobin) of Bayer Crop Science was used as standard chemical control treatment to compare the efficacy of bio-pesticides or the bio-control agents following the method of Groth (2005).

Isolation of *R. solani*. The test pathoges *R. solani* was isolated from the infected sheath. Infected sheath samples were cut off with a pair of sterilized scissors, kept in a sterilized polyethylene bag and brought into the laboratory for microscopic study and isolation work. The fungus was isolated from infected parts of the rice plants following tissue planting method (Bashar *et al.*, 2010). Sheath blight infected sheath with culm was cut into small pieces (5-6 mm) with the help of sterilized scissors. The cut pieces were washed with sterile water for two minutes and then surface sterilized by 5% Clorox for 2-3 minutes. Finally, these pieces of sheath were washed with sterile water for 2-3 minutes and were dried on sterile tissue paper. The dried samples were placed on potato dextrose agar (PDA) plate and incubated for seven days at room temperature (25±2 ^{o}C). The isolate was purified by the hyphal tip method which consists of cutting the hyphal tip of a growing mycelium. Fungus was identified based on mycelial growth, colony character, sclerotia formation and sclerotial size. The fungal strain was stored on PDA medium at 4°C.

The experiments were conducted both in *in vitro* and also in net house conditions to confirm the efficacy of the treatments.

***In-vitro* experiment.** *In-vitro* experiment was conducted in the Plant Pathology Laboratory, BRRI, Gazipur. The treatments were T1: *Trichoderma harzianum* (BT1) @ OD600=1, T2: Microtech1 containing *Bacillus. subtilis* @ 20 µl/ml, T3: *B. subtilis* @ OD600=1, T4: Agroplus @ 20 µl/ml, T5: Recharge (*Glomus* spp, *Bacillus* spp. and *Trichoderma* spp.) @ 20 mg/ml, T6: Chitin @ 20 µl/ml, T7: Nativo 75 G @ 20 mg/ml as a chemical control and T8: Control (only water). The *in vitro* antagonistic assay was performed according to the dual culture method (Wang *et al.*, 2018) on PDA medium. Bio-pesticides and chemical @ 0.3% (w/v or v/v) were over lapped (50 µl) on the PDA plates. Then six mm mycelial block of *R. solani* isolated from pure culture was disposed at the center of Petri dishes and incubated at 25±2 ^{o}C for 2-3 days. The antagonistic activity of the bio-pesticides was estimated by the inhibition of the fungal growth in comparison to a solely cultivated fungal agar disk. The fungal growth was monitored by measuring the diameter in centimeter of the colony. Each treatment was tested in three different plates and the experiment was carried out twice. Effect of bio-pesticides, bio-control agents and chemical on the growth inhibition of *R. solani* over control treatment was calculated as percent inhibition using the following formula reported by Satish *et al.*, 2007 and Dubey *et al.*, 2009.

Fungal growth inhibition% = (C-T/C)×100, Where C = *R. solani* growth in the control treatment, T = *R. solani* growth in the bio-pesticide or bio-control agent or chemical treatments.

Net house experiments. These experiments were conducted to know the efficacy of some bio-pesticides and bio-control agents on sheath blight (ShB) disease of rice in net house condition using soil application, root dipping and spray methods. Two seedlings of test variety BR11 were transplanted maintaining three hills per pot. Three methods namely soil application, root dipping and spray were used for treatments application. In soil application and root dipping method, the treatments were T_1 = Recharge (0.3 g/m^2 with 50 ml water) by soil application at two times; 0 days after transplanting (DAT), 30 DAT, T_2 = Root dipping with Recharge (0.3 g/m^2 with 50 ml water) of seedlings for 30 min, $T_3 = T_1 + T_2$, T_4 = *Bacillus subtilis* (*Bs*) (OD_{600}=0.3) by soil application at two times (0 DAT, 30 DAT), T_5 = Root dipping of seedlings for 30 min with *Bs* (OD_{600}=0.3), $T_6 = T_4 + T_5$, T_7 = Control (without Recharge or *Bs*. Artificial inoculation of ShB was done at 60 days after transplanting (DAT) in plants. *Rhizoctonia solani* was cultured on PDA medium and incubated at 26-28 ^{o}C. After 7-10 days of incubation upto sclerotia formation, the inoculums were placed on the beneath of the rice plant into the sheath.

In spray method, bio-pesticides and others were applied by spraying at maximum tillering stage. The bio-pesticides along with chemical were sprayed at three days before inoculation and 4 days after inoculation @ 3% w/v or v/v. Spray was done both as preventive and curative. Percent disease reduction was calculated over diseased control treatment. The bio-pesticides, bio-control agents along with chemical fungicide were sprayed at three days before inoculation and four days after inoculation @ 3% (w/v or v/v) during maximum tillering stage of rice plant. Treatments were Recharge, Microtech1, Agroplus, Chitin, Chemical control (Nativo) and disease control (ShB inoculation but no spray).

Disease assessment. For assessing the percent relative lesion height (RLH) of sheath blight disease, data were taken from nine hills from each treatment following the Standard Evaluation System (IRRI, 2013). Plant height and lesion height were measured at 21 days after inoculation. The percent relative lesion height (RLH) was calculated following the formula:

Relative Lesion Height, RLH (%) = (Lesion height/Total plant height) × 100.

Experimental design and data analysis. The experiments were conducted by completely randomized design (CRD) with three replications. Whenever necessary, the data were distorted before statistical analysis following appropriate methods.

RESULTS

Efficacy of bio-pesticides and bio-control agents in *in-vitro* against *R. solani*

After 24 hours of dual contact, mycelial growth of *R. solani* was very low in *Trichoderma harzianum* (BT1), Recharge and chemical fungicide Nativo 75 WP. Similar and higher growth was observed in other bio-pesticides (Microtech 1, Agroplus, Chitin), *Bacillus* strain and control treatment (Figs. 1 and 3). In the dual contact, the radial growth of *R. solani* was obtained fully at 48 hours in control treatment. The radial growth of the fungus was significantly stopped on the PDA medium-containing BT1, Nativo 75 WP and Recharge Bio-pesticide at 48 hours of incubation (Figs. 1 and 4).

Inhibition of mycelial growth over control. Inhibition of mycelial growth of *R. solani* over control at 48 hours after culturing was calculated. In case of fungal inhibition, highest percent inhibition of mycelial growth of *R. solani* was obtained in the PDA medium containing chemical fungicide Nativo (96%) followed by Bio-pesticide Recharge (87%) and *Trichoderma* strain BT1 (86%) (Fig. 2). Other bio-pesticides (Microtech1, Agroplus and Chitin), *Bacillus subtilis* were not effective for inhibiting mycelia growth of *R. solani* as similar growth of ShB in this treatment was observed with control (no treatment) at 48 hours after dual culture (Figs. 2 and 4). This result suggests that Recharge and BT1 has the effective antifungal activity to *R. solani*, and they showed similar results as like chemical fungicide Nativo 75 WP.

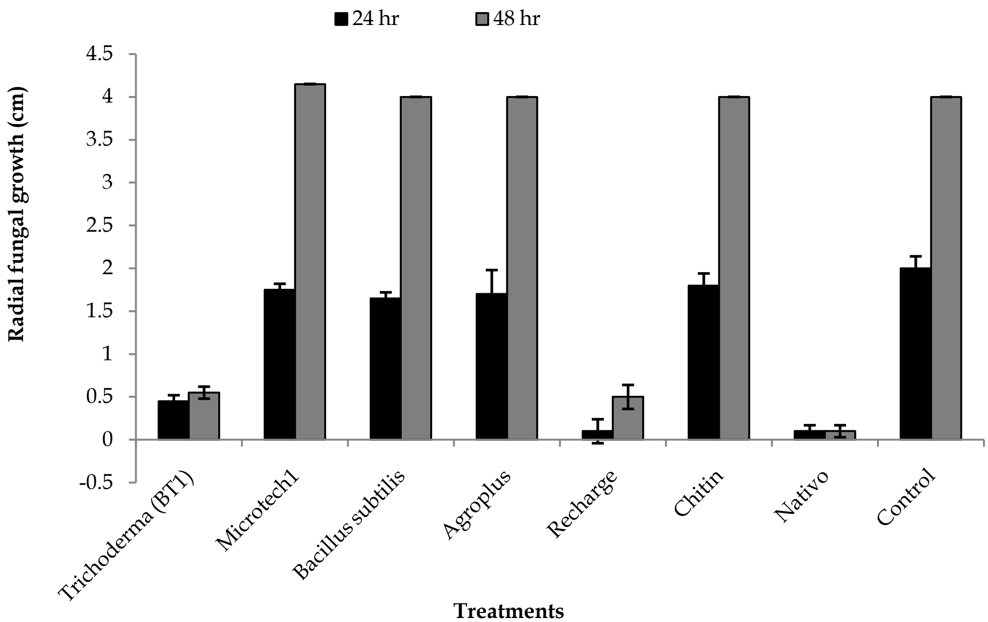

Fig. 1. Mycelial growth of *Rhizoctonia solani* on PDA medium in different bio-pesticides, bio-control agents and chemical fungicide at 24 and 48 hours of direct contact.

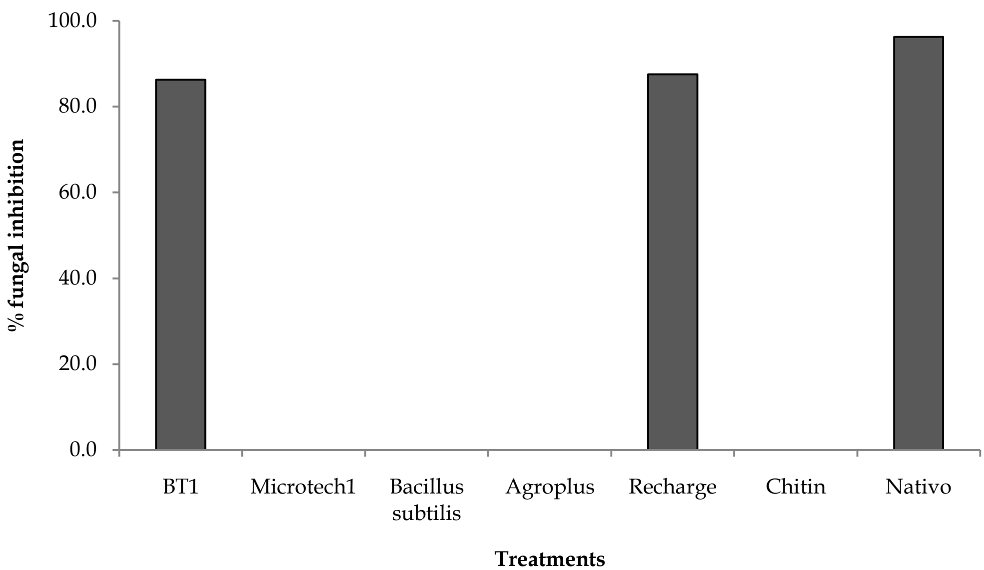

Fig. 2. Inhibitory actions of bio-pesticides, bio-control agents and chemical fungicide over control treatment at 48 hours in *in-vitro*.

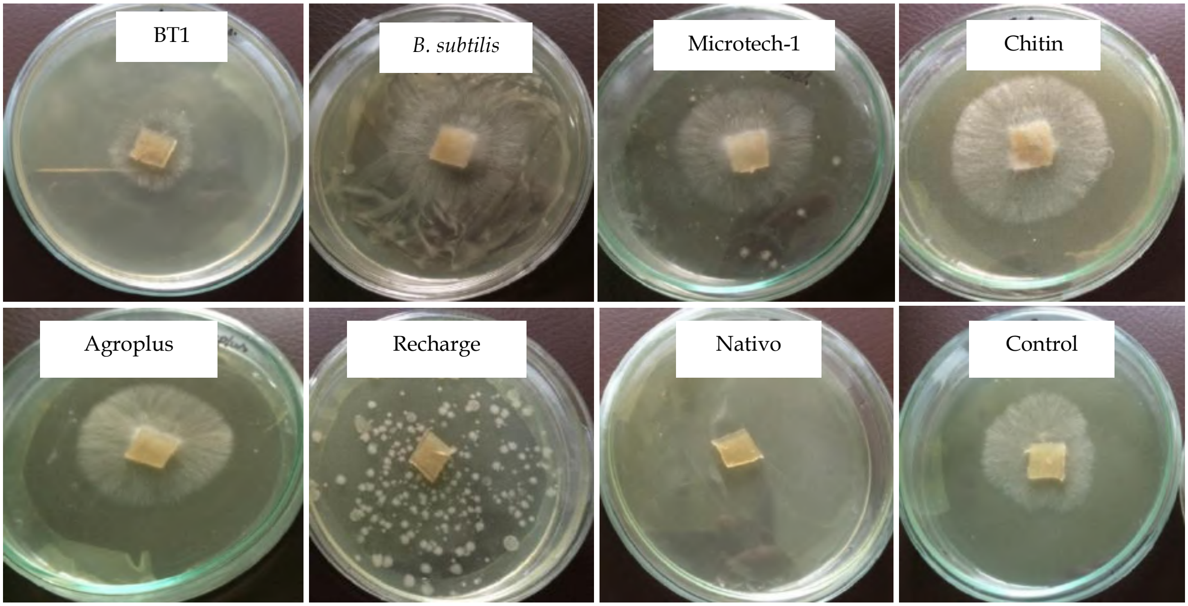

Fig. 3. Dual culture assay of *Rhizoctonia solani* with bio-pesticides, bio-control agents compared to chemical fungicide (Nativo) and control treatment on PDA medium at 24 hours after direct contact.

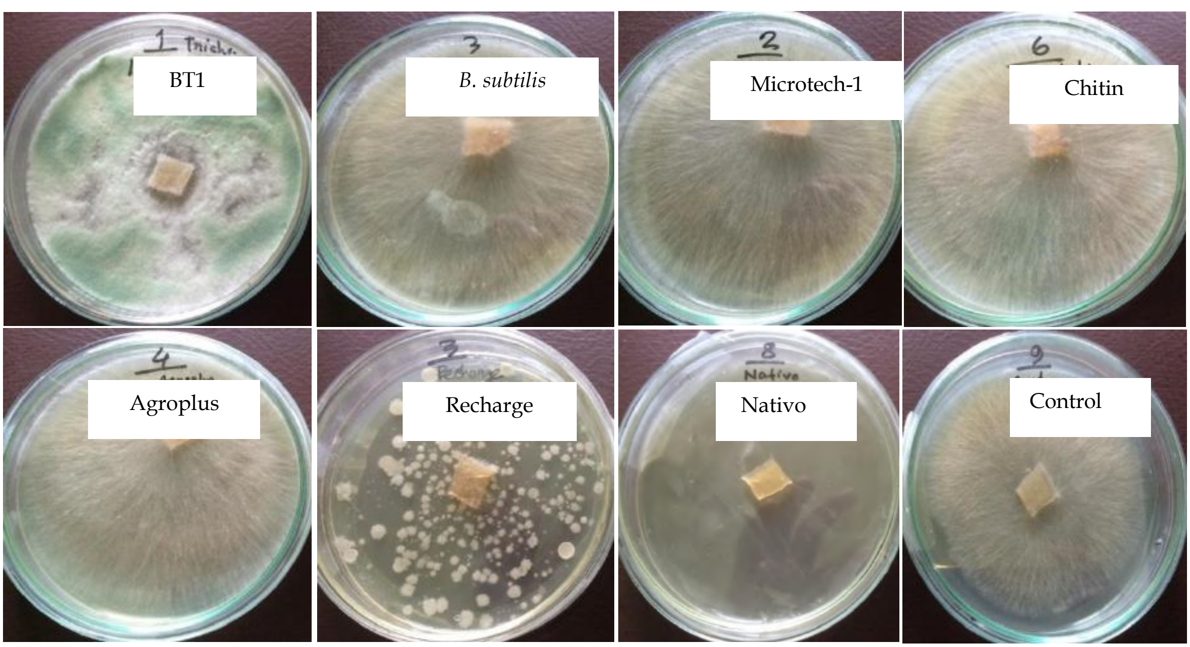

Fig. 4. Dual culture assay of *Rhizoctonia solani* with bio-pesticides, bio-control agents compared to chemical fungicide (Nativo) and control treatment on PDA medium at 48 hours after direct contact.

Efficacy of bio-pesticides in net house condition against ShB disease of rice

Soil application and root dipping method. In this study, one bio-pesticide Recharge was found most effective in *in-vitro* experiment and that's why the effectiveness and appropriate application method of the bio-pesticide were investigated. Sheath blight disease was significantly decreased by the application of Recharge @ 0.3g/m2 in soil for two times during transplanting and 30 days after transplanting (DAT) compared to the other treatments (Fig. 5). Root dipping of the seedling with Recharge was also effective to some extent but not at acceptable level. *Bacillus subtilis* was not found effective on the ShB disease reduction. About 76% disease was reduced over control treatment by soil application of Recharge followed by root dipping (52%) of the seedlings before transplanting (Fig. 6). This result indicates that efficacy of Recharge is more effective by soil application to control sheath blight disease of rice.

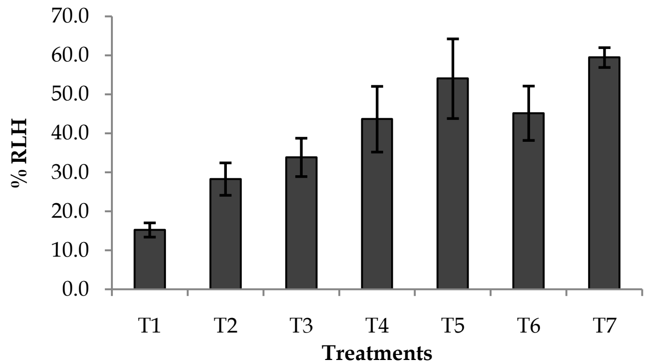

Fig. 5. Efficacy of bio-pesticides and bio-control agents against ShB disease of rice in net house condition by soil application method. % Relative Lesion Height (RLH) of ShB disease showed. T_1 = Use of Recharge (0.3 g/m^2 with 50 ml water) by soil application two times (0 DAT, 30 DAT), T_2 = Root dipping with Recharge (0.3 g/m^2 with 50 ml water) of seedlings for 30 min, $T_3 = T_1 + T_2$, T_4 = *Bacillus subtilis* (*Bs*) (OD_{600}=0.3) by soil application two times (0 DAT, 30 DAT), T_5 = Root dipping of seedlings for 30 min with *B. subtilis*, $T_6 = T_4 + T_5$, T_7 = Control (without bio-pesticides).

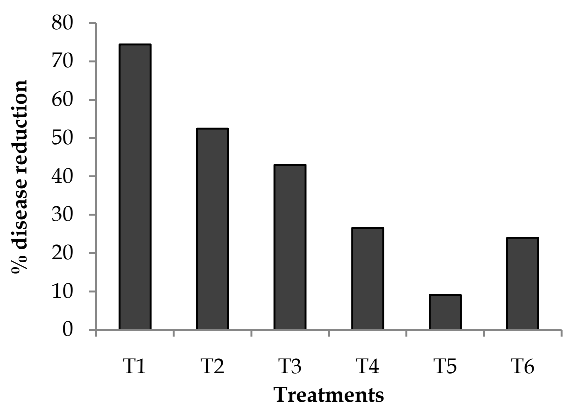

Fig. 6. Percent ShB disease reduction over control treatment in net house condition by application in soil. T_1 = Use of Recharge (0.3 g/m^2 with 50 ml water) by soil application two times (0 DAT, 30 DAT), T_2 = Root dipping with Recharge (0.3 g/m^2 with 50 ml water) of seedlings for 30 min, $T_3 = T_1 + T_2$, T_4 = Use *Bacillus subtilis* (*Bs*) (OD_{600}=0.3) by soil application two times (0 DAT, 30 DAT), T_5 = Root dipping of seedlings for 30 min with *Bs*, $T_6 = T_4 + T_5$, T_7 = Control (without Recharge or *Bs*).

Spray method. After 21 days of inoculation, sheath blight disease was significantly reduced by spraying of *Trichoderma harzianum* (BT1) and recharge (Fig. 7). Disease was mostly controlled by spraying the chemical fungicide Nativo 75 WP. Disease reduction of 89 % was obtained by spraying *Trichoderma harzianum* (BT1) and 94 % by chemical fungicide Nativo 75 WP and 71% disease was inhibited by Recharge over diseased control treatment (Fig. 8). Though the chemical fungicide performed the best but besides the chemicals, Recharge and *Trichoderma harzianum* (BT1) can be the environmentally friendly alternative option of chemicals for controlling ShB disease of rice. Further field experiments with Recharge and formulations of *Trichoderma harzianum* (BT1) are needed in different locations to clarify the present study.

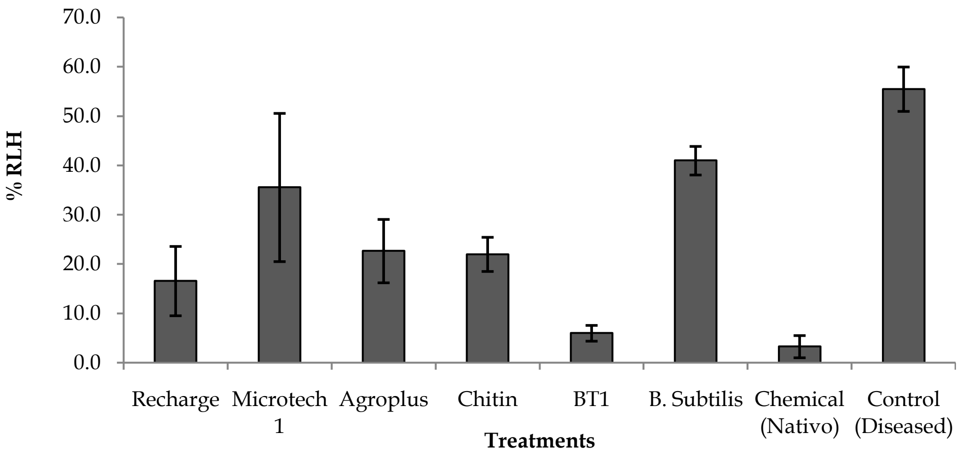

Fig. 7. Efficacy of bio-pesticides and bio-control agents against ShB disease of rice in net house condition by spray method. % Relative Lesion Height (RLH) of ShB disease data were collected during 21 days after inoculation. The bio-pesticides, bio-control agents along with chemical were sprayed at three days before inoculation and four days after inoculation @ 3% w/v or v/v.

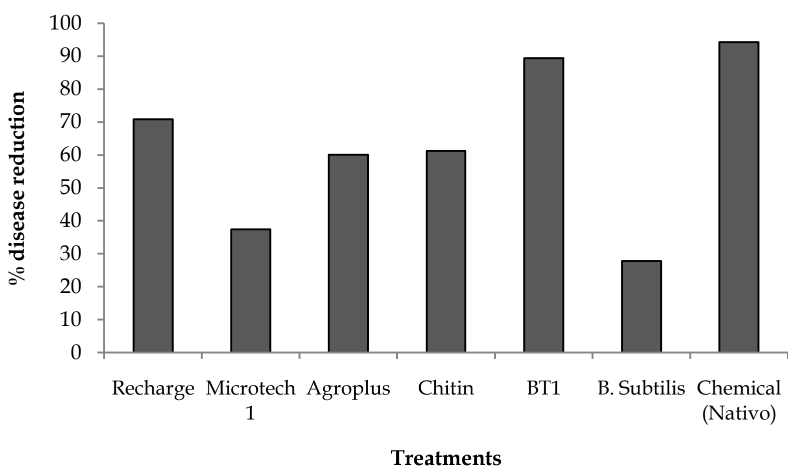

Fig. 8. Percent ShB disease reduction over diseased control treatment in net house condition by spray method. Data of % Relative Lesion Height (RLH) of ShB disease were used for calculating disease reduction over diseased control.

DISCUSSION

Bio-pesticides are potential alternatives to chemical pesticides. Microbial bio-pesticides are living natural enemy organisms and/or their products including plant and microbial products and/or their byproducts and they could reduce pathogen populations. In the present decade, bio-pesticides are widely acceptable and demanded for sustainable agriculture and for production of safe foods. It was significantly considered that, bio-pesticides are eco-friendly, target-specific, easily biodegradable and safer alternatives. Economically, chemical pesticides are very expensive in comparison to bio-pesticides. Many scientists in the world developed and experimentally validated different bio-pesticides and bio-control agents for controlling different diseases including rice diseases (Kazempour, 2004; Chowdhury *et al.*, 2013; Sindhu *et al.*, 2016; Naeimi *et al.*, 2019; Raj *et al.*, 2019).

The biological control of plant diseases is a promising alternative approach to maintaining plant health and promoting crop yield. Several bacterial isolates including *B. subtilis* from soil are effective against the fungal pathogen *R. solani* (Kang *et al.*, 2015; Raj *et al.*, 2019). One UK's Bio-pesticide (Recharge), three Bangladeshi company's bio-pesticides (Microtech 1, Agroplus, Chitin), two bio-control agents (*Trichoderma harzianum* and *Bacillus subtilis*) were tested against one of the major rice diseases sheath blight caused by *Rhizoctonia solani* in *in vitro* and net house conditions and the results were compared with one chemical control and another is control (no treatments, only sterilized water). Bio-pesticide Recharge was found effective antagonist to *R. solani* in *in vitro* and in net house condition. The findings of the present study also supporting by the findings of Hossain *et al.* (2001) and Bashar *et al.* (2010), who showed bacterial isolates exhibited comparatively higher growth inhibition of *R. solani*. Bashar *et al.* (2010) reported that ShB disease development reduced tremendously when antagonistic bacteria treated sclerotia were inoculated. The tested isolates of antagonistic bacteria reduced sheath blight disease development upto 35% over to control.

Elkahoui *et al.* (2012) reported that two bacterial strains, *Bacillus subtilis* and *Bacillus cereus,* showed a clear antagonism against *R. solani* on potato dextrose agar (PDA) medium. Elkahoui *et al.* (2011) also found some bacterial isolates collected from Marine Bio-Films for antifungal activity against *R. solani*. The tested strain of *Bacillus subtilis* didn't show any inhibitory reaction on *R. solani* in the same condition. It might be the differences of the species of *Bacillus* strains. Many researchers reported different bio-control agents effective to control sheath blight causing pathogen *R. solani* (Harman *et al.*, 2004; Jacobsen *et al.*, 2004; Kloepper *et al.*, 2004; Kumar *et al.*, 2009a & 2009b; Peng *et al.*, 2014; Mishra *et al.*, 2015; Shrestha *et al.*, 2016).

Our results also showed that one strain of *Trichoderma harzianum* (BT1) can reduce more than 70% sheath blight disease and similar results was found with the report of Naeimi *et al.* (2019). Sharma *et al.* (2012) also reported that *Trichoderma*-based enzymes (chitin and glucans) are known to show pest resistant activity. Studies concerning commercialization and field applications of integrated stable bio-formulations of *Trichoderma harzianum* (BT1) as an effective bio-control strategy would be needed in future. Recharge bio-pesticide was found comparatively better than the other bio-pesticides tested. The recommended application methods of Recharge Bio-pesticide are soil application and spray method. In order to fully exploit Recharge potential, further studies on field experiments are required to establish it as an effective Bio-pesticide for controlling sheath blight disease along with other major rice diseases.

CONCLUSION

From this study, *Trichoderma harzianum* (BT1) could be suggested as Bio-pesticide with suitable formulation followed by field trial. Bio-pesticide Recharge could also be used as Bio-pesticide for controlling sheath blight disease of rice after some field trial by using soil application as well as spray method. Bio-pesticides can be a satisfactory substitute to the chemical pesticide when used as part of an overall integrated disease management plan. Advances in Bio-pesticide technology like use of beneficial microbes, nanopesticide, encapsulation, Recombinant DNA technology make Bio-pesticide more effective, selective or specific and cause less environmental pollution and less toxic to mammals as compared to conventional pesticides.

AUTHORS' CONTRIBUTION

MMR, MAIK and MAL generated idea; MAH, NH, MMR and MAL coordinated the experiment/research/project; MMR, MAIK and MAL developed methodology; MAH and NH provided scientific insights; MMR, MRB and HAD gathered data and carried out analysis and synthesis; MMR did the writings for all versions of the manuscript; MAL and MAIK performed critical review and editing; All authors read and approved the final manuscript.

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DECLARATION OF INTERESTS

Every author accepts and consents to the publishing of the manuscript. The authors declare having no conflicting interests.

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Elucidation of Genotype × Environment Interaction for Identification of Stable Genotypes to Grain Yield of Rice (*Oryza sativa* L.) Varieties in Bangladesh Rainfed Condition

S K Debsharma[1*], P R Roy[2], R A Begum[2], K M Iftekharuddaula[1]

ABSTRACT

The research was evaluated in seven ecological zones throughout the country following randomized complete block design with three replications in each location. The combined analysis of variance for grain yield indicated that the differences among all sources of variation were highly significant (P<0.01). Environment (E), Genotype (G) and G × E interaction effects explained by 25.54%, 17.02% and 48.97% for inbred and 35.26%, 17.03%, 31.23% for hybrid of the total sum of square, respectively. Locations E2 (Chattogram); E3 (Dhaka) for inbred and E2 (Chattogram); E4 (Khulna); E5 (Rajshahi); E7 (Sylhet) for hybrid varieties were found most discriminating and more informative among all. Ideal environment was found in E6 (Rangpur) for inbred and E4 (Khulna) for hybrid varieties. According to GGE mean and stability biplot, the most stable genotypes were G18 (BRRI dhan34); G26 (BRRI dhan52); G28 (BRRI dhan57); G19 (BRRI dhan37); G13 (BR25); G27 (BRRI dhan56); G21 (BRRI dhan39) for inbred and G2 (BADC hybrid dhan-2); G4 (BADC hybrid dhan-6); G5 (Bayer hybrid dhan-4) for hybrid compared to the other genotypes. The ideal genotypes were found G18 (BRRI dhan34) for inbred and G26 (BRRI hybrid dhan6) for hybrid varieties. In summary, we identified stable genotypes adapted across the environments for grain yield. These genotypes can be used as commercial cultivation with sustainable production as well as a parent/pre-breeding material in future rice breeding program.

Key words: Genotype, environment, rice, yield, rainfed.

INTRODUCTION

Rice is an important cereal crop which received the most attention of specialists in plant breeding and production technologies. However, its production is limited by the adverse environmental conditions (Wassmann *et al.,* 2009). Multi-environment yield trials are conducted for different crops throughout the world (Yan and Rajcan, 2002; Dehghani *et al.,* 2006) not only to identify high yielding cultivars but also to identify sites that best represent the target environment (Yan, 1999; Yan *et al.,* 2000; Yan and Hunt, 2001). It is often important to the plant breeders for developing improved genotypes and reduces the genetic progress in plant breeding program through minimizing the association between phenotype and genotype (Comstock and Moll, 1963). Even for similar ecological conditions, general adaptability is an important quality in a variety. According to Sharma (1994), adaptability refers to the capacity of a genotype to macro-environmental factors in its favour in order to a consistent performance over time and locations. Development of location specific variety has been considered for future challenge and sustainable food production (Iftekharuddaula *et al.,* 2002). Performance of a genotype in diverse environments is a true evaluation of its inherent potential adaptiveness (Pandey *et al.*, 1981).

Thus, ideal trial site and genotype identification are needed through effective statistical tools. For instance, regression coefficient (Finlay and Wilkinson, 1963), sum of squared deviations from regression (Eberhart and Russel, 1966), stability variance (Shukla, 1972), coefficient of determination (Pinthus, 1973), coefficient of variability

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(Francis and Kanneberg, 1978) and additive main effects and multiplicative interaction (AMMI) (Gauch and Zobel, 1988; Annicchiarico, 1997). However, Yan (1999) and Yan *et al.,* (2000) proposed another methodology known as a Genotype and Genotype by Environment (GGE) biplot for graphical display of Genotype by Environment Interaction (GEI) pattern of multi-location data with many advantages. In biplot study, both genotype (G) main effects and genotype × environment interaction (G×E) are considered simultaneously for genotype and environment evaluation (Yan and Kang, 2002). Through data visualization, a "which-won-where" view of biplot helps to mark distinct mega-environments to identify the best performing genotypes in the respective environments (Gauch and Zobel, 1997; Yan and Hunt, 1998; Yan, 1999; Yan *et al.,* 2000). Moreover, GGE and AMMI models are widely useful for detection of G × E interaction by visualizing the graphical representation. Also, ranking of environments and genotypes means stability and comparing the genotype with the popular cultivar is essential for location specific variety development and the biplot analysis paved the way to more reliable and proper interpretation in multi-location trials.

Thus, the present study was undertaken to evaluate the yield performance of each genotype, examine the possible existence of different mega environments, identify the winning genotype for each mega environment and point out the best location as a representative rainfed conditions as well as select stable and superior genotypes for commercial cultivation in Bangladesh.

MATERIALS AND METHODS

Plant materials and testing locations

A total of 48 rice genotypes, 36 inbred and 12 hybrid rice genotypes were evaluated, consisted of 28 Bangladesh Rice Research Institute (BRRI), 8 Bangladesh Institute of Nuclear Agriculture (BINA), 2 Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), 3 Bangladesh Agricultural Development Corporation (BADC), 2 Bayer Crop Science Private Company (BCS), 3 Supreme Seed Company Limited (SSC), 1 Building Resources Across Communities (BRAC), 1 Petrochem Agro Industries Limited (PAIL) (Table 1). Table 2 shows the environmental codes of different location based trials with these varieties.

Table 1. A list of rainfed lowland rice genotypes developed by different research institutes in Bangladesh.

Variety	Genotype	Place of collection	Variety	Genotype	Place of collection
Inbred			Inbred		
BR10	G1	BRRI	BRRI dhan75	G26	BRRI
BR11	G2	BRRI	Binasail	G27	BINA
BR22	G3	BRRI	Binadhan-4	G28	BINA
BR23	G4	BRRI	Binadhan-7	G29	BINA
BR25	G5	BRRI	Binadhan-11	G30	BINA
BRRI dhan30	G6	BRRI	Binadhan-12	G31	BINA
BRRI dhan31	G7	BRRI	Binadhan-15	G32	BINA
BRRI dhan32	G8	BRRI	Binadhan-16	G33	BINA

Table 1. Continued.

Variety	Genotype	Place of collection	Variety	Genotype	Place of collection
BRRI dhan33	G9	BRRI	Binadhan-17	G34	BINA
BRRI dhan34	G10	BRRI	BU dhan-1	G35	BSMRAU
BRRI dhan37	G11	BRRI	BU dhan-2	G36	BSMRAU
BRRI dhan38	G12	BRRI		Hybrid	
BRRI dhan39	G13	BRRI	BRRI hybrid dhan4	V1	BRRI
BRRI dhan44	G14	BRRI	BRRI hybrid dhan6	V2	BRRI
BRRI dhan46	G15	BRRI	Mukti-1(HB-12)	V3	BRAC
BRRI dhan49	G16	BRRI	Agro dhan-12	V4	PAIL
BRRI dhan51	G17	BRRI	Bayer hybrid dhan4	V5	BCS
BRRI dhan52	G18	BRRI	Bayer hybrid dhan6	V6	BCS
BRRI dhan56	G19	BRRI	Hera-10	V7	SSC
BRRI dhan57	G20	BRRI	Hera-16	V8	SSC
BRRI dhan62	G21	BRRI	Subrona-8	V9	SSC
BRRI dhan66	G22	BRRI	BADC hybrid dhan2	V10	BADC
BRRI dhan71	G23	BRRI	BADC hybrid dhan6	V11	BADC
BRRI dhan72	G24	BRRI	BADC hybrid dhan4	V12	BADC
BRRI dhan73	G25	BRRI			

Note: BR= Bangladesh Rice; BRRI= Bangladesh Rice Research Institute; BINA= Bangladesh Institute of Nuclear Agriculture; BSMRAU= Bangabandhu Sheikh Mujibur Rahman Agricultural University; BADC= Bangladesh Agricultural Development Corporation; BRAC= Building Resources Across Communities; PAIL= Petrochem Agro Industries Limited; BCS= Bayer Crop Science Pvt. Company; and SSC= Supreme Seed Company Limited.

Table 2. Location code of the trials for 48 rice genotypes in rainfed conditions.

Code	Location	Season
E1	Farmers field of Barishal region	Transplanted Aman
E2	Farmers field of Chattogram region	Transplanted Aman
E3	Farmers field of Dhaka region	Transplanted Aman
E4	Farmers field of Khulna region	Transplanted Aman
E5	Farmers field of Rajshahi region	Transplanted Aman
E6	Farmers field of Rangpur region	Transplanted Aman
E7	Farmers field of Sylhet region	Transplanted Aman

Field experiment and experimental design

The experiment was conducted in rainfed ecosystem in the 2018. Seeding was established at various study locations from mid to last week of July, and transplanting was completed within third to fourth week of August in the year of 2018. Thirty to 35 day-old seedlings were transplanted at a spacing of 20 × 15 cm with 2-3 seedlings per hill. The unit plot size was 5.4 m × 2.4 m. The field layout was randomized complete block design with three replications. Fertilizers were applied @ 234:87:115:78:12 kg Urea, TSP, MoP, Gypsum, Zinc sulphate per hectare respectively. All fertilizers except urea were used as basal during final land preparation. Urea was applied in three splits at 10-15 days after transplanting, 4-5 tillering stage and 5-7 days before panicle initiation stage. Crop management such as weeding, irrigation etc was done in time. Insects, diseases and other pests were controlled properly. The harvested area was 10.2 m^2. Two border rows were transplanted to minimize the border effects. The grain yield (tha^{-1}) data were collected at 14% moisture level. Data were collected followed by standard method as described by Yoshida *et al.,* (1976). The yield (tha^{-1}) conversion formula as follows:

$$\text{Yield } (tha^{-1}) = \frac{100 - \text{Grains moisture content (\%)}}{100 - 14} \times \text{Plot yield}$$

Statistical Analysis

The grain yield data for 48 genotypes in seven environments were used to perform combined analysis of variance (ANOVA) to determine the effects of environment (E), genotype (G) and their interactions. Combined analysis of variance, co-efficient of variation was measured by STAR software (version 2.0.1, http://bbi.irri.org) and broad sense heritability (h^2) for each trial was generated by PB Tools software (version 1.3). GGE biplot was constructed through principal component analysis performed by PB Tools software (version 1.3, http://bbi.irri.org) with the model equation:

$$Y_{ij} - \mu + G_i + E_j + \Sigma\lambda_k\alpha_{ik}\gamma_{jk} + e_{ij}$$

Where Y_{ij} is the yield of i^{th} genotype in the j^{th} environment; G_i and E_j represent the genotype and environment deviations from the grand mean, respectively; μ denotes the grand mean λ_k is the eigenvalue of the PCA axis k; α_{ik} and γ_{jk} indicate the genotype and environment PC scores, respectively, for the axis k and e_{ij} denotes the error term.

RESULTS AND DISCUSSION

Combined analysis of variance

Analysis of variance was done for the grain yield by 36 inbred and 12 hybrid rice varieties experimented in T. Aman 2018 (Table 3). The combined analysis revealed that the yield of rice genotypes was highly significant ($P<0.01$) influenced and contributed the major part by environment (E), which explained 37.88% and 35.26% of the total variation for inbred and hybrid varieties, respectively. Additionally, the relative contribution of genotype sum of squares was found 17.02% and 17.03% for inbred and hybrid respectively. Genotype by Environment (G × E) contributed the most 48.97% to the total variation for inbred varieties followed by 31.23% for hybrid varieties. Greater portion of total variation was explained by genotype × environment interaction effect in inbred where environment in hybrid indicating that the environments were diverse and a major part of variation in grain yield was reflected from environmental changes (Table 3). The highly significant genotype × environment interaction effects for grain yield confirmed that genotypes may be selected for adaptation to specific environments. This finding was found in Aina *et al.,* (2009) in cassava, Fentie *et al.,* (2013) in finger millet; Xu *et al.,* (2014), Akter *et al.,* (2015) and Debsharma *et al.,* (2020) in rice. The presence of a significant proportion of GEI is necessary for stability analysis of rice. This is in harmony with the findings of Samyuktha *et al.,* (2020) in mungbean.

Grouping of test environments relation to ideal environments

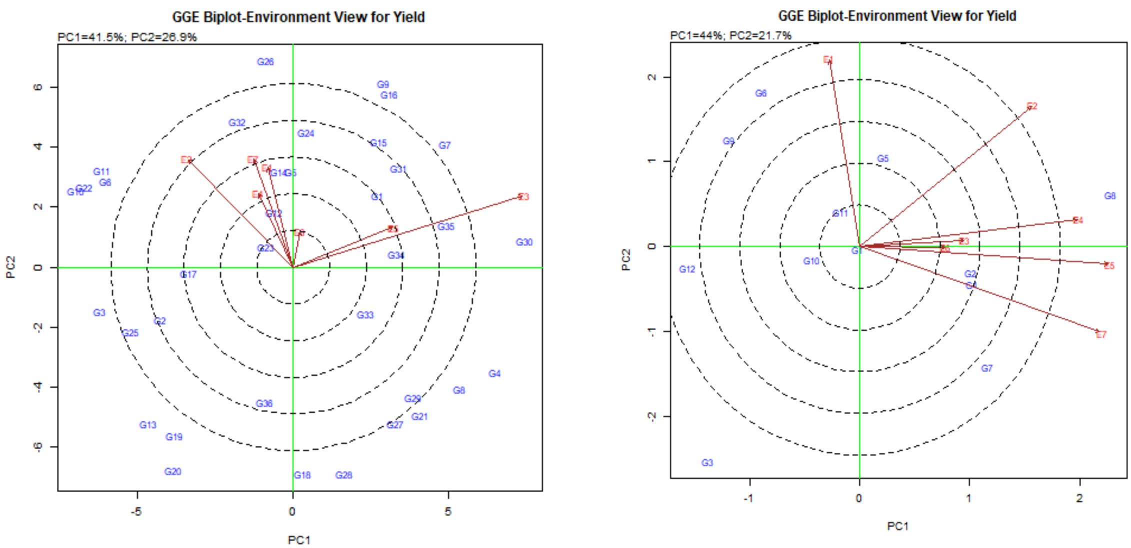
Multi-environment trials are being conducted by plant breeders around the respective trial sites to evaluate superior genotypes with wider adaptability. To visualize the relationship between environments, lines are drawn to connect the test environments to the biplot origin known as environment vectors. The most discriminating environment is a virtual environment that has the longest vector of all test environments (Yan and Hunt, 2001). For inbred varieties, The GGE biplot was explained 41.5% for PC1, 26.9% for PC2 and 68.4% of the total variation or interaction of the environments. Two distinct clusters were observed in the inbred GGE biplot study (Yan and Tinker, 2006). One contains E1 (Barishal), E2 (Chattogram), E4 (Khulna) and E7 (Sylhet)); the other cluster contains E3 (Dhaka), E5 (Rajshahi) and E6 (Rangpur). Among seven environments, E1 (Barishal), E4 (Khulna) and E7 (Sylhet) were closely associated which belonged to first cluster (Fig.1a). The location E2 (Chattogram) showed negative or no correlation with E3 (Dhaka) and E5 (Rajshahi) indicates moderately large G × E interaction due to presence of wide obtuse (<90˚) angle. Also, location E3 (Dhaka) found negative or no correlation with E1 (Barishal), E4 (Khulna) and E7 (Sylhet). E2 (Chattogram) and E3 (Dhaka) had the longest vector and making it more discriminating (informative) than other the environments. E6 (Rangpur) have very short vector and considered as an ideal environment for testing genotypes for inbred varieties with its representativeness and appreciable discriminating ability.

For hybrid varieties (Fig. 1b), GGE biplot was accounted 44% for PC1, 21.7% for PC2 and 65.7% of the total variation of the environments. There were two cluster of environments, one containing E3 (Dhaka) and E6 (Rangpur); second cluster containing E4 (Khulna) and E5 (Rajshahi). Among these two, E3 and E6 were closely related (Fig. 1b). E2 (Chattogram), E4 (Khulna), E5 (Rajshahi) and E7 (Sylhet) had the longest vector and indicates highly discriminating. There are negative or no correlation between E1

Table 3. Analysis of variance of rice grain yield (t ha^{-1}) across seven environments for rainfed condition in Bangladesh.

Source of variation	Inbred			Hybrid		
	DF	Mean square	Explained SS (%)	DF	Mean square	Explained SS (%)
Env	6	37.88**	25.54	6	15.03**	35.26
Rep within Env	14	0.08	0.12	14	0.20	1.12
Genotype	35	4.32**	17.02	11	3.96**	17.03
Env : Genotype	210	2.07**	48.97	66	1.20**	31.23
Pooled Error	490	0.15	8.34	154	0.25	15.35
Total	755			251		

Note: DF= Degree of freedom; Env= Environment; Rep within Env= Replication with environment; SS= Sum of square.
**indicate significant at P<0.01 probability level.



(a) Inbred (b) Hybrid

Fig. 1. Association among the test environments of rice genotypes evaluated across seven environments of Bangladesh for grain yield.

(Barishal) and E7 (Sylhet) due to its largest angle (more than 90 °). The location E6 (Rangpur) and E3 (Dhaka) were highly representative (Fig. 1b). Yan and Kang (2003) described that the degree and causes of G × E interaction is useful for identifying ideal test locations and best performing genotypes from multi environment trials. As Kaya *et al.*, (2006) reported, the presence of close associations between testing environments reveals that similar information about the genotypes could be obtained from fewer test environments and hence there could be better potential to reduce testing cost under limited resources.

Identification of ideal environment

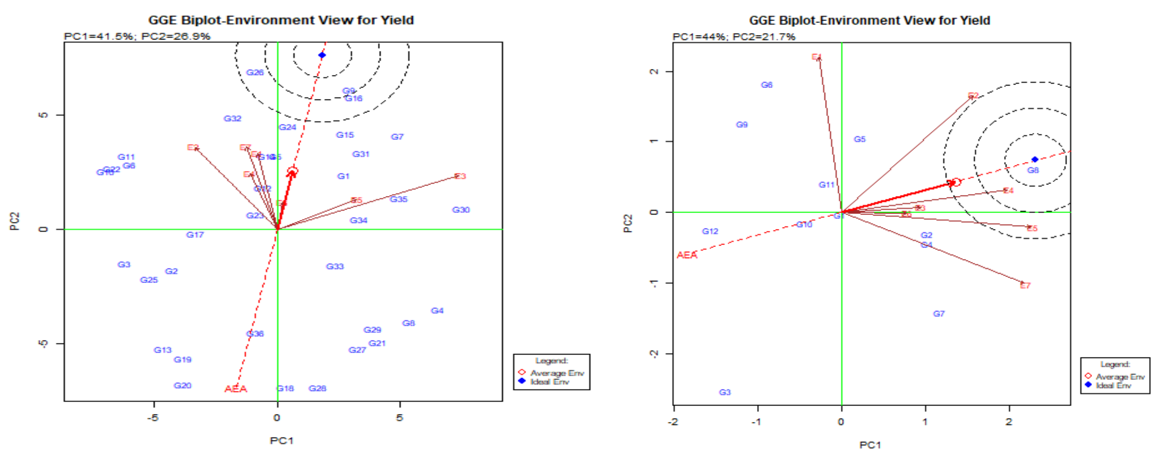
Discriminating power and representativeness of the GGE biplot is an important measure of testing environment (Dehghani *et al.*, 2006). The length of concentric circles on the biplot helps to visualize the length of the environment vectors which is proportional to standard deviation within the respective environments on the biplot and also shows the discriminating ability of the environments (Yan and Tinker, 2006). Average Environment Axis (AEA) is the line that passes through the average environment (represented by small circle) and biplot origin. The cosine of the angle between the two environments is used to approximate the relation between them (Yan and Tinker, 2006).

In the inbred varieties, E6 (Rangpur) had the narrowest angle with average environment axis (AEA) (Fig. 2a). Thus, it was highly representative among all the locations followed by E1 (Barishal) and E5 (Rajshahi). In opposite, E2 (Chattogram) and E3 (Dhaka) showed the least discriminating ability and were the least representative locations. Considering the above mentioned criteria, E6 (Rangpur) was the ideal location for testing inbred varieties. For the hybrid varieties, E4 (Khulna) showed a smaller angle with the AEA and thus was a highly representative environment followed by E3 (Dhaka) and E6 (Rangpur) (Fig. 2b). Considering the ideal environment criteria, the location E4 (Khulna) can be considered ideal environment for evaluating hybrid varieties throughout the country. Yan and Tinker (2006) explained that the narrower angle of two arrows means the closer relation between two environments. The wider angle of two arrows means the more variation of results, because of the bigger effect of G × E of the observed traits.

Mean grain yield and its stability of inbred and hybrid genotypes

Visualization of GGE biplot is very useful to evaluate and find the most stable genotypes (Farshadfar *et al.*, 2013). Genotypes laid in the concentric area were more stable in giving the yield compared to the genotypes laid outside, even though the environmental effect was very strong. Within mega-environment, genotypes should be evaluated on both mean performance and stability across environments. Figs. 3a and 3b show average-environment coordination (AEC) views of the GGE biplot for grain yield. Table 4a and 4b shows the yield performances and genotypes with code.

For inbred varieties, on the basis of GGE biplot G18 (BRRI dhan34) is the ideal genotype (shown by the bold dot in the center of the concentric area) (Fig. 3a) (Table 5). There were seven genotypes laid in the concentric area, i.e. G18 (BRRI dhan34), G26 (BRRI dhan52), G28 (BRRI dhan57), G19 (BRRI dhan37), G13 (BR25), G27 (BRRI dhan56) and G21 (BRRI dhan39) were the most stable genotypes, indicated by their positions which were closely on the AEA lines having very small vector deviation. It meant that these genotypes had the widest adaptability and stable yield across the environment compared to other genotypes which have long vector. Although, their yields were below the average mean. On the other hand, genotypes G5 (Binadhan-17), G10 (BR11), G12 (BR23) and G23 (BRRI dhan46) had above average yield with short vector. Susanto *et al.*, (2015) and Akmal *et al.*, (2014) reported that genotype with the highest yield average was not necessarily be the most stable and vice versa.



(a) Inbred (b) Hybrid

Fig. 2. Identification of ideal environments based on the average environment axis (AEA), considering degree of angle of environmental vector evaluated across seven environments for grain yield.

In the present study, it was observed that the highest yield was obtained in Khulna (4.69 tha^{-1}) followed by Barishal (4.53 tha^{-1}) and Chattogram (4.21 tha^{-1}) (Table 4a). Positive environmental index in the location Chattogram (0.23), Khulna (0.71) and Barishal (0.55) indicated higher yield potential of the three locations. Khulna was the most favourable location followed by Chattogram and Barishal suggested almost all the genotypes had the potential to exploit these three locations.

In the hybrid varieties, G8 (BRRI hybrid dhan6) had highest yield based on the average from all the environments and it was visualized by its position in the concentric area of AEA line. G8 had the yield average of 5.20 tha^{-1} (Table 4b) with vector deviation so close to the origin point of the vector, indicating the most stable genotype. G2 (BADC hybrid dhan-2), G4 (BADC hybrid dhan-6) and G5 (Bayer hybrid dhan-4) were also stable, indicated by their position almost near on the encircled area of AEA lines having very small vector deviation. Nevertheless, these genotypes had above average yield followed the others.

Table 4a. Location wise mean yield (t ha^{-1}), heritability in broad sense (h^2) and environmental index of 36 inbred rainfed rice varieties in seven environments.

Variety (Inbred)	Code	E1	E2	E3	E4	E5	E6	E7	Mean±SE
BR10	G9	4.43a	5.37a	5.30a	4.67a	4.47a	3.20b	5.13a	4.65±0.17
BR11	G10	5.47ab	4.87b	1.57d	6.13a	3.07c	2.68c	4.73b	4.07±0.35
BR22	G11	5.60a	5.03a	2.17b	5.10a	2.60b	2.91b	5.23a	4.09±0.31
BR23	G22	5.63a	4.23bc	4.00bc	3.80cd	2.60e	2.89de	4.87ab	4.00±0.23
BR25	G13	4.37ab	3.53bc	1.63d	5.13a	2.67c	2.79c	3.23c	3.34±0.24
BRRI dhan30	G14	5.23a	4.63ab	3.83bc	5.03a	3.70bc	3.12c	4.33ab	4.27±0.17
BRRI dhan31	G15	4.67a	4.63a	5.43a	5.23a	3.27b	3.06b	4.53a	4.40±0.22
BRRI dhan32	G16	4.60b	5.07ab	5.73a	5.20ab	3.47c	3.06c	4.83ab	4.57±0.22
BRRI dhan33	G17	4.07b	5.43a	2.93c	4.03b	3.00c	2.75c	4.37b	3.80±0.21
BRRI dhan34	G18	4.03a	3.13a	3.12a	3.57a	3.40a	1.37b	3.23a	3.12±0.18
BRRI dhan37	G19	3.13bc	5.30a	2.37cd	3.67b	2.83b-d	2.16d	3.03b-d	3.21±0.22
BRRI dhan38	G20	3.43ab	4.23a	1.90d	3.70ab	2.97bc	2.34cd	3.33ab	3.13±0.17
BRRI dhan39	G21	4.07ab	2.00d	4.70a	4.50ab	2.83cd	2.55d	3.63bc	3.47±0.22
BRRI dhan44	G22	4.93a	5.13a	1.43c	5.53a	3.77b	2.85b	5.20a	4.12±0.32
BRRI dhan46	G23	4.60a	4.57a	3.94ab	4.63a	2.57c	3.04bc	4.23a	3.94±0.18
BRRI dhan49	G24	5.13ab	4.37bc	4.10c	5.70a	4.07c	3.03d	4.83a-c	4.46±0.21
BRRI dhan51	G25	4.00b	5.77a	2.23d	4.00b	2.70cd	2.77cd	3.53bc	3.57±0.25
BRRI dhan52	G26	5.63a	5.57a	4.40b	5.10ab	3.30c	3.14c	5.03ab	4.60±0.23
BRRI dhan56	G27	3.93ab	1.83c	3.67b	4.77a	4.17ab	3.27b	3.53b	3.60±0.22
BRRI dhan57	G28	3.57ab	2.60c	3.03bc	4.10a	4.27a	3.05bc	3.03bc	3.38±0.15
BRRI dhan62	G29	4.03a	3.00c	4.33a	4.00ab	4.03a	2.74bc	3.00c	3.59±0.13
BRRI dhan66	G30	4.33bc	3.40c	5.83a	4.00c	5.07ab	3.58c	3.83c	4.29±0.18
BRRI dhan71	G31	5.33a	3.90bc	4.37bc	4.33bc	5.43a	3.54c	4.50ab	4.49±0.17
BRRI dhan72	G32	5.20a	5.13a	2.97b	5.50a	5.07a	3.35b	4.63a	4.55±0.22
BRRI dhan73	G33	3.57b	3.60b	5.13a	5.37a	5.10a	3.13b	3.53b	4.20±0.25

Table 4a. Continued.

Variety (Inbred)	Code	E1	E2	E3	E4	E5	E6	E7	Mean±SE
BRRI dhan75	G34	4.13bc	3.80c	4.97ab	5.70a	3.80c	2.26d	3.70c	4.05±0.24
Binasail	G8	3.90bc	2.90d	5.10a	4.10b	3.70b-d	2.89d	3.00cd	3.66±0.18
Binadhan-4	G6	5.23ab	4.93b	1.33d	6.17a	4.40bc	3.57c	4.40bc	4.29±0.32
Binadhan-7	G7	5.67a	4.40c	5.53ab	4.10c	4.67bc	2.86d	4.03c	4.47±0.21
Binadhan-11	G1	5.87a	3.90bc	3.97bc	4.17b	5.50a	3.14c	3.93bc	4.35±0.21
Binadhan-12	G2	4.67a	4.43a	1.93d	4.17ab	3.43bc	2.92c	4.23ab	3.68±0.21
Binadhan-15	G3	3.97bc	5.23a	1.67e	4.67ab	2.83d	3.27cd	4.10bc	3.68±0.25
Binadhan-16	G4	3.00d	3.27cd	4.97ab	4.17bc	5.50a	2.47d	3.30cd	3.81±0.25
Binadhan-17	G5	4.60b	4.43bc	3.50cd	6.03a	4.77b	3.33d	4.30bc	4.42±0.19
BU dhan-1	G35	4.40a	4.30ab	5.13a	4.67a	5.10a	2.94c	3.43bc	4.28±0.18
BU dhan-2	G36	4.50a	3.57a-c	2.80c	4.00ab	3.37bc	3.54bc	3.00c	3.54±0.14
Environmental mean		4.53	4.21	3.64	4.69	3.82	2.93	4.02	3.98
Environmental index		0.55	0.23	-0.34	0.71	-0.16	-1.04	0.05	0.00
LSD at 5%		0.73	0.44	1.22	0.52	0.25	0.29	0.22	0.87
Heritability		0.88	0.97	0.9	0.94	0.99	0.94	0.99	0.54

Table 4b. Location wise mean yield (tha^{-1}), heritability in broad sense (h^2) and environmental index of 12 hybrid rainfed rice varieties in seven environments.

Variety (Hybrid)	Code	E1	E2	E3	E4	E5	E6	E7	Mean±SE
BRRI hybrid dhan4	G7	3.40cd	4.38bc	4.13b-d	6.17a	4.93b	3.12d	4.50bc	4.38±0.22
BRRI hybrid dhan6	G8	4.97b	5.07b	6.43a	6.43a	5.47ab	3.38c	4.67b	5.20±.23
Mukti-1(HB-12)	G11	5.37a	3.93b-d	4.40a-c	4.97ab	4.53a-c	2.95d	3.73cd	4.27±0.18
Agro dhan-12	G1	4.47ab	4.63a	4.27ab	4.67a	4.30ab	3.38b	3.83ab	4.22±0.13
Bayer hybrid dhan-4	G5	5.37a	5.00ab	3.67cd	5.47a	3.90b-d	3.03d	4.27a-c	4.39±0.20
Bayer hybrid dhan-6	G6	5.30a	4.93ab	4.00bc	5.43a	3.20cd	3.48cd	2.43d	4.11±0.25
Hera-10	G9	5.27a	4.03b-d	4.70a-c	5.23ab	3.63cd	2.98de	2.07e	3.99±0.25
Hera-16	G10	4.57ab	4.14bc	5.40a	4.97ab	3.23cd	2.75d	3.90b-d	4.14±0.30
Subrona-8	G12	4.87a	3.60b	3.93ab	4.03ab	3.07b	2.98b	3.53b	3.72±0.16
BADC hybrid dhan-2	G2	4.37b	4.50b	3.83b	6.13a	4.30b	4.81b	4.43b	4.63±0.16
BADC hybrid dhan-6	G4	4.23b	4.70ab	4.43ab	5.63a	4.60ab	3.60b	4.60ab	4.54±0.14
BADC hybrid dhan-4	G3	3.27c	2.40c	4.53ab	4.67a	3.43bc	3.07c	3.33bc	3.53±0.17
Environmental mean		4.62	4.28	4.48	5.32	4.05	3.29	3.77	4.26
Environmental index		0.36	0.02	0.22	1.06	-0.21	-0.97	-0.49	0.00
LSD at 5%		0.81	0.84	1.48	0.79	0.31	0.34	0.33	0.66
Heritability		0.84	0.84	0.52	0.84	0.98	0.95	0.98	0.73

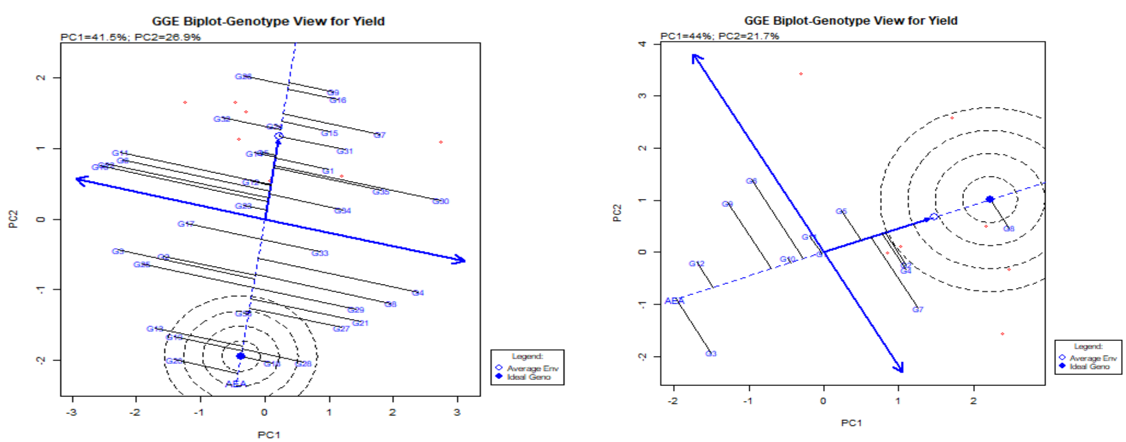
Note: E1= Barishal, E2= Chattogram, E3= Dhaka, E4= Khulna, E5= Rajshahi, E6= Rangpur, E7= Sylhet, LSD= Least significant difference, SE= Standard Error.

The location Khulna (5.32 tha^{-1}) had the highest yield followed by Barishal (4.62 tha^{-1}) and Dhaka (4.48 tha^{-1}) (Table 4b). Positive environmental index in the location Dhaka (0.22), Khulna (1.06) and Barishal (0.36) indicated higher yield potential of these locations. Khulna was the most favourable location followed by Dhaka and Barishal (Table 5) suggested almost all the genotypes had the potential to exploit these three locations. In addition, the presence of high heritability for grain yield in all the environments indicated reliability of the data. Besides this, high heritability is useful in the selection of the genotypes for high yield. This coincides with the report of Kaya *et al.*, (2006) in wheat. Similarly Ceccarelli (1996) reported heritability is higher in high yielding environment than low yielding environment in barley (*Hordeum vulgare* L.) and Abdelmula *et al.*, (2008) also found the similar report in faba bean (*Vicia faba* L.) (Table 4b).

Identification of mega-environment based on which-won-where pattern

Visualization of the which-won-where pattern of multi-location data is necessary for studying the possible existence of different mega environments in the target environment (Gauch and Zobel, 1997; Yan *et al.*, 2000; Yan and Hunt, 2001). Mega-E is determined by the vertex genotype, i.e. the highest yield genotypes in each quadran developed by GGE analysis visualization (Yan and Hunt, 2001). Position of the vertex genotypes were connected by connecting lines, i.e. a linear line started from the base of biplot that cross perpendicularly each connecting line and separated the biplots into some sectors. Sectors containing environments, i.e. sectors containing dots representing environments, called as Mega-E (Jambormias, 2011).

In the inbred study, biplot showed three sectors containing all the test environments and accordingly three mega-environments were identified (Fig. 4a): One mega-environment had two locations, E3 (Dhaka) and E5 (Rajshahi); the second consisting of four locations, E1 (Barishal), E4 (Khulna), E6 (Rangpur) and E7 (Sylhet); the third had one location, E2 (Chattogram). G7 (Binadhan-7) and G30 (BRRI dhan66) were the winning varieties in the first mega-environment; G9 (BR10), G16 (BRRI dhan32) and G26 (BRRI dhan52) were the winner in the second; and G6 (Binadhan-4) and G11 (BR22) were the winning varieties in the third mega-environment (Fig. 4a). G3 (Binadhan-15), G4 (Binadhan-16), G13 (BR25), G18 (BRRI dhan34), G19 (BRRI dhan37), G20 (BRRI dhan38) and G28 (BRRI dhan57) were the low yielder of inbred varieties evaluating the whole country.



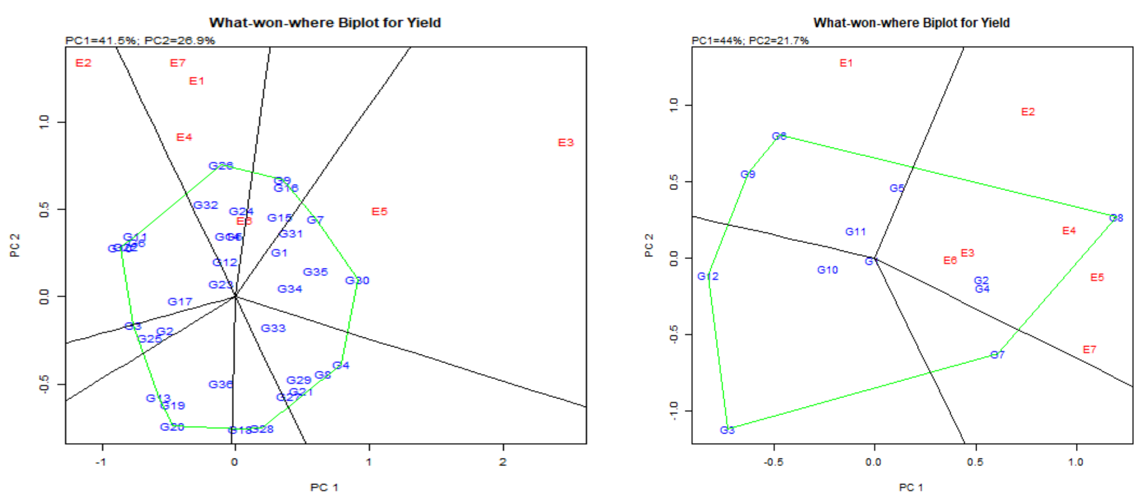
(a) Inbred (b) Hybrid

Fig. 3. Average environment axis (AEA) view based on pooled mean performance and stability of 36 inbred and 12 hybrid rice genotypes during rainfed condition in 2018.

Table 5. Summary of ideal environment and genotypes with stable and high mean yields in inbred and hybrid varieties.

Category	Ideal near ideal genotype	Stable genotype	High mean	Ideal near ideal environment	Most discriminate location
Inbred	G18 (BRRI dhan34)	G18 (BRRI dhan34) G26 (BRRI dhan52) G28 (BRRI dhan57) G19 (BRRI dhan37) G13 (BRRI dhan25) G27 (BRRI dhan56) G21 (BRRI dhan39)	G9 (BR10) G26 (BRRI dhan52)	E6 (Rangpur)	E2 (Chattogram) E3 (Dhaka)
Hybrid	G8 (BRRI hybrid dhan6)	G8 (BRRI hybrid dhan6) G2 (BADC hybrid dhan-2) G4 (BADC hybrid dhan-6) G5 (Bayer hybrid dhan-4)	G8 (BRRI hybrid dhan6) G2 (BADC hybrid dhan-2)	E4 (Khulna)	E2 (Chattogram) E4 (Khulna) E5 (Rajshahi) E7 (Sylhet)

The biplot was divided into two mega-environments for hybrid varieties (Fig. 4b). The first mega-environment had six locations, E2 (Chattogram); E3 (Dhaka); E4 (Khulna); E5 (Rajshahi); E6 (Rangpur) and E7 (Sylhet) with G8 (BRRI hybrid dhan6) being the winning varieties. The second mega-environment consisted of one location, E1 (Barishal); and G6 (Bayer hybrid dhan-6) and G9 (Hera-10) as the winning varieties. G3 (BADC hybrid dhan-4); G7 (BRRI hybrid dhna4) and G12 (subrona-8) were the low yielder of hybrid varieties evaluating the tested locations (Fig. 4b). Also, those genotypes within the polygon (for example G2 and G4 for first mega-environment) were less responsive to location than the winning genotypes (Karimizadeh *et al.*, 2013).



(a) Inbred (b) Hybrid

Fig. 4. Identification of winning genotypes by GGE biplot and their related mega-environments during rainfed condition in 2018.

CONCLUSION

The locations E2 (Chattogram); E3 (Dhaka) for inbred and E2 (Chattogram); E4 (Khulna); E5 (Rajshahi); E7 (Sylhet) for hybrid varieties were most discriminating and more informative locations. These respective locations could be used for decisions on genotypes to retain for further testing. Among the seven locations, ideal environment was found in E6 (Rangpur) for inbred and E4 (Khulna) for hybrid varieties. Genotypes G18 (BRRI dhan34); G26 (BRRI dhan52); G28 (BRRI dhan57); G19 (BRRI dhan37); G13 (BR25); G27 (BRRI dhan56); G21 (BRRI dhan39) for inbred and G2 (BADC hybrid dhan-2); G4 (BADC hybrid dhan-6); G5 (Bayer hybrid dhan-4) for hybrid were the most stable genotypes compared to all other genotypes. Among all the genotypes, G18 (BRRI dhan34) and G26 (BRRI hybrid dhan6) were the ideal genotype for both inbred and hybrid respectively. These genotypes could be used for commercial cultivation across different locations as well as used as potential breeding materials even for crossing program in the future inbred and hybrid rice research in Bangladesh.

AUTHOR'S CONTRIBUTION

SKD and KMI generated idea; PRR and RAB coordinated the experiment/research/project; SKD and RAB developed methodology; SKD and KMI provided scientific insights; PRR and RAB gathered data; SKD and KMI carried out analysis and synthesis; SKD and PRR did the writings of all versions of the manuscript; SKD, PRR and KMI performed critical review and editing; All authors read and approved the final manuscript.

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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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Genetic Divergence of Rice Genotypes Revealed by Bacterial Blight Disease and Morphological Traits

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ABSTRACT

Bacterial blight is a perilous impediment for rice production. Resistant variety is a sustainable approach to fend off the loss of rice due to bacterial blight disease. In this study, 94 genotypes were screened against bacterial blight disease and its morphological diversity was assessed to find out the resistant donor with desirable morphological characters. Bacterial blight pathogen was inoculated following leaf clipping method for disease scoring. Out of 94 genotypes, 12 showed a resistant reaction, 13 showed moderately resistant reaction and 69 genotypes showed a susceptible reaction. Positive correlation was recorded between yield and most of the morphological characters. Yield hill^{-1} was significantly correlated with the number of tiller hill^{-1} (0.503**), number of effective tiller hill^{-1} (0.538**), total number of spikelets panicle^{-1} (0.595**), number of filled grain panicle^{-1} (0.595**), number of unfilled spikelet panicle^{-1} (0.239*) and 1000 grain weight hill^{-1} (0.843**). Eleven quantitative characters grouped 94 rice genotypes in 16 clusters at coefficient 3.38 and it indicated the presence of great amount diversity among the genotypes. Principal component analysis (PCA) supported the cluster analysis and the first four principal components explained around 70.99% of total divergence for all morphological characters. Principal coordinate analysis (PCoA) demonstrated that the genotypes BR8862-29-1-5-1-3, SVIN301, SVIN321, BR9207-45-2-2, SVIN018, lRBB5, SVIN038, BRRI dhan28 and BRRI dhan29 were placed in distant position from the centroid and it indicated that they were more diverse than the genotypes near the centroid. However, based on disease reaction and genetic diversity analysis crossing could be made between, resistant genotypes such as SVIN317, SVIN017, SVIN316, SVIN313, SVIN315, SVIN314, SVIN038, SVIN307, SVIN302, SVIN304 with the susceptible variety more specifically with BRRI dhan28, BRRI dhan29, BRRI dhan50, BRRI dhan58, BRRI dhan63, BRRI dhan74, BRRI dhan81 and BRRI dhan84 to develop bacterial blight resistant variety.

Key words: Bacterial blight, Correlation, Disease screening, Genetic divergence analysis, Morphological traits, Rice genotypes.

INTRODUCTION

Rice is the primary diet of around half of the Earth's people (Wennberg, 2014). Changing weather parameters of the climate are responsible for several biotic and abiotic stresses which become a threat to rice cultivation in the world (Juroszek and Von Tiedemann, 2011; Zayan, 2018). Rice is threatened by many diseases where bacterial blight is responsible for 20-30% yield loss (Ou, 1985), and the severe attack may cause 80% (Singh *et al.*, 1997) to 100% yield loss of rice (Zhai and Zhu, 1999). Bangladesh is an overpopulated country and it is not beyond the effect of climate change and emerging of several pests for crop production. Rice is also a fundamental foodstuff for the population of Bangladesh and here food security is equivalent to rice security (Kabir *et al.*, 2015). To date, 32 diseases have been identified in Bangladesh from here blast, tungro, bacterial leaf blight and sheath blight are the severe threats for rice production in Bangladesh (Latif *et al.*, 2013). *Xanthomonas oryzae pv oryzae* is the causal organism of bacterial leaf blight disease. The occurrence of this disease was first reported in 1968 in Bangladesh. “Leaf blight” and “Kresek” are the two phases of this disease and the outbreak of these two phases may cause an epidemic in the rice production area (Reddy and Ou, 1976; Ou, 1985). Overdose of nitrogen fertilizer make the rice plant susceptible and favours the outbreak of the disease. Water soak lesion from the leaf margin followed by yellow to white stripes and pale yellow to necrotic symptoms on leaf blades at later stage are the identified symptoms of bacterial leaf blight disease

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(Mizukami and Wakimoto, 1969; Ou, 1985). The word "Kresek" is generated by the Vernacular word of Java, which means "the sound of dead leaves" stroked with one another (Wakimoto, 1969). Kresek was first identified in Indonesia during midcenturies and that time it was considered as a different rice disease but after consecutive studies, it was discovered that the disease kresek occurred by the same pathogen of bacterial leaf blight disease (Mizukami, 1956). The disease kresek generally appears after 1-2 weeks of transplanting and grayish green to whitish leaf blades along with sudden wilting of the plants are the identified symptoms of the kresek disease (Goto, 1992; Watanabe, 1975). Moreover, bacterial ooze in water and rotting smell from the roots are ideal symptoms for kresek disease identification.

As bacterial leaf blight is a bacterial disease, use of antibiotics is the prime solution to control it but due to policy regulation and environment concern adoption of antibiotics in Bangladesh is strictly prohibited. However, no chemicals except antibiotics are effective against bacterial disease. However, use of resistant variety is one and only economic and sustainable environment friendly strategy to tackle up the bacterial disease of rice (Khush *et al.*, 1989; Islam *et al.*, 2017). A resistant variety containing the resistant genes have been released to reduce the rice yield loss by bacterial blight disease (Chen *et al.*, 2002). However, emerging of new races shorten the sustainability of resistant variety and so it is necessary to seek out for the new donors of resistance. To develop bacterial blight resistant high yielding variety there is no alternative of continuous searching of the resistant source to initiate a breeding programme (Islam *et al.*, 2017). Moreover, variation among the parents are also a prime concern to find desirable progeny with superior characters.

Bacterial blight resistant advanced lines of International Rice Research Institute (IRRI) are being used as donor parents in several countries to develop resistant variety. In this study, 94 genotypes were tested against the bacterial blight isolate of Bangladesh to screen out the resistant and susceptible genotypes. Moreover, diversity analysis based on morphological characters were also measured to detect the variation among the genotypes.

MATERIALS AND METHODS

Genotypes collection and plant generation

A total of 94 genotypes were collected from IRRI, Los Banos, Philippines and Bangladesh Rice Research Institute (BRRI), Gazipur-1701, Bangladesh (Table 1). Plants were grownup in the experimental plot of Plant Pathology Division for bacterial blight screening. Genotypes were grown in the seedbed and 25 days aged plants were planted in the plot by implementing randomized complete block design (RCBD) with three replications.

Isolation and purification of pathogens

Bacterial blight infected plants were obtained from rice field for isolation of the pathogen. Infected leaves were cut into small pieces (5mm infected tissue and 5mm of adjacent healthy tissue) and placed in 70% ethanol for 10 seconds, after that the leaves were washed through sterilized water and immersed in 300 µl sterilized water for 15 minutes. A loop was dipped into the water and streaked on PSA (peptone 1.2%, sucrose 1.2%, agar 2%) plates followed by incubation for 3 to 4 days at 30°C for bacterial colony development. The yellow colonies were selected and purified on fresh PSA plates with a sterilized wire loop. The pathogenicity was confirmed according to Koch's postulates on a susceptible variety.

Bacterial culture preparation and disease scoring

After dilution of the bacterial inoculum by distilled water, the concentration was adjusted to 3.3×10^8 colony forming units per milliliter (cfu/mL), which is a suitable concentration for

Xoo infection in the host. Bacterial culture suspension was inoculated in the plants by clipping methods. Studied genotypes were inoculated at the booting stage. The scissors were dipped in the inoculum and one-fourth of top 3- 4 leaves were clipped by the scissors. After 21 days of inoculation, disease severity and incidence were scored based on following IRRI Standard Evaluation System (IRRI-SES) (IRRI, 2013). Resistant, 1-5% of diseased leaf area (Score 1), moderately resistant 6-12% (Score 3), moderately susceptible 12-25% (Score 5), susceptible 26-50% (Score 7), highly susceptible >50% (Score 9). Later, moderately susceptible, susceptible and highly susceptible were merged into one group as susceptible. However, other groups (resistant and moderately resistant) remain the same as before.

Morphological characters

Morphological characters such as plant height (PHT, cm), number of tillers per hill (NTH^{-1}, no), number of effective tiller per hill (ETH^{-1}, no), days to flowering (DF, no), days to maturity (DM, no), Panicle length (PL, cm), number of filled spikelet per panicle ($NFSP^{-1}$, no), number of unfilled spikelet per panicle ($UFSP^{-1}$), total number of spikelets per panicle ($TNSP^{-1}$), 1000 grain weight (TGW) and yield per hill measured from each replication plot of the respective genotypes.

Data analysis

Descriptive statistics of morphological parameters of the genotypes were calculated by Microsoft excel version 2016. To measure the associations among the 11 morphological characters Pearson's correlation coefficient was done by SPSS software version 20. Euclidean distance of the 94 genotypes was measured based on morphological data by using NTSYS-pc version 2.1 (Rohlf, 1998). Moreover, unweighted pair group methods of arithmetic mean (UPGMA) algorithm and SAHN clustering were applied to determine the relationship among the genotypes. The principal component analysis (PCA) of studied rice lines were revealed by EIGEN and PROJ modules of NTSYS-pc. Moreover, the principal coordinate analysis was done by following the manual instruction of the same software.

RESULTS AND DISCUSSION

Descriptive statistics of morphological parameters of the genotypes

Ninety-four genotypes were screened and out of them 12 showed resistant reaction, 13 showed moderately resistant and 69 showed susceptible reaction against bacterial blight pathogen (Table 1). Table 2 shows the descriptive statistics of morphological parameters of the studied genotypes**.** Among all rice genotypes, the plant height ranged between 64.4 to 105.2 cm with an average of 81.95 cm. The highest (105.2 cm) value for plant height was observed in BR9207-45-2-2 and the lowest (64.4) plant height were observed in genotypes SVIN037 and IRBB8. Besides, number of tiller/hill was ranged from 11 to 33 including an average of 22.87. The maximum and minimum number of tillers belonged to genotypes SVIN311 and BRRI dhan29-SC3-28-16-10-6-HR6 (com)-HR1(GAZ)-P11(Hbj) respectively. The number of effective tillers $hill^{-1}$ varied between 8 to 32 with an average of 20.96. The highest number of effective tillers $hill^{-1}$ was obtained in BRRI dhan74. The lowest number of that tillers was found in BRRI dhan29-SC3-28-16-10-6-HR6 (com)-HR1(GAZ)-P11(Hbj) and BR8862-29-1-5-1-3. Days to flowering varied from 103 to 118 days with an average of 110.43 days. In case of days to maturity, the value was ranged from 133 to 148 with a mean value of 140.43. The line SVIN039 showed the highest panicle length (29.4 cm) and BR8862-8-3-4-4-1 showed the lowest panicle length (17.6 cm), whereas the average panicle length was 23.94 cm. The highest (141) number of spikelets $panicle^{-1}$ was recorded in genotype SVIN301 while that of the lowest (54) was recorded in genotype IRBB10. The average number of spikelet panicle^{-1} was 87.48. The range of filled grains panicle^{-1} was 45 to 106 with an average value of 67.24. The highest (106) filled grain was found in BR8862-29-1-5-1-3 and that of the lowest (45) was recorded in IR99285-1-1-1-P1. The maximum (40) number of unfilled grains was recorded IR99285-1-1-1-P2 and that of the lowest (4) number was found in BRRI dhan63 with an average value of 18.24. The range of 1000-seed weight was 13 to 28 g with an average value of 21.69 g. The minimum value for TGW was observed in SVIN304 and the highest value was found in BR8862-8-3-4-4-1. Whereas the grain yield hill^{-1} ranged from 12.56 to 80.80 g with the average value of 30.74 g. The maximum yield per hill was recorded in BR9207-45-2-2 and that of the lowest was found in SVIN020.

Table 1. List of 94 genotypes and their reactions to bacterial blight disease.

Designation	Code	DR	Designation	Code	DR	Designation	Code	DR
SVIN317	G1	R	SVIN308	G33	S	lRBB64	G65	S
SVIN017	G2	R	SVIN296	G34	S	lRBB8	G66	S
SVIN316	G3	R	SVIN010	G35	S	Purbachi	G67	S
SVIN313	G4	R	SVIN035	G36	S	IR99056-B-B-15	G68	S
SVIN315	G5	R	SVIN012	G37	S	BR-8938-30-2-4-2-1	G69	S
SVIN314	G6	R	SVIN045	G38	S	BR8904-28-1-2-2-2	G70	S
SVIN038	G7	R	SVIN301	G39	S	KARJAT-5	G71	S
SVIN307	G8	R	SVIN050	G40	S	BR9675-68-5-1	G72	S
SVIN302	G9	R	SVIN287	G41	S	BR8562-11-2-6-1-1-1	G73	S
SVIN304	G10	R	SVIN037	G42	S	BRRI dhan29-SC3-28-16-10-6-HR6(com)-HR1(GAZ)-P8(Hbj)	G74	S
SVIN291	G11	MR	SVIN306	G43	S	BRRI dhan29-SC3-28-16-10-6-HR6(com)-HR1(GAZ)-P11(Hbj)	G75	S
SVIN017	G12	MR	SVIN029	G44	S	BR8862-29-1-5-1-3	G76	S
SVIN046	G13	MR	SVIN296	G45	S	BR8862-8-3-4-4-1	G77	S
SVIN045	G14	MR	SVIN003	G46	S	BR8995-2-5-5-2-1	G78	S
SVIN305	G15	MR	SVIN020	G47	S	BR9205-10-1-5-3	G79	S
SVIN039	G16	MR	SVIN001	G48	S	BR8590-5-2-5-2-1	G80	S
SVIN018	G17	MR	SVIN041	G49	S	BR8590-5-2-5-2-2	G81	S
SVIN312	G18	MR	SVIN321	G50	S	BR9207-45-2-2	G82	S
SVIN318	G19	MR	SVIN024	G51	S	IR99285-1-1-1-P2	G83	S
SVIN046	G20	MR	SVIN047	G52	S	BR(Bio) 9777-26-4-3	G84	S
SVIN311	G21	MR	SVIN299	G53	S	BRRI dhan28	G85	S
lRBB27	G22	MR	SVIN026	G54	S	BRRI dhan29	G86	S
IR99285-1-1-1-P1	G23	MR	SVIN306	G55	S	BRRI dhan50	G87	S

Table 1. Continued.

Designation	Code	DR	Designation	Code	DR	Designation	Code	DR
SVIN301	G24	S	SVIN038	G56	S	BRRI dhan58	G88	S
SVIN048	G25	S	IRBB10	G57	S	BRRI dhan63	G89	S
SVIN020	G26	S	IRBB11	G58	S	BRRI dhan74	G90	S
SVIN008	G27	S	IRBB13	G59	S	BRRI dhan81	G91	S
SVIN040	G28	S	IRBB2	G60	S	BRRI dhan84	G92	S
SVIN001	G29	S	IRBB24	G61	S	IRBB60	G93	R
SVIN319	G30	S	IRBB3	G62	S	IRBB65	G94	R
SVIN033	G31	S	IRBB4	G63	S			
SVIN298	G32	S	IRBB5	G64	S			

Note: DR-Disease reaction, R-Resistant, MR-Moderately resistant, S-Susceptible.

Table 2. Descriptive statistics of 11 traits of 94 rice genotypes.

	PHT	NTH^{-1}	ETH^{-1}	DF	DM	PL	NSP^{-1}	FGP^{-1}	$UFGP^{-1}$	TGW	YH^{-1}
Max	105.2	33	32	118	148	29.4	141	106	40	28	80.80
Min	64.4	11	8	103	133	17.6	54	45	4	13	12.56
Mean	81.95	22.87	20.96	110.44	140.44	23.94	87.00	67.24	18.24	21.69	30.74
CV (%)	12.35	23.74	25.81	5.30	4.17	10.09	23.31	21.41	44.37	13.87	40.57

Note: PHT-Plant height, NTH^{-1} – Number of tiller per hill, ETH^{-1}- Effective tiller per hill, DF-Days to flowering, DM- Days to maturity, PL-Panicle length, $TNSP^{-1}$-Total number of spikelet per panicle, FSP^{-1}-Number of filled spikelet per panicle, $UFSP^{-1}$-Number of unfilled spikelet per panicle, TGW-1000 grain weight, YH^{-1}-Yield per hill.

Correlation study of morphological characters

Pearson's correlation coefficient was measured from the data of 11 morphological characters of 94 rice genotypes (Table 3). Maximum traits showed a positive relationship after correlation analysis. Total number of spikelets panicle^{-1} displayed significant (p ≤0.01) positive relationship with the number of filled grain panicle^{-1} (0.895**), number of unfilled grain panicle^{-1} (0.593**), TGW (0.389**) and Yield hill^{-1} (0.595**). Yield hill^{-1} had highly significant and positive correlation with the number of tiller hill (0.503**), number of effective tiller hill^{-1} (0.538**), total number of spikelets panicle^{-1} (0.595**), number of filled grain panicle^{-1} (0.595**), number of unfilled spikelet panicle^{-1} (0.239*) and TGW hill^{-1} (0.843**). Many rice scientists reported that the relationship between grain yield and TGW is highly significant (Mazid *et al.*, 2013; Xu *et al.*, 2015; Li *et al.*, 2019). Morphological traits are highly influenced by environmental conditions so it is better to select highly correlated traits for the breeding programme.

Cluster analysis

Eleven morphological characters grouped the studied genotypes in sixteen principal groups at coefficient 3.38 and it indicated the presence of diversity among the genotypes. Based on 18 quantitative characters, 58 rice genotypes were clustered into four groups (Ahmadikhah *et al.*, 2008) whereas Mazid *et al.*, 2013 stated six groups in terms of 13 morphological characters of 41 accession of rice. Melchinger (1993) suggested that multivariate statistical techniques i.e. cluster and PCA could be applied to study the variation among the samples perfectly. Table 4 depicted that Cluster 2 was the largest (containing 24 genotypes) followed by Cluster-6 (21 genotypes),

Table 3. Correlation studies of 11 morphological characters of 94 rice genotypes.

Traits	PHT	NTH-1	ETH-1	DF	DM	PL	NSP-1	FGP-1	UFGP-1	1000 GW	YH-1
PH	1										
NTH-1	-0.029	1									
ETH-1	-0.017	0.953**	1								
DF	0.123	0.070	0.081	1							
DM	0.123	0.070	0.081	1.000**	1						
PL	-0.157	-0.124	-0.230	0.040	0.040	1					
NGP-1	-0.181	0.025	0.017	0.052	0.052	0.0880	1				
FGP-1	-0.128	0.003	-0.003	0.11	0.110	0.1160	0.895**	1			
UFGP-1	-0.169	0.051	0.043	-0.084	-0.084	-0.0150	0.593**	0.172	1		
1000 GW	-0.130	0.171	0.209*	0.143	0.143	-0.1900	0.389**	0.372**	0.187	1	
YH-1	-0.114	0.503**	0.538**	0.117	0.117	-0.1720	0.595**	0.595**	0.239*	0.843**	1

Note: PHT-Plant height, NTH-1 – Number of tiller per hill, ETH-1- Effective tiller per hill, DF-Days to flowering, DM- Days to maturity, PL-Panicle length, TNSP-1-Total number of spikelet per panicle, FSP-1-Number of filled spikelet per panicle, UFSP-1-Number of unfilled spikelet per panicle, TGW-1000 grain weight, YH-1-Yield per hill.
** indicates significant at the 0.01 level, * indicates significant at the 0.05 level.

Cluster-5 (9 genotypes), Cluster-4 (8 genotypes), Cluster-1 (7 genotypes), Cluster-8 (5 genotypes), Cluster-7 (4 genotypes), Cluster-3 and Cluster-10 (3 genotypes each), Cluster-9, Cluster-11 and Cluster-12 (2 genotypes per cluster) and Cluster-13, Cluster-14, Cluster-15, and Cluster-16 (each contains a single genotype). Moreover, genotypes having resistant, moderately resistant and susceptible phenomena were placed in the same cluster and this happened because they might be originated from the same ancestors having similar morphological characters. The cluster-14 had the highest average value for the three characters (Table 5) those are plant height (102.67 cm), days to flowering (118) and days to maturity (148). Cluster-16 contained the maximum number spikelets per panicle (132) and filled grain per panicle (106). The highest (32.63) average number of tiller was found in cluster-7 while the highest (30.33) number of effective tiller per hill was found in cluster-3. The highest mean panicle length (27.20 cm) and yield per hill (61.51 g) were found in cluster-13 whereas the maximum mean value (29 g) for TGW was found in cluster-12. On the contrary, cluster-16, showed the lowest mean value for number of tiller hill^{-1} (14.33), number of effective tiller per hill (8.67), TGW (18.00 g) and yield per hill (16.54 g). Average lowest value for number of tiller per hill (14.33), number of effective tiller per hill (12.83) and TGW (19.50 g) were found in cluster-9. Moreover, the lowest value for plant height (69.50), days to flowering (105.05), days to maturity (134.25), panicle length (22.48 cm) and yield per hill (19.10) was found in cluster-11, cluster-6, clster-4, cluster-8 and cluster-5, respectively.

Table 4. Cluster wise distribution of genotypes.

Cluster	No. of genotype	Genotype	Reaction
Cluster-1	7	SVIN317, SVIN315, SVIN291, SVIN305, SVIN039, SVIN046, IR99285-1-1-1-P1	R+MR
Cluster-2	24	SVIN048, SVIN008, SVIN001, SVIN319, SVIN035, SVIN012, SVIN287, SVIN003, lRBB11, lRBB13, lRBB4, Purbachi, BR8904-28-1-2-2-2, BR9675-68-5-1, BR8562-11-2-6-1-1-1, BR8862-8-3-4-4-1, BR9205-10-1-5-3, BR8590-5-2-5-2-1, BR8590-5-2-5-2-2, BRRI dhan58, BRRI dhan81, BRRI dhan84, IRBB60, IRBB65.	S+ R
Cluster-3	3	lRBB27, lRBB8, BRRI dhan74	MR+ S
Cluster-4	8	SVIN313, SVIN314, SVIN038, SVIN302, SVIN304, SVIN017, SVIN045, SVIN312	R+MR
Cluster-5	9	SVIN301, SVIN020, SVIN296, BR-8938-30-2-4-2-1, KARJAT-5, BRRI dhan28, BRRI dhan29, BRRI dhan50, BRRI dhan63	S
Cluster-6	21	SVIN040, SVIN033, SVIN298, SVIN308, SVIN010, SVIN045, SVIN050, SVIN306, SVIN029, SVIN296, SVIN001, SVIN041, SVIN024, SVIN047, SVIN299, SVIN306, lRBB2, lRBB24, lRBB3, BR8995-2-5-5-2-1, BR(Bio) 9777-26-4-3	S
Cluster-7	4	SVIN311, SVIN026, SVIN038, lRBB10	MR+S
Cluster-8	5	SVIN017, SVIN316, SVIN307, SVIN018, SVIN318	R+MR
Cluster-9	2	BRRI dhan29-SC3-28-16-10-6-HR6(com)-HR1(GAZ)-P11(Hbj), IR99285-1-1-1-P2	S
Cluster-10	3	SVIN301, SVIN037, SVIN321	S
Cluster-11	2	lRBB5, lRBB64	S
Cluster-12	2	IR99056-B-B-15, BR9207-45-2-2	S
Cluster-13	1	SVIN020	S
Cluster-14	1	SVIN046	MR
Cluster-15	1	SVIN305	S
Cluster-16	1	BR8862-29-1-5-1-3	S

Note: R-Resistant, MR-Moderately resistant, S-Susceptible.

Table 5. Cluster wise mean of respective characters.

Cluster	PHT	NTH^{-1}	ETH^{-1}	DF	DM	PL	$TNSP^{-1}$	FSP^{-1}	$UFSP^{-1}$	TGW	YH^{-1}
Cluster-1	85.76	21.05	19.52	117.00	147.00	24.94	81.14	62.00	19.14	20.86	25.12
Cluster-2	85.47	22.51	20.53	115.17	145.17	24.07	82.42	66.58	15.21	21.88	30.02
Cluster-3	70.33	31.50	30.33	117.33	147.33	22.67	76.67	66.33	10.33	20.00	40.40
Cluster-4	76.71	22.92	20.63	104.25	134.25	23.48	75.00	59.75	15.25	20.13	24.53
Cluster-5	88.78	15.00	13.33	106.00	136.00	24.84	78.78	67.89	10.89	21.00	19.10
Cluster-6	77.80	22.44	20.86	105.05	135.05	23.00	88.67	64.71	22.48	21.67	29.24
Cluster-7	79.96	32.63	29.42	106.25	136.25	26.45	63.00	51.75	11.25	23.25	35.87
Cluster-8	81.13	28.33	26.07	112.40	142.40	22.48	112.40	85.20	27.20	22.80	50.88
Cluster-9	74.50	14.33	12.83	112.00	142.00	25.10	127.50	91.00	36.50	19.50	22.44
Cluster-10	73.67	27.22	25.22	107.00	137.00	24.50	132.00	74.00	26.00	24.00	44.33
Cluster-11	69.50	30.42	29.58	118.00	148.00	20.00	72.50	58.00	14.50	24.00	41.21
Cluster-12	101.33	25.33	23.83	117.00	147.00	24.80	111.00	82.50	28.50	29.00	59.22
Cluster-13	88.67	32.00	29.00	103.00	133.00	27.20	123.00	101.00	22.00	21.00	61.51

Table 5. Continued.

Cluster	PHT	NTH-1	ETH-1	DF	DM	PL	TNSP-1	FSP-1	UFSP-1	TGW	YH-1
Cluster-14	102.67	19.67	17.33	118.00	148.00	23.60	100.00	77.00	23.00	20.00	26.69
Cluster-15	88.67	19.33	14.00	112.00	142.00	25.00	80.00	64.00	16.00	19.00	17.02
Cluster-16	71.20	14.33	8.67	112.00	142.00	27.00	132.00	106.00	26.00	18.00	16.54

Note: PHT-Plant height, NTH-1 – Number of tiller per hill, ETH-1- Effective tiller per hill, DF-Days to flowering, DM- Days to maturity, PL-Panicle length, TNSP-1-Total number of spikelet per panicle, FSP-1-Number of filled spikelet per panicle, UFSP-1-Number of unfilled spikelet per panicle, TGW-1000 grain weight, YH-1-Yield per hill.

Principal component analysis (PCA)

Correlation matrix of the samples were used to compute the principal components and the first component had the maximum variance. However, the PCA typically supported the cluster analysis. Some of the genotypes did not actually follow the clustering pattern in PCA and they grouped with another cluster. The first four principal components of PCA explained about 70.99% of overall divergence for all quantitative characters. From the eigenvectors study, it was found that 23.33%, 19.81%, 17.59% and 10.26% variation could be revealed by the first four principal components (Table 6 and Fig. 1). Caldo *et al.* (1996) reported 67% of the total divergence of quantitative characters from 10 principal components while Lasalita-Zapico *et al.* (2010) reported 82.7% of total variation from 32 rice accesions.

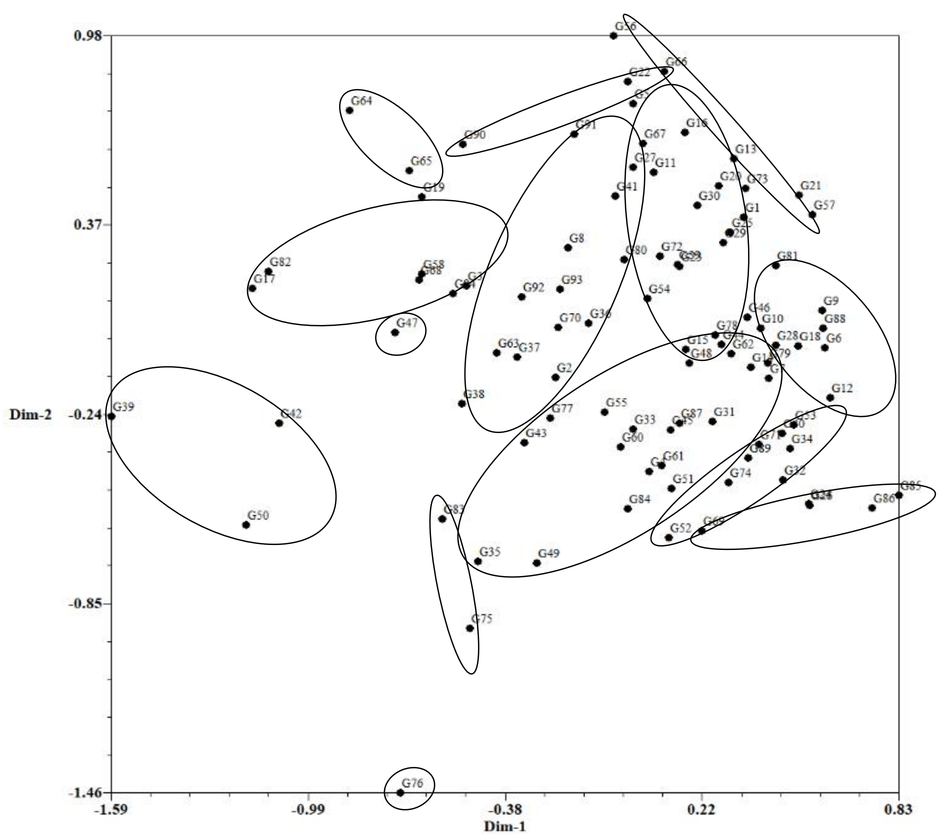

Fig. 1. Two-dimensional plot of principal component analysis portrayed the relationships of 94 genotypes by utilizing the data of 11 morphological characters.

Table 6. Eigenvectors and eigen values of the first four principal components.

Variable	Principal component			
	PC1	PC2	PC3	PC4
Eigen value	2.566	2.179	1.936	1.129
Percent	23.329	19.811	17.596	10.261
Cumulative	23.329	43.141	60.737	70.998
PHT	0.226	0.283	0.182	0.515
NTH^{-1}	-0.333	0.624	-0.625	-0.193
ETH^{-1}	-0.340	0.647	-0.634	-0.104
DF	-0.346	0.618	0.686	-0.051
DM	-0.346	0.618	0.686	-0.051
PL	0.005	-0.263	0.312	-0.686
NSP^{-1}	-0.866	-0.413	0.028	-0.032
FGP^{-1}	-0.780	-0.317	0.140	-0.024
$UFGP^{-1}$	-0.504	-0.339	-0.193	-0.027
TGW	-0.642	0.035	-0.089	0.376
YH^{-1}	-0.151	-0.267	0.084	0.442

Note: PHT-Plant height, NTH^{-1} – Number of tiller per hill, ETH^{-1}- Effective tiller per hill, DF-Days to flowering, DM- Days to maturity, PL-Panicle length, $TNSP^{-1}$-Total number of spikelet per panicle, FSP^{-1}-Number of filled spikelet per panicle, $UFSP^{-1}$-Number of unfilled spikelet per panicle, TGW-1000 grain weight, YH^{-1}-Yield per hill.
PC1-Principal component-1, PC2-Principal component-2, PC3- Principal component-3. PC4- Principal component-4

Principal coordinate analysis (PCoA)

PCoA described the spatial distribution of the studied genotypes based on morphological traits. Two-dimensional graph of PCoA demonstrated that the genotypes BR8862-29-1-5-1-3 (G76), SVIN301 (G39), SVIN321 (G50), BR9207-45-2-2 (G82), SVIN018 (G17), lRBB5 (G64), SVIN038 (G56), BRRI dhan28 (G85) and BRRI dhan29 (G86) were placed in distant position from the centroid and remaining genotypes situated at near to the centroid (Fig. 2). Results of the PCoA plot described that the genotypes which were situated in distant position from the central point were more diverse and genotypes near to the central point were less diverse. Strong heterosis is expected to be found by crossing between the parents having low similarity (Abubakar *et al.*, 2011; Nihad *et al.*, 2021).

CONCLUSION

In this study 94 genotypes were screened for disease reaction and morphological diversity. Out of 94 genotypes, 12 showed resistant reaction, 13 showed moderately resistant reaction and rest of the genotypes showed susceptible reaction. Yield hill^{-1} had high and significant positive correlation with the number of tiller hill^{-1}, number of effective tiller hill^{-1} , total number of spikelets panicle^{-1}, number of filled grain panicle^{-1}, number of unfilled spikelet panicle^{-1} (0.239*) and 1000 grain weight hill^{-1}. Moreover, based on 11 morphological characters, 94 rice genotypes were clustered into sixteen major groups and it indicates the presence of diversity among the genotypes. However, the PCA and PCoA mostly confirmed the cluster analysis. The first four principal components explained around 70.99% of total divergence for all quantitative

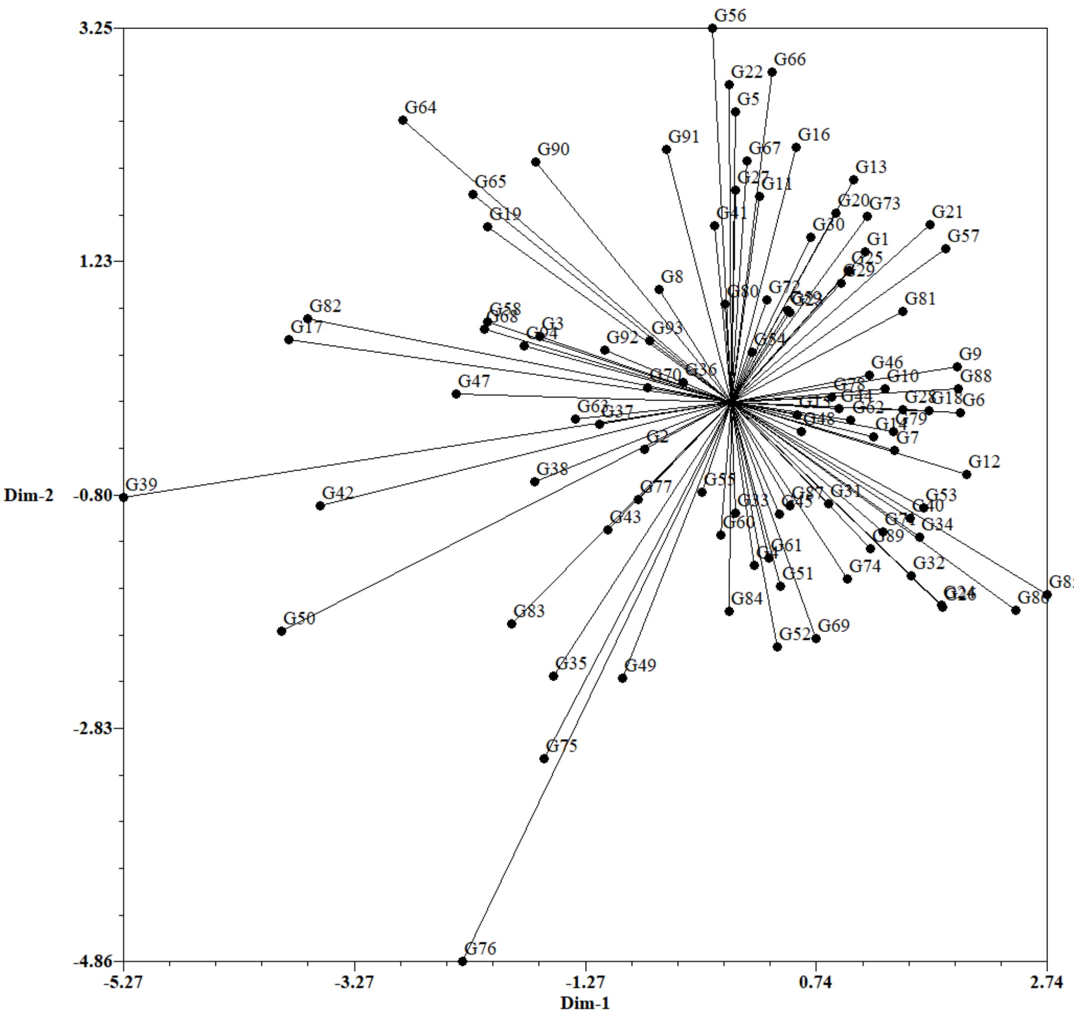

Fig. 2. Two-dimensional plot of principal coordinate analysis depicted the relationships of 94 rice genotypes by using the data of 11 morphological characters.

characters. However, based on disease reaction and genetic diversity analysis crossing could be done between genotype of two distant clusters, resistant genotypes such as SVIN317, SVIN017, SVIN316, SVIN313, SVIN315, SVIN314, SVIN038, SVIN307, SVIN302, SVIN304 with the susceptible lines or variety more specifically with BRRI dhan28, BRRI dhan29, BRRI dhan50, BRRI dhan58, BRRI dhan63, BRRI dhan74, BRRI dhan81 and BRRI dhan84 to develop bacterial blight resistant variety.

AUTHORS' CONTRIBUTION

SAIN: Conceptualization, data curation, formal analysis, investigation, methodology, resources, software, validation, writing - original draft, writing - review and editing. **AA**: Conceptualization, methodology, data curation. **MMR**: Methodology, investigation. **MAIH**: Formal analysis. **MAIK**: Formal analysis, visualization. **MAL**: Conceptualization, resources, funding acquisition, supervision, writing – review and editing. All authors read and approved the final manuscript.

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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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Is Agricultural Credit Programme Effective in Boro Cultivation? Evidence from State-owned Bank of Mymensingh District

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ABSTRACT

High input-intensive Boro rice cultivation needs substantial agricultural credit for the resource-poor Bangladeshi farmers. An investigation was conducted at Fulbaria upazila of Mymensingh district to assess loan attainment cost from Bangladesh Krishi Bank (BKB) and its utilization pattern; evaluate the effects of credit on Boro cultivation, and identify the major drivers of the agricultural credit programme. For the study, 140 farmers were divided into two groups: those who took a loan from BKB and those who did not. Results revealed that the borrowers had to pay Tk 10.23 for getting a hundred taka loan from BKB most of which was an unofficial cost. More than half of the obtained loan was used for Boro cultivation whereas 21% was used for family consumption and the rest (25%) was used for other purposes such as reimbursement of the previous loan from formal and informal sources, wedding and other income-generating activities including petty business. BKB credit borrowers obtained more benefits through Boro cultivation than non-borrowers. The major strengths of the BKB's agricultural credit programme were well-established infrastructure, experienced manpower, country-wide network, and lower interest rate. Whereas complex and lengthy institutional procedures, the inevitability of collateral and poor institutional capacity were being revealed as the weaknesses of the programme. Prevalence of brokers or corrupt officials and political influence were identified as the major constraints for the loan acquirement. More advanced research is recommended, with an emphasis on agricultural credit programmes, to ensure their effectiveness.

Key words: Bangladesh Krishi Bank, cost of credit, credit utilization, profitability, drivers of credit.

INTRODUCTION

Agriculture is still considered as the driving force of the rural economy of Bangladesh, which is heading towards commercialization to cope up with increased demand and rapid industrialization (Deb, 2016). It is well documented that the recent technological breakthrough that was incepted by Green Revolution has not only resulted in increased productivity but also brought significant changes in the magnitude and structure of cost associated with production process (Alauddin and Biswas, 2014a). Poor farmers in developing countries are often incompetent to afford the cost of crop production from their own sources which resulting in the delayed application of inputs even forcing them to apply less or lower quality inputs sometimes (Binswanger-Mkhize, 2012). Few farm expenses need to be paid within the shortest time even before the harvesting of crops and short-term credit become a foreseeable necessity (Khan *et al.*, 2017). Furthermore, Alauddin and Biswas, 2014a noticed that even though rich and middle-class farmers who are assumed to be in a good position in terms of solvency, also feel the inevitability of credit in a certain period, particularly during Boro season in Bangladesh. As a result, farmers' crop production is reliant on rural financial markets. The Bangladeshi rural financial market is divided into three categories: formal sector, semi-formal sector, and informal sector. State-owned specialized and commercial banks, along with private commercial banks, make up the formal market. In Bangladesh, state-owned banks both specialized and commercial are still

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recognized as the main sources of agricultural financing (Alauddin and Biswas, 2014b). Among the specialized banks, BKB, Rajshahi Krishi Unnayan Bank (RAKUB) and other state-owned commercial banks (SCBs) are the dominant players in the expanse of agricultural credit in the country, more specifically in the rural farming community (BB, 2018). At the same time despite the higher rate of interest, a large number of farmers borrow money from informal sources (e.g., friends, relatives, commission agents, traders, private money-lenders, and *mohazons*) to avoid the lengthy bureaucratic process and rigid reimbursement system of most formal sources. But it was observed that outflows as the interest charges on such informal loans result in a major drain in the income of the small even medium and large farmers, which dampen their living standard and make them perpetually indebted (Deb *et al.*, 2016). Farmers in Bangladesh are well aware of this scenario nowadays (Alauddin and Biswas, 2014a). To escape from the hassle that exists in the formal credit sources and to avoid the vicious cycle of indebtedness of informal sources (Salam *et al.*, 2019), farmers often rely on their own sources of funding, which is inadequate mostly in the case of small or medium farmers. As a result, non-borrower farmers often fall behind in terms of productivity or profitability, as productivity varies between borrowers and non-borrowers, with borrowers being in a stronger position to accelerate the adoption of modern technologies (inputs and machinery) (Spio, 2006). Again, a timely flow of agricultural credit, which fulfills farmers' demand, is a prerequisite for ensuring higher agricultural productivity (Alauddin and Biswas, 2014b).

The Bangladesh Krishi Bank was established under the Bangladesh Krishi Bank Order 1973 to promote the agricultural development of Bangladesh. From the very beginning, the main and foremost focus of BKB is to make institutional credit accessible to the rural community. It has established several branches in the distant rural parts of the country, often in areas with a weak economic base. As mentioned before the main sources of agricultural credit here are still state-owned banks among which BKB is the most dominant one (Alauddin and Biswas, 2014a). In Fiscal Year (FY) 2016-17, 28 percent of the total disbursement of agricultural credit was made by BKB solely. Table 1 presents the contribution of BKB in agricultural lending in 2016-17.

Table 1. Agricultural credit performance by lenders in the fiscal year 2016-17.

Lender	Number of entities	Disbursement Target (Billion Taka)	Actual Disbursement (Billion Taka)
SCBs	6	28.90	27.21
BKB	1	48.00	49.40
RAKUB	1	16.00	11.15
Sub Total	8	92.90	87.86
FCBs	9	3.93	5.10
PCBs	38	67.17	83.60
Sub Total	47	71.10	88.70
Grand Total	55	164.00	176.46

Note: SCBs: State-owned Commercial Banks; BKB: Bangladesh Krishi Bank; RAKUB: Rajshahi Krishi Unnyan Bank; FCBs: Foreign Commercial Banks; PCBs: Private Commercial Banks.

Source: Agricultural Credit Department, Bangladesh Bank.

Attainment of the agricultural credit programme typically relies on the borrowers' side as well. A few studies have been made so far addressing the insight of the agricultural credit programme from the borrowers' perspective. The concept of this research has been made purposively. There are various sources of agricultural credit for lending. Among these sources, the state-owned source is the bank, from where loans are available at a lower interest rate. However, due to various bureaucratic complications, farmers have to face many difficulties in getting loans. BKB, as one of the important state-owned sources, has agricultural credit programme. Therefore, this study is intended to look at the effectiveness of BKB's agricultural credit programme. BKB provides various crop-based agricultural loans. In this study, we have purposively selected the Boro rice crop as it plays a significant role in the food security of Bangladesh. Farmers, on the other hand, use more production inputs during Boro season. This increases the production costs of farmers (Rahman and Al-Amin, 2016). At that time the farmers become financially indigent and dependent on loans. So the real picture of the agricultural credit programme would be better portrayed at this time. Hence, we have undertaken a study on the effect of the agricultural credit programme on Boro rice cultivation.

Boro rice farmers in the Mymensingh district take a loan from BKB as one of the lending sources of low-interest rates. It is so often presumed that the credit taken for agricultural purposes more precisely for Boro rice cultivation is not merely used for the purpose. Therefore, when the loan is advanced to the farmers, they use it according to their priority of needs. On the other hand, there are some unwanted costs involved in obtaining agricultural credit (Miah *et al.*, 2006). Therefore, it is needed to know how much is the cost for the borrowers to obtain the credit, how it is being used, and what is the impact of those credits in Boro cultivation. Thus, the study has focused to assess the cost of getting a loan and its utilization pattern; to evaluate the effects of credit on the profitability of Boro cultivation by borrowers and non-borrowers, and identify the major drivers of BKB's agricultural credit programme in the study areas.

MATERIALS AND METHODS

The study was conducted in Fulbaria upazila of Mymensingh District purposively. Two criteria were set for respondent selection; (i) who only took loans in the fiscal year 2016-17, and (ii) who only took loans for Boro rice cultivation. Based on these criteria, we have collected the list of borrowers from BKB's Fulbaria branch, where 70 respondents (farmers) were selected randomly from the listed 90 borrowers (credit users) of the branch and the other 70 farmers (credit non-users) were also selected randomly from the Department of Agricultural Extension (DAE) listed Boro farmers of the same village. Therefore, the total sample size of the study was 140. Both the credit users and non-user were interviewed using a pre-designed semi-structured questionnaire during June 2017. Descriptive statistics mainly in tabular form were used to analyze and interpret the surveyed data. In this study, financial (cost and return) analyses were done on both variable or cash and full cost basis.

The profitability of Boro rice was estimated by applying the conventional profit equation as follows:

$$\Pi = TR - TC \qquad (1)$$

Where,

Π= Net return (Tk/ha); TR= Total return (Tk/ha); TC= Total costs (Tk/ha)

Thus, the model can be written as:

$$\Pi = \sum Q_y \cdot P_y + \sum Q_b \cdot P_b - \sum_{i=1}^{n} (X_i \cdot P_{xi}) - TFC$$

Where, $Q_y =$ Total quantity of (paddy) output (kg/ha); $P_y =$ Per unit price of (paddy) output (Tk/kg); $Q_b =$ Total quantity of the concerned byproduct (kg/ha); $P_b =$ Per unit price of the relevant byproduct (Tk/kg); $X_i =$ Quantity of the concerned i[th] input; $P_{xi} =$ Per unit price of the relevant i[th] input; TFC = Total fixed cost involved in production process; and $i = 1,2,3,...,n$ (number of inputs).

Strength, Weakness, Opportunity, and Threat (SWOT) analysis has been done at the end to identify the major drivers of BKB's agricultural credit programme.

RESULTS AND DISCUSSION

Cost of credit

Figure 1 presents the item-wise average cost of receiving hundred taka loans from BKB in the study area. On average the cost of receiving a hundred Taka loan from BKB was Tk 10.23. Among the major cost items, the official cost was significantly lower (e.g., application fee, Tk 0.89) than unofficial costs (Tk 9.34). The entertainment cost (Tk 6.82) was the highest among all unofficial costs followed by transportation and food cost (Tk 1.63) and the opportunity cost of man-days for time pass to approve the credit (Tk 0.89). It is to be mentioned that the item-wise cost of receiving a loan was estimated from the response of the borrowers and simplified accordingly by converting the loan amount to a hundred taka. That findings obviously not delineate that the afore-mentioned costs or their share will be the same for next each hundred taka loan or the total loan as a whole. It is being reported by the borrower respondents that the actual total cost ranges between Tk 800- 5200 based on the total amount of loaned money in the study area. Farmers mentioned that fulfilling an undue demand of brokers (*dalal*) and/or some unscrupulous bank officials covers a significant portion of the cost, which appears as a huge drawback in the case of obtaining a loan from BKB. Also, farmers had to visit the respective branch of the bank several times for getting their loan which made them incur a mentionable amount of cost for transportation, food as well as the opportunity cost of man-days for time passes to approve the loan. It is to be mentioned that, Miah *et al.* (2006) also listed the above-mentioned items of costs for obtaining agricultural credit from Grameen Bank (GB) as well as RAKUB.

Loan utilization pattern

Ensuring proper utilization of agricultural credit for crop production is critically important to achieving the bank's goal of disbursing loans to farmers. Figure 2 exemplifies the utilization pattern of obtained loans on MV Boro cultivation in the study areas. It depicts that farmers used more than half (54%) of the BKB sanctioned loan for Boro rice cultivation, about 21% to purchase foods for family consumption or other family expenditures and the rest (25%) was used for other purposes such as reimbursement of the previous loan from formal and informal sources, wedding and various other income-generating activities including petty trading. Paying wage to the labourer was the major cost item of rice production for which borrower farmers had to pay 15% of their obtained loan as Boro cultivation is a labour-intensive endeavour. Again, as most of the sample farmers were small and marginal, land mortgaged constituted a significant amount as an item of rice production cost in the study villages. On the other hand, farmers in the study areas spent one-fourth of their obtained loans in different non-farm activities like repayment of the old loan, investment in trade, petty business, bribe and so on. Previous studies (Miah *et al.*, 2006; Deb *et al.*, 2020) also exposed a similar kind of utilization pattern of the borrower farmers from RAKUB and GB.

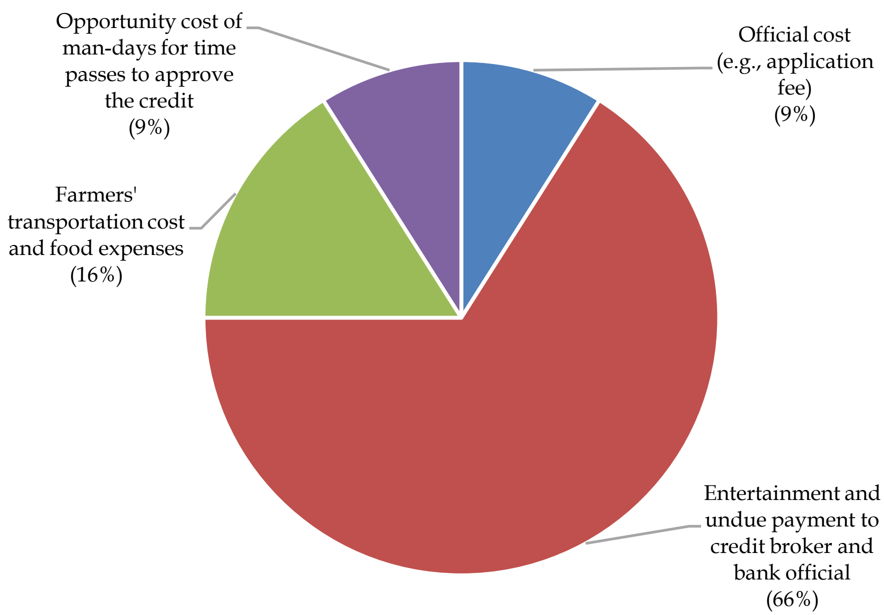

Fig. 1. Item-wise farmers' cost of receiving a hundred taka loan from BKB.
Source: Prepared by authors based on field survey.

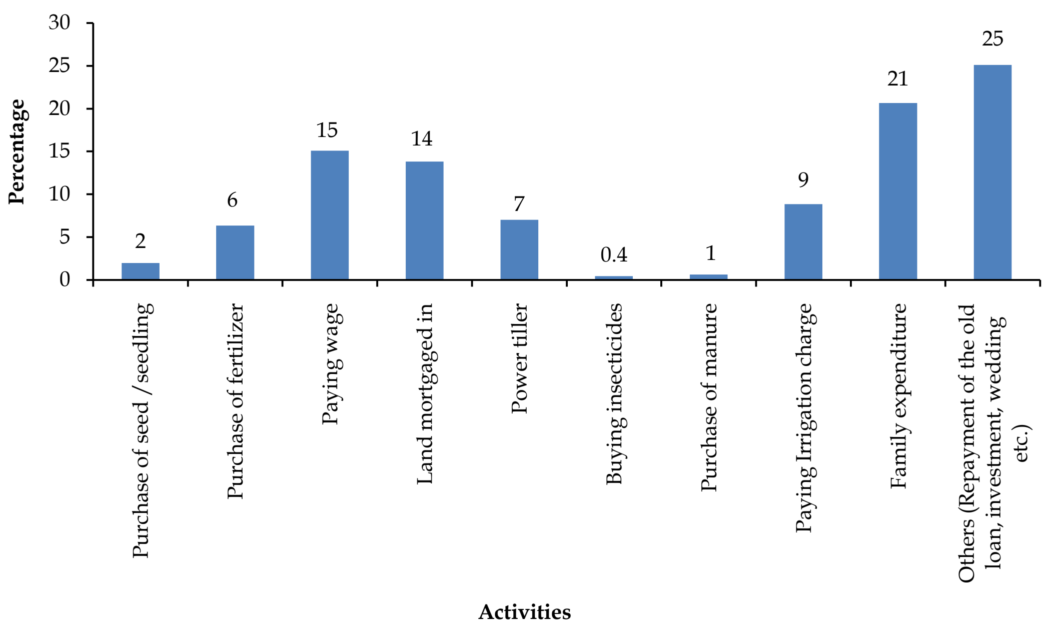

Fig. 2. Loan utilization patterns of Boro rice farmers. Other activities include repayment of the old loan, investment, wedding, etc.
Source: Prepared by authors based on field survey.

Input use pattern in the study areas

Table 2 shows the per hectare input use pattern of credit users and non-users for Boro rice cultivation. Major operations of Boro rice cultivation such as harvesting, carrying, and threshing were carried out by hired labour but other activities were mainly performed by family labour in the study village. It revealed that credit users and non-users applied approximately equal amounts of fertilizer even though it was argued in the study before that the credit non-user have less access to some inputs. However, in case of fertilizer application, farmers in Bangladesh usually apply more fertilizer than the recommended dose irrespective of their class or status (BRRI, 2018). High government subsidy that let the fertilizer price be minimum as well as lack of proper knowledge about optimum practice might be a probable explanation of this fact. On the contrary, per hectare labour deployment for credit users was higher than the farmers who did not use loaned money. It may be because credit users had a higher ability to hire labour and other inputs than credit non-users. These findings also support the previous finding that higher credit use is allied with the improved use of inputs in the production process (Satyasai, 2012).

Costs of cultivation

Table 3 presents the per hectare cost of credit users and credit non-users for Boro rice cultivation in the study villages. It was found that per hectare variable cost of credit users (Tk 88,123/ha) was higher than credit non-users (Tk 84,234/ha) in the study area. It was mainly due to the per hectare labour cost of credit users (Tk 47,220/ha) was higher than the credit non-users (Tk 43,140/ha).

It is to be mentioned that apart from the higher amount of hired labour used by the credit users, there are some differences in land preparation as well as irrigation cost though those are not significant. This extra cost of credit users mainly occurred for using the irrigation schemes more intensively as well as more hired labour than credit non-user.

Table 2. Per hectare input use pattern of credit user and non-user for Boro rice cultivation in the study villages.

Input item	Credit user	Credit non-user
Human labour (man-day/ha):	90	80
Hired	52	40
Family	38	40
Seed (kg/ha)	41	41
Fertilizer (kg/ha):		
Urea	252	259
TSP	99	101
MP	80	78
DAP	10	10

Source: Prepared by authors based on field survey.

Table 3. Per hectare cost of credit user and credit non-user for Boro rice cultivation in the study villages.

Cost item	Credit user	Credit non-user
Seedbed preparation (Tk/ha)	2,490	2,487
Seed (Tk/ha)	1,740	1,742
Human labour	47,220(44.23)	43,540 (42.23)
Family labour	10,760	12,580
Hired labour	16,240	11,960
Contract	20,220	19,100
Land preparation cost (Tk/ha)	8,115 (7.60)	8,095 (7.85)
Fertilizer (Tk/ha)	9,110 (8.53)	9,455 (9.17)
Urea	3,820	4,322
TSP	2,167	2,222
MP	1,155	1,170
DAP	255	260
Cowdung (Tk/ha)	1,713	1,481
Irrigation (Tk/ha)	15,200 (14.24)	14,689 (14.23)
Herbicide (Tk/ha)	380	308
Insecticide (Tk/ha)	2,068	2,198
Interest on operating capital @10 for five months	1,800	1,720
Variable cost (Tk/ha)	88,123 (80.86)	84,234 (80.02)
Land rent (Tk/ha)	18,515 (17.34)	18,595 (18.32)
Total cost (Tk/ha)	1,06,638	1,02,829

Source: Prepared by authors based on field survey.

Profitability

Table 4 shows per hectare returns of credit users and non-user for Boro rice cultivation. Per hectare yield of credit users (5.89 ton/ha) was slightly higher than that of credit non-users (5.59 ton/ha) due to better crop management (timely planting, weeding, and application of fertilizer by credit user because of availability of capital to purchase inputs timely as mentioned by the respondents). It is also evident from the past study (Datta and Ghosh, 2013) that borrowers of the formal sector have better access to electricity and irrigation facilities, belong to the comparatively privileged group of the society, and have better access to infrastructure facilities. For the same reason, per hectare gross return of credit users (Tk 10,6815/ha) was higher than that of the credit non-users (Tk 96,984/ha) as credit users harvested higher yields and higher price of paddy/rice for not selling the marketable surplus immediately after harvesting. Similarly, the ratio of benefit over cost (BCR) indicated that BKB credit borrowers were more benefited through Boro rice cultivation than non-borrowers. Even though the farm productivity, income level as well as agriculture development are closely related to agricultural credit (Sharma and Prasad, 1971) but it is always difficult to determine a causal relationship between agriculture credit and production due to the presence of serious endogeneity problem (Das *et al.*, 2009). However, improved supply and well-administered valuing of credit assist to intensify the agricultural productivity and the well-being of cultivators as well as all actors involved in the agricultural sector as credit is considered as life-line of the total investments made in agriculture (Sriram, 2007).

Table 4. Per hectare returns of credit user and non-user for Boro rice cultivation.

Item	Credit user	Credit non-user
Yield (kg/ha)	5,880	5,585
Paddy price (Tk/kg)	15.96	15.05
Return from paddy (Tk/ha)	93,845	84,054
Return from Straw (Tk/ha)	12,970	12,930
Gross return (Tk/ha)	1,06,815	96,984
Variable cost (Tk/ha)	88,123	84,234
Total cost (Tk/ha)	1,06,638	1,02,829
Gross margin (Tk/ha)	19,401	14,470
Net return (Tk/ha)	966	-6,124
Unit cost of production (Tk/kg)	18.33	17.36
BCR on cash cost basis	1.21	1.15
BCR on full cost basis	1.01	0.94

Source: Prepared by authors based on field survey.

Drivers of BKB's agricultural credit programme

Table 5 delineates the results obtained from the SWOT analysis of the BKB agricultural credit programme in the study area. SWOT of BKB's agricultural credit programme in the study area was identified based on the respondents' opinion and secondary sources, which help to determine the drivers of the agricultural credit programme of BKB.

Strengths

Wide operational network. It has been considered as one of the strengths of the BKB agricultural credit programme. It has a total of 1,038 branches all over the country covering 50 districts, nine city corporations, and 607 unions (BKB, 2020).

Well-established infrastructure. Since the establishment, BKB is trying to reach the rural community of the country. Being one of the largest specialized banks in the country currently, BKB is operating its banking activities through seven corporate, 239 cities, and 792 rural branches in the country (BKB, 2020). As a part of internal control, integrated compliance system as well as smooth operation, BKB has also established 63 field-level audit offices of which nine at divisional and 54 at regional levels (BKB, 2020).

Experienced human resource. BKB is running with 9,430 manpower against the approved number of 13680 as of 31 December 2010 (BKB, 2020). Even though BKB is running with inadequate manpower in some cases but as one of the oldest specialized banks, it is holding very experienced human resources in the banking sector of the country.

Lower interest rate. One of the key mandates of BKB is to help in poverty alleviation in the rural community. Thus, BKB is extending an agricultural loan with comparatively lower interest as mentioned by the respondents.

Weaknesses

Long and complex institutional procedure. The key hitches faced by farmers in securing agricultural credit from the formal sector banks are the long and complex institutional procedure. BKB is not an exception in that case as well. Respondents irrespective of their categories pointed to this as the main difficulties in securing agricultural credit from BKB in the study area.

Lack of timely loan assistance. The respondents identified lengthy and delayed loan approval processes as major flaws in BKB's agricultural credit program. The same scenario was observed in another study (Deb et al., 2020), in which 63 percent of RAKUB agricultural loan recipients claimed that they did not receive credit on time.

Strong need for collateral. The strong need for collateral in institutional sources like BKB in turn enforces plenty of formalities on credit seekers that make them finally penchant for taking a loan from semi-institutional and non-institutional sources. Majority of RAKUB borrower farmers in Chapai Nawabganj district mentioned the strong need for collateral in institutional sources as a major hindrance for poor and marginal farmers (Deb *et al.*, 2020).

Poor institutional capacity. Even though BKB has many branches in the rural areas but these are still inadequate against the requirement. Moreover, there are shortages of manpower, which often make the bank to limit its operations as reported by the respondents.

Opportunities

As a key specialized bank, BKB is always having the privilege of being patronized by the government. With the increasing capital, BKB is characterized by plenty of programmes targeting the rural community which will be extended further by the government policy and interventions. Due to its diversified programmes, government patronization, lower interest rate, and fastest-growing demand for agricultural credit, BKB has wide social acceptance among the rural community. It has been the most reliable formal source of agricultural credit in the study area.

Threats

The prevalence of brokers or unscrupulous bank officials results in higher non-interest costs in loan transactions for the borrowers. The higher non-interest cost of BKB credit for the small farmers acts as a hindrance to the development of their productive forces. Moreover, institutional credit is supposed to be allocated according to the relative efficiency of the cultivator rather than being allocated according to the economic and political supremacy of credit recipients. Agricultural loans are often used for political motives. To avoid these kinds of hassles farmers especially small and marginal farmers often go to NGOs for borrowing money despite higher interest rate.

Table 5. SWOT analysis to BKB agricultural credit programme in the study areas.

Strength	**Weakness**
Wide operational network	Long and complex institutional procedure
Well established infrastructure	Lack of timely loan assistance
Experienced human resource	Strong need for collateral
Lower interest rate	Poor institutional capacity
Opportunity	**Threat**
Government patronization	Prevalence of brokers or unscrupulous bank officials
High social acceptance	Competition with NGOs
Growing demand for agricultural credit	Political influence

CONCLUSION

Agricultural credit has gained importance among policymakers, bankers, and agricultural fraternities in Bangladesh. As a result, the extent of this programme is increasing every year in terms of both target and actual disbursement. Farmer's loan sanction cost substantially high due mainly to undue deals with some unscrupulous bank officials and brokers. The borrower used nearly half (54%) of the BKB sanctioned credit for Boro rice cultivation, about 21% to purchase foods for family consumption, and the rest (25%) for other purposes (e.g., reimbursement of previously received credit of formal and informal sources, and various other income-generating activities including petty trading). The cost of Boro rice cultivation was higher for credit users as they used more labour, and they obtained higher returns as credit users harvested higher yield. It may due to better management (e.g., timely performed intercultural operations because of availability of capital) and for not selling the marketable surplus immediately after harvesting. The benefit-cost ratio (BCR) indicated that BKB credit borrowers obtained more benefits through Boro rice cultivation than non-borrowers. Wide operational network with well-established infrastructure and experienced manpower, the lowest interest rate was being reported as strengths of the BKB agricultural credit programme whereas long and delayed institutional procedure, the strong need for collateral, and poor institutional capacity was being identified as the weaknesses of the programme. On the other hand, government patronization, high social acceptance, and the fastest-growing demand for agricultural credit were being mentioned as great opportunities while the prevalence of brokers or corrupt officials and political influence were marked as major threats to the agricultural credit programme of BKB. Making the whole agricultural credit programme procedure more convenient and user-friendly for the borrower farmers may reduce the amount of unofficial cost of loan sanctioning, which will affect the ultimate goal of the programme to a positive extent. The presence of brokers or notorious activities by the corrupt bank officials should be stopped by any means. The requirements for collaterals should be reconsidered in order to ensure the inclusion of poor and marginal group of farmers. Also, the allocation of credit should be increased to enable the farmer to cope up with modern input-intensive Boro cultivation. BKB needs to be strengthened more by including more trained personnel and increasing the institutional capacity with adequate facilities. However, focusing on such an important tool for the country's long-term crop production, more advanced research is strongly recommended.

AUTHORS' CONTRIBUTION

LD and MARS generated idea; MABS coordinated the research; LD developed methodology; LD, MARS and MABS provided scientific insights; LD and MARS gathered data; LD carried out analysis, synthesis and drafted the manuscript; LD, MARS and RB did the writings of all versions of the manuscript; MARS, MABS and RB performed critical review and editing; All authors read and approved the final manuscript.

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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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