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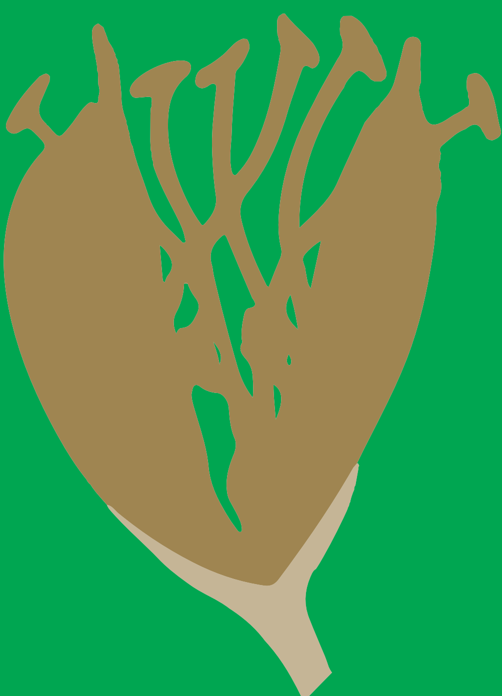

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Assessing Impact of BRRI Released Modern Rice Varieties Adoption on Farmers' Welfare in Bangladesh: Application of Panel Treatment Effect Model

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ABSTRACT

This study assesses the impact of Bangladesh Rice Research Institute (BRRI) released modern wet (*Aman*) season rice variety adoption on farmers' well-being in Bangladesh. Bangladesh Integrated Household Survey (BIHS) data collected by IFPRI were used for this study. The study applied difference-in-difference treatment effect and difference-in-difference quantile treatment effect models using unbalanced panel data to achieve the set objectives. Analysis revealed that BRRI released wet (*Aman*) season rice technology has a robust and positive effect on small farmers' welfare in Bangladesh as indicated by the level of increases in per capita household real income, increases in real aman rice income, and also increases in yield and decreases both in poverty gap and squared poverty gap over time. The marginal and near landless farmers have not gained significantly through adopting BRRI released modern variety over non-adopters in terms of all the indicators except aman rice yield. However, only yield of BRRI released modern wet (*Aman*) season rice technology has positive and significant impact on the marginal and near landless farmers. As such, BRRI variety adoption seemed to be conducive in increasing the level of yield of marginal and near-landless farms but it hardly helps them to overcome the poverty level, unless other equity-enhancing policy measures are undertaken. Overall, there was large scope for enhancing adoption of BRRI released rice variety in order to reduce the poverty level in rural areas. The current rice policy (rice self-sufficiency) appears to be supportive to help Bangladesh rice sector for achieving food security in the country.

Key words: Adoption, Farmers' welfare, Treatment effect model, Poverty, Self-selection bias, quantile treatment effect model

INTRODUCTION

In Bangladesh, agriculture is the vital sector for attaining the development goals of alleviating poverty and increasing food security. Reducing poverty and improving food security through stimulating agricultural growth primarily depends on the adoption of modern agricultural technologies, including modern rice varieties (MVs). Rice is the main staple food grown in Bangladesh and is the vital crop for food security. Here, rice is grown throughout the year on high land to low land in three seasons. Modern varieties of rice were introduced in Bangladesh in the mid-sixties. In Bangladesh, BRRI was set up in 1970 to develop modern rice varieties better suited to local growing condition. The major achievements of rice research in Bangladesh as in other Asian countries, has been the development of high yielding modern varieties, i.e. seed based technologies. With the rapid development of local rice research capacity 100 high yielding rice varieties (including six hybrid rice) were developed during the last few decades (BRRI, 2019). Efforts were made to popularize those modern varieties among the farmers in different seasons.

The BRRI developed modern rice varieties (MVs) and technology packages played the key role in boosting annual rice production in Bangladesh from 9.93 million tons in 1972-73 to nearly 38.66 million tons annually in 2018-19 (MOA). The respectable growth in rice production was propelled by

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adoption of high yielding modern rice varieties facilitated by an expansion of irrigation infrastructure. The adoption of modern rice seed technology has reached to nearly 87% of the total rice cropped area and rice production has increased more than three folds over the last four and half decades as a result of using high yielding modern rice varieties (BBS, 2019). The official statistics further indicate that, almost 91% of the total rice production in Bangladesh comes from high yielding modern rice varieties (MVs) (FPMU, 2019).

Available literature indicate that, modern rice varieties significantly contribute to improve farmers' well-being over traditional rice varieties (Hazell, 2010). In Bangladesh, modern rice technology developed by BRRI have been disseminated and profusely adopted by the farmers both in the dry (*boro*) and wet (*aman*) seasons over the last four and half decades. There is a large economic literature that investigate the effects of modern rice technology adoption on poverty alleviation and improvement in farmers' welfare (Bellon *et al.* 2006; Evenson and Gollin, 2003; Just and Zilberman, 1988). However, whether the dissemination of modern rice technology contributes to poverty reduction in rain-fed/Aman areas still remained controversial (Hazell, 2010). Given the complex causes underlying poverty and the diversity of livelihoods found among poor people, the relationship between agricultural research and poverty alleviation is necessarily perplexing (Hazell, 2010). There are a number of pathways through which Modern technologies could potentially benefit the poor farmers (Hazell and Haddad, 2001). In fact, gains from Modern agricultural technology have influenced the poor farmers directly by raising incomes of farming households and indirectly by raising employment and wage rates of functionally landless laborers and lowering the price of staple foods (Hossain *et al.* 1994; Winters *et al.* 1998; de Janvry and Sadoulet, 1992; 2002). On the other hand, agricultural research could also work against the poor, since technologies are more suited to larger farms. Recent studies have highlighted that modern technologies have a positive impact on many small farmers, while the gains for the marginal farmers and landless agricultural laborers are too small to raise them above the poverty threshold (Islam, 2018; Hossain *et al.* 2007; Mendola, 2007 in Hazell, 2010). Notably, Pingali (2012) pointed out that petty farmers and landless agricultural laborers in South Asia might not be able to increase their welfare by adopting modern varieties (MVs) of rice, particularly in the rainy season, due to insecure ownership and tenancy rights, poorly developed input, credit, and output markets, and policies that discriminate against the poor.

A major difficulty in assessing the impact of a specific technology, such as Modern rice technology, requires establishing a suitable counterfactual against which the impact can be measured. The impact of Modern rice technology adoption must be separated from that of other socioeconomic factors that simultaneously determine the welfare of the households. Failure in doing so will cause the corresponding impact estimates to be biased (Wu *et al.* 2010 and Mendola, 2007). According to Angrist and Pischke (2009), instrumental variable (IV) based 2sls methodology is good, if the appropriate instruments can be applied. But it is very difficult to discover proper instruments to satisfy the assumptions of IV. Some studies have been conducted earlier to investigate the impact of agricultural technology on farmers' welfare in Asian and African countries using the propensity score matching (PSM) method based on cross sectional data (Mendola, 2007; Becerril and Abdulai, 2010; Khonje *et al.* 2015; Wu *et al.* 2010). However, Crost *et al.* (2007) measured the impact of agricultural technology on farmers' welfare using fixed effect models in India. The above mentioned studies did not consider the sample selection bias and the time invariant source of bias together. Unlike most of the previous studies, the present study is unique as it uses difference-in-difference with treatment effect model using unbalanced panel data to measure the impact of BRRI released modern rice technology in the wet (*aman*) season in rural Bangladesh. A combination of the PSM and DID estimators may overcome both the self-selection bias and time invariant source of bias problems. The DID with PSM estimators measure the impact of the 'treatment' with the difference between the adopters and the non-adopters of modern rice technology in the before-after periods difference in outcome variable.

Although there is little formal evidence to justify bootstrapping (Imbens, 2004), the approach has been widely applied. Specifically, kernel based matching with bootstrapping standard error gives better results (Abadie and Imbens, 2006; Rabalino and Pfaff, 2013). This study followed a bootstrapping methodology to calculate the corresponding standard error of the estimate of the technology impact.

Although Bangladesh has achieved remarkable progress in rice self-sufficiency, poverty is still a major problem. However, this study aims to investigate the heterogeneous impacts of BRRI released MV rice adoption during the rainy season on the welfare of the small, medium, and large farmers as well as to evaluate the current rice sector development policies in Bangladesh.

METHODOLOGY

Data source

For this study, two period panel data were obtained from the Bangladesh Integrated Household Survey (BIHS). The International Food Policy Research Institute (IFPRI) conducted two nationwide survey covering 6,500 nationally representative sample rural households in different divisions of Bangladesh during 2011/12 and 2015. Out of these 6,500 rural households, there are 1,542 wet (*aman*) season rice growing rural households in 2011/12 period and there are 1,522 wet (*T. Aman*) season rice growing households in 2015. The study did not consider 955 households in 2011/12 period and 935 households in 2015 those have adopted both modern and traditional rice varieties. Finally, 587 rural households (same for both periods) were selected on the basis of adoption and non-adoption of modern rice technology. This study used wet (T. Aman) season unbalanced panel data (because approximately 79% of same l and have been cultivated to follow-up period from the base period data) for DID-treatment effect model and quantile DID treatment effect model by using wet (T. Aman) season rice farming households' data of Bangladesh. In this study, real income was calculated using rural general consumer price index (CPI). All income data were converted to make equivalent to that of 2016-17 financial period for better understanding. Data modification and filtering were performed to ensure that the unit of measurement of each variable was consistent with the study objectives, and the quality of data were satisfactory. Although rice production in Bangladesh is carried out in three distinct seasons, this study used data of rice growing households only in the wet season, to achieve the set objectives.

Analytical techniques

i) DID treatment effect approach. According to Villa (2016), DID treatment effects approach[1] is based on the existence of a pair of before-and-after periods, namely, one baseline ($t = 0$) and one follow-up ($t = 1$). The basic DID framework is dependent on the availability of two groups of units i, including a treated

[1]DID treatment effect methodology has borrowed heavily from Villa (2016) article.

group to which the treatment is delivered ($Z_i = 1$) and a control group to which the treatment is not delivered ($Z_i = 0$). The treatment indicator in the DID setting requires absence of any intervention in the baseline for either group ($D_{i,t=0} = 0 | Z_i = 1, 0$), and it requires the intervention to be positive for the treated group in the follow-up ($D_{i,t=1} = 1 | Z_i = 1$). For a given outcome variable, Y_{it}, the population DID treatment effect is given by the difference in the outcome variable for treated and control units before and after the intervention. The single DID setting is given by

$$DID = \{E(Y_{it=1} | D_{it=1} = 1, Z_i = 1) - E(Y_{it=1} | D_{it=1} = 0, Zi = 0)\} - \{E(Y_{it=0} | D_{it=0} = 0, Z_i = 1) - E(Y_{it=0} | D_{it=0} = 0, Z_i = 0)\} \ldots\ldots (1)$$

This single DID can be combined with other non-experimental evaluation methods. Additional control covariates are important when observed heterogeneity may confound the identification strategy. Given the features of DID estimation, observed covariates should be exempted from the effects of the treatment. Thus, if observable covariates (X_i) are available, they can be added into the analysis.

$$DID = \{E(Y_{it=1} | D_{it=1} = 1, Z_i = 1, X_i) - E(Y_{it=1} | D_{it=1} = 0, Z_i = 0, X_i)\} - \{E(Y_{it=0} | D_{it=0} = 0, Z_i = 1, X_i) - E(Y_{it=0} | D_{it=0} = 0, Z_i = 0, X_i)\} \ldots\ldots (2)$$

A complementary method to the DID treatment effect is the incorporation of kernel propensity-score weights. Apart from the inclusion of control variables, observed covariates can be used to estimate the propensity score (the likelihood of being treated) and to calculate kernel weights following Heckman, Ichimura, and Todd (1997, 1998). Instead of accounting for control variables, this method matches treated and control units according to their propensity score. Each treated unit is matched to the whole sample of control units instead of on a limited number of nearest neighbors. To begin, one obtains the propensity score (p_i) for both groups.

$p_i = E(Z_i = 1 | X_i)$

According to Heckman, Ichimura, and Todd (1997), the kernel matching is given by the propensity score, given the covariates, which leads to the calculation of the kernel weights,

$$w_i = \frac{K(\frac{p_i - p_k}{h_n})}{\sum K(\frac{p_i - p_k}{h_n})} \ldots\ldots (3)$$

in which K(·) is the kernel function and h_n is the selected bandwidth. The kernel weights are then introduced into (1) to obtain a kernel propensity-score matching DID treatment effect as follows:

$$DID = \{E(Y_{it=1} | D_{it=1} = 1, Z_i = 1) - w_i \times E(Y_{it=1} | D_{it=1} = 0, Z_i = 0)\} - \{E(Y_{it=0} | D_{it=0} = 0, Z_i = 1) - w_i \times E(Y_{it=0} | D_{it=0} = 0, Z_i = 0)\} \ldots\ldots (4)$$

Now, to increase the internal validity of the DID estimand, one can restrict (4) to the common support of the propensity score for treated and control groups. The common support is the overlapping region of the propensity for treated and control groups. This sample of i units can be restricted to the region defined as

$(i : p_i \in [max\{min(p_i | Z_i = 1), min(p_i | Z_i = 0)\}, min\{max(p_i | Z_i = 1), min(p_i | Z_i = 0)\}])$

Complementarily, when treated and control units cannot be followed over the baseline and follow-up periods, the DID treatment effects can be estimated with repeated cross-sections. This is very common when a treatment has been administered to certain regional or demographic groups over several cross-sections. The kernel propensity score matching with repeated cross-section DID treatment effects is specified following Blundell and Dias (2009).

$$DID = \{E(Yit=1 | Dit=1 = 1, Zi = 1) - w^c_{it=1} \times E(Y_{it=1} | D_{it=1} = 0, Z_i = 0)\} - w^t_{it=0} \times \{E(Y_{it=0} | D_{it=0} = 0, Z_i = 1) - w^c_{it=0} \times E(Y_{it=0} | D_{it=0} = 0, Z_i = 0)\}$$

Here $w^c_{it=0}$ and $w^c_{it=1}$ are the kernel weights for the control group in the baseline and follow-up periods, respectively, while $w_{it=0}^{t}$ is the kernel weight for the treated groupin the baseline period. The three sets of kernel weights are calculated independently according to the estimated propensity score and do not require the panel structure ofthe units in the sample.

Finally, the balancing property of the treated and the control can be tested. Given the availability of observable covariates, it can be shown that in absence of the treatment, the outcome variable is orthogonal to the treatment indicator given the set of covariates. In other words, the balancing property can be tested in the baseline as

$Y_{it=0} \perp Z_i \mid X_i$.................................. (5)

Note that the balancing property is optional in the DID setting. The most important assumption, which is not tested in this approach, is the complement of the parallel paths of the outcome for the treated and the control groups. Given the availability of two periods in this analysis, this assumption cannot be tested here. For an extension of this test, see Mora and Reggio (2012).

DID quantile treatment effect approach. Ninety-five percent of applied econometrics is concerned with mean effects, yet distributional effects are no less important. The distribution of the dependent variable may change in many ways that are not revealed or are only incompletely revealed by an examination of averages. For example, the income distribution can become more compressed or the upper-tail inequality may increase while the lower-tail inequality decreases. Therefore, applied economists and policy makers are increasingly interested in distributional effects. The estimation of quantile treatment effects (QTEs) is a powerful and intuitive tool that allows us to discover the effects on the entire distribution. As an alternative motivation, median regression is often preferred to mean regression to reduce susceptibility to outliers.

We consider the effect of a binary treatment variable D on a continuous outcome variable Y. Let Y_i^1 and Y_i^0 be the potential outcomes of individual i. Hence, Y_i^1 would be realized if individual i were to receive treatment 1, and Y_i^0 would be realized otherwise. Y_i is the observed outcome, which is $Y_i \equiv Y_i^1 D_i + Y_i^0 (1-D_i)$. In this study, we identify and estimate the entire distribution functions of Y^1 and Y^0. Because QTEs are an intuitive way to summarize the distributional impact of a treatment, we focus our attention especially on them. We often observe not only the outcome and the treatment variables but also some characteristics X (independent variables). We can therefore either define the QTEs conditionally on the covariates or unconditionally. In addition, we have to deal with selection on unobservables. Finally, we used this concept to DID kernel framework. See Angrist and Pischke (2009) for detailed information on quantile treatment effects and Meyer, Viscusi, and Durbin (1995) for an illustrative example.

Estimation procedure. To obtain the expected estimates for the specified model equation (1), we rely on linear regression for the single DID analysis. The subsequent complementary introduction of control variables or kernelpropensity-score matching weights is similarly specified by linear regression. In thebasic framework, the estimation can be shown as follows:

$$Outcome\_var_i = \beta_0 + \beta_1 \times period()_i + \beta_2 \times treated()_i + \beta_3 \times period()_i \times treated()_i + e_i$$

Here $outcome\_var_i$ is the outcome variable for each unit; $period()_i$is a binary variable taking the value of 0 in the baseline and 1 in the follow-up periods; and $treated()_I$ is a binary variable indicating the treatment status for each unit, similar to $Z_i = 1$.

The expected values in (1) are obtained from the interaction of the estimated coefficients. The estimated coefficients have the following interpretation:

- $\widehat{\beta_0}$: the mean outcome of the control group at the baseline.

• $\widehat{\beta_0} + \widehat{\beta_1}$: the mean outcome of the control group in the follow-up.
• $\widehat{\beta_2}$: the single difference between the treated and the control groups at the baseline.
• $\widehat{\beta_0} + \widehat{\beta_2}$: the mean outcome of the treated group at the baseline.
• $\widehat{\beta_0} + \widehat{\beta_1} + \widehat{\beta_2} + \widehat{\beta_3}$: the mean outcome of the treated group in the follow-up.
• $\widehat{\beta_3}$: the DID estimation.

Measuring Poverty. In the context of measuring poverty in a population the indices in Foster *et al.* (1984) are commonly used which is expressed as:

$$P_\propto = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{Z-y_i}{Z}\right]^\propto (\alpha > 0)\ and\ (y_i < Z) \ldots\ldots (6)$$

where Z is the agreed-upon poverty line (US$ 1.25/capita/day) converted to Bangladeshi Taka, N is the total household population, y_i is household income per capita for the i[th] person, and $\propto$ is a poverty aversion (sensitivity) parameter. When $\propto = 1$, it is a measure of the poverty gap. When $\propto = 2$, P equals the squared poverty gap, which is used as a measure of the severity of poverty. The study used the international poverty line of US$ 1.25/capita/day for round 1 (2011-12: base period) and US$ 1.90/capita/day (adjusted from US$ 1.25) (WBG, 2016) for round 2, which is converted to taka per capita per year using official exchange rate.

RESULTS AND DISCUSSION

Level of MV rice adoption in two different periods

Data in Table 1 represent the level of rice technology adoption by farm size categories over time. In the base period (2011/12), adoption of BRRI released MV rice varieties by marginal and near landless farms was higher (76.03%) compared to that of medium and large farms (74.51%) and small farms (70.77%), respectively. However, in the follow-up period (2015), adoption of MVs showed a reverse situation for the case of medium and large farms. In case of marginal and near landless farms and small farms, the level of area devotion to modern rice (MVs) adoption increased at a higher rate compared to that for local rice varieties (LV) in wet season over time.

The data in Table 2 depict the level of differences in yield and other relevant economic parameters of the sample farms in the study areas. The result indicates that there is a difference between the yield of adopters and non-adopters within four years. As for the welfare impact of modern rice technology, a straightforward comparison between both per capita total household real income of adopters and non-adopters was considered. While per capita total household real income indicates the ability of the household to purchase its basic needs of life, and thus it provides information on the food security status of households. The result indicates that there is a difference between the per capita total household real income of adopters and non-adopters over time. The mean differences in per capita real income from rice production in the wet (*T. Aman*) season, and wet season rice yield (kg/ha) of adopters and non-adopters indicates that adopters of Modern rice technology are better off than non-adopters over time.

As evident in Table 2, the incidence of poverty was lower among adopters (35.02%) than non-adopters (39.56%) in the base period. On the other hand, incidence of poverty decreased in case of adopters (25.34%) than non-adopter (33.32%) in the follow-up period. The level of poverty in case of adopters decreasing more compared to that of non-adopter over the periods.The depth of poverty was lower among adopters (14.87%) than non-adopters (20.59%) in the base period. On the other hand, depth of poverty decreased in the case of adopters (8.46%) than non-adopter (15.69%) in the follow-up period, and the trend or rate in decrease of poverty was higher in case of the MV adopters. In addition, severity of poverty was also lower (7.51%) among adopters as compared to the non-adopters (11.24%) in the base period. Similarly, the severity of poverty was also lower (4.42%) among adopters as compared to the non-adopters (8.71%) in the follow-up period.

Based on the availability of unbalanced panel data, the welfare impact of the adoption of modern rice technology (BRRI varieties) in wet season on comparatively resource-poor rural households were assessed. Specifically, the focus was on the underlying causal effect of 'direct' impact of modern rice technology adoption. For measuring the impact of modern rice technology adoption on household welfare, the DID treatment effect model (DID-PSM) was employed. Quantile DID treatment effects model was also used for the estimation at specified quantile like 0.25, 0.50 and 0.75.

The study did not employ DID-PSM model in case of large and medium farms, since in this case the sample size was small. For the small farms, causal effect of wet season BRRI developed modern rice technology adoption on per capita household annual real income (tk/year) appeared positive and statistically significant. The increase in real income by the MV adopting farms was 67.80% higher than the non-adopters over the period (Table 3). Furthermore, wet (*T. Aman*) season per capita real rice income (tk/year) was positive and statistically significant and the

Table 1. Rice technology adoption by farm size categories in wet (*T. Aman*) season in Bangladesh.

Farm categories	2011/12 (base period)			2015 (follow-up period)		
	BRRI MVs	LVs	Total	BRRI MVs	LVs	Total
Marginal and near landless farms (<0.21 ha) (no.)	111	35	146	97	24	121
(% of farms)	(76.03)	(23.97)	(100)	(80.17)	(19.83)	(100)
Small farms (0.21 ha –1.01 ha) (no.)	276	114	390	320	90	410
((% of farms)	(70.77)	(29.23)	(100)	(78.04)	(21.96)	(100)
Medium and large farms[1](> 1.01 ha) (no.)	38	13	51	35	21	56
(% of farms)	(74.51)	(25.49)	(100)	(62.50)	(37.50)	(100)
Total farms (no.)	425	162	587	452	135	587
(% of farms)	(72.40)	(27.60)	(100)	(77.00)	(23.00)	(100)

Note: [1)] Due to few sample large farms (2 for 2011-12 and 5 for 2015), they are included in the same category as medium farms.

Table 2. Differences in wet season rice yield and other economic parameters of the sample households by adoption category in two periods.

Items	2011-12 (base period)			2015 (follow up period)		
	Adopter	Non-adopter	T-test	Adopter	Non-adopter	T-test
Rice yield (t/ha)	3180.27	1969.13	1211.14**	3959.92	2243.03	1716.89***
Per capita wet (*aman*) season real income (tk/year)	7501.51	5536.66	1964.85**	7166.43	3520.28	3646.15***
Per capita household real income (tk/year)	92737.04	85099.87	7637.17**	107871.8	76148.69	31723.11***
Head count ratio (HCR) (%)	35.02	39.56	4.54**	25.34	33.32	7.98***
Poverty gap index (PGI) (%)	14.87	20.59	5.72**	8.46	15.69	7.23***
Squared poverty gap index (SPGI) (%)	7.51	11.24	3.73*	4.42	8.71	4.29**
Sample size	425	162	-	452	135	-

Note: Real income based calculation (using rural general consumer price index (CPI): base year 2016-17)
Data source: IFPRI, BIHS: 2011-12 and BIHS: 2015 data.
Official exchange rate:2016-17: US$ 1= 79.1192 Bangladeshi Taka.
***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

effect of adopting MV rice was 88.50% higher than non-adopters over the period. The results further imply that, difference in rice yield in wet season was statistically significant and the effect of adopting BRRI MVs was 30.10% higher than non-adopter over the years. Moreover, poverty gap index and squared poverty gap index appeared positive and statistically significant. The decrease in poverty gap index and squared poverty gap index by the MV adopting farms was 12.90% and 6.10%, higher respectively than the non-adopter over the period. However, per capita household real income, wet (*T. Aman*) season per capita real rice income, and yield obtained by the MV adopters under DID-kernel 1st, 2nd and 3rd quantile farmers have increased significantly compared to that of non-adopter over the period (Table 3).

On the contrary, marginal and near landless farmers did not gain significantly through adopting BRRI released wet (T. Aman) season rice technology vis-à-vis non-adopter for the case of per capita real income, and wet season real rice income, poverty gap index and squared poverty gap index over time (Table 4). However, on average, difference of yield of rice (kg/ha) in wet season was positive and statistically significant and effect of adopting BRRI MVs was 18.5% higher than non-adopter over the period. It implies that dissemination of new rice technology contributes to food availability though it does not impact on the welfare of the marginal and near landless farmers (Table 4). However, per capita household real income, wet (*T. Aman*) season per capita real rice income, and yield obtained by the MV adopters under DID-kernel 1st, 2nd and 3rd quantile farmers did not increase significantly compared to that of non-adopter (Table 4).

Thus, DID treatment effect model estimates indicate that wet season BRRI MV rice technology adoption has a positive and robust impact on household welfare in terms of per capita household annual real income, wet season per capita real rice income, as well as wet season rice yield in Bangladesh. In addition, there has been a trend towards decreasing poverty over the periods of 2011-12 to 2015 in Bangladesh.

Table 3. Results of DID treatment effect analysis for BRRI released modern rice growing households in the wet *(Aman)* season in Bangladesh (Small farm size)

Indicator	DID Kernel (bw=0.03)	Quantile regression		
		DID Kernel (bw=0.03) Quantile(0.25)	DID Kernel (bw=0.03) Quantile (0.50)	DID Kernel (bw=0.03) Quantile (0.75)
Ln rice yield (t ha^{-1})	30.10** (0.130)	15.0** (0.071)	20.30** (0.081)	13.81** (0.064)
Ln per capita wet (Aman) season real income (Tk/year)	88.50** (0.359)	106.80*** (0.194)	129.50*** (0.186)	94.70*** (0.450)
Ln per capita household real income (Tk/year)	67.80*** (0.188)	41.60*** (0.124)	38.10*** (0.114)	46.90*** (0.133)
Poverty gap index (PGI) (%)	-12.90** (0.071)	-	-	-
Square poverty gap index (SPGI) (%)	-6.1* (0.036)	-	-	-
Balancing property satisfied	yes	yes	yes	yes
Common support imposed	yes	yes	yes	yes
Sample size	410	410	410	410

Note: 1) Parentheses indicate bootstrap standard error with 100 replications.
2) ***p < 0.01, **p < 0.05, *p < 0.10.

Table 4. Results of DID treatment effect analysis for BRRI released modern rice growing households in the wet *(aman)* season in Bangladesh (Marginal and near to landless farm size)

Indicators	DID Kernel (bw=0.03)	Quantile regression		
		DID Kernel (bw=0.03) Quantile(0.25)	DID Kernel (bw=0.03) Quantile (0.50)	DID Kernel (bw=0.03) Quantile (0.75)
Ln rice yield (t/ha)	18.5* (0.105)	14.39* (0.077)	16.70** (0.071)	15.3** (0.061)
Ln per capita wet season real income (tk/year)	49.60^{NS} (0.585)	70.90^{NS} (0.669)	98.40^{NS} (0.605)	85.10^{NS} (0.802)
Ln per capita household real income (tk/year)	45.00^{NS} (0.390)	21.0^{NS} (0.453)	14.6^{NS} (0.246)	37.01^{NS} (0.235)
Poverty gap index (PGI) (%)	-21.2^{NS} (0.201)	-	-	-
Square poverty gap index (SPGI) (%)	-12.7^{NS} (0.108)	-	-	-
Balancing property satisfied	yes	yes	yes	yes
Common support imposed	yes	yes	yes	yes
Sample size	146	146	146	146

Note: 1) Parentheses indicate bootstrap standard error with 100 replications.
2) ***p < 0.01, **p < 0.05, *p < 0.10. NS = Not significant

Table 5. Results of DID treatment effect analysis for BRRI released modern rice growing households in the wet *(aman)* season in Bangladesh (Pool farm size)

Indicators	DID Kernel (bw=0.03)	Quantile regression		
		DID Kernel (bw=0.03) Quantile(0.25)	DID Kernel (bw=0.03) Quantile (0.50)	DID Kernel (bw=0.03) Quantile (0.75)
Ln rice yield (t ha^{-1})	25.4** (0.117)	11.0** (0.053)	19.4*** (0.063)	11.8** (0.053)
Ln per capita wet season real income (tk/year)	82.2** (0.326)	99.3*** (0.184)	132.5*** (0.228)	33.6^{NS} (0.306)
Ln per capita household real income (tk/year)	48.8*** (0.133)	22.8** (0.095)	28.2*** (0.084)	36.1*** (0.083)
Poverty gap index (PGI) (%)	- 14.4*** (0.058)	-	-	-
Square poverty gap index (SPGI) (%)	- 6.2** (0.030)	-	-	-
Balancing property satisfied	yes	yes	yes	yes
Common support imposed	yes	yes	yes	yes
Sample size	587	587	587	587

Note: 1) Parentheses indicate bootstrap standard error with 100 replications.
2) ***p < 0.01, **p < 0.05.

CONCLUSION AND POLICY RECOMMENDATIONS

Findings of the study revealed that BRRI released wet (*aman*) season rice technology has a robust and positive effect on small farmers' welfare in Bangladesh as measured by the level of increases in per capita household real income, increases in wet (*aman*) season real rice income, and also increases in wet season rice yield, and decreases both poverty gap and squared poverty gap over time.

On the other hand, the marginal and near landless farmers have not gained significantly through adopting BRRI released modern rice technology over non-adopter in terms of all the indicators except rice yield. However, difference of yield of rice was positive and statistically significant and effect of adopting BRRI MVs was 18.5% higher than non-adopter over the period. Therefore, BRRI rice technology adoption seems to be conducive in increasing the level of yield of marginal and near-landless farms but it hardly helps them to overcome the poverty line, unless other equity-enhancing policy measures are undertaken.

Overall, there is large scope for the enhanced adoption of BRRI released rice technology in order to reduce the level of poverty in rural areas. It is necessary to develop rice technology targeting to increase the level of income as well as reduce the poverty of the resource poor marginal and near landless farmers. Furthermore, the government policy makers, and rice breeders should emphasize not only on the development of stress tolerant rice varieties for addressing the climate change situation but also to take into consideration of different stress prone areas under rice cultivation. Moreover, the government policy makers should further emphasize on the creation of employment opportunity (i.e., expansion of readymade garments industries, cottage industries, jute industries, rural processing and manufacturing industries, handloom industries, transport operations, re-construction and expansion of roads and highways, construction of different infrastructures, and post-harvest processing industries) for the surplus agricultural workers in non-agricultural sector for improving the welfare of the poorest group of farmers. However, the government should focus on the diversification of agricultural production systems in the dry season (introduce new cropping patterns) to increase the annual income and reduce the poverty of the poor farmers. Therefore, the current rice policy might be supported to help to Bangladeshi rice sector for achieving food security in Bangladesh. Thus it (rice self-sufficiency) appears to be supportive to help Bangladeshi rice sector for achieving food security in the country using BRRI released modern seed technology.

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Comparative Study on Seed Production Potentiality of Selected Rice (*Oryza sativa* L.) Hybrid Combinations

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ABSTRACT

The seed production potentialities of selected 20 hybrid rice combination were assessed in this study. Higher seed yield potentiality and earliness in maturity were two of the most important indicators for popularizing hybrid rice variety in Bangladesh. The field performance of the selected hybrid rice combinations were found to vary significantly for different traits except number of total spikelets per panicle showed insignificant variation among the hybrid rice genotypes. The highest number of tillers per plant was recorded in BRRI7A/BRRI31R (17.33) which was followed by BRRI10A/BRRI20R (16.33) and BRRI7A/BRRI20R (16.17). Maximum number of panicles per plant was produced by BRRI7A/BRRI31R (14.00) which was followed by BRRI10A/BRRI31R (13.07), and BRRI11A/BRRI31R (12.47). The highest number of filled spikelets per panicle was produced by BRRI7A/BRRI31R (48.20) which was followed by IR79156A/BRRI31R (47.83) and BRRI7A/BRRI10R (44.63) respectively. The highest value for percent out crossing rate (%OCR) was observed in the combination of BRRI7A/BRRI31R (50.23%) which was followed by BRRI10A/BRRI10R (46.40%). The highest value for grain yield per plant was recorded in BRRI7A/BRRI31R (8.17g) followed by BRRI10A/BRRI10R (7.85 g) and BRRI11A/BRRI15R (7.68 g), respectively. The lowest value for grain yield per plant was found in IR79156A/BRRI31R (3.97 g). Considering comparative study of floral traits, BRRI7A/BRRI31R hybrid rice combination has good commercial prospects but seed production potentiality under Bangladesh conditions needs to be estimated with fine tune.

Key words: Out crossing rate, seed production, potentiality and combinations

INTRODUCTION

Rice is arguably the most important staple food crop in the world. More than half of the world's population consumes rice as their primary source of food, and will almost certainly continue to use rice as the main diet in the future. The most remarkable achievement of Bangladesh since her independence in 1971 is the acceleration of rice production, enabling her self-sufficiency in food production rather than an import dependent one. The production of food grain was 8.74 million metric tons (MMT) in 1971-72 which increased to 34.70 million metric tons in 2014-15 (BBS, 2018).

Hybrid rice technology is one of the most talked issues in our country where strengthening food security is a priority agenda. Feeding the expanding population from the decreasing cultivable land is a great challenge to our agriculture. Moreover, climate change and bio-energy have added extra challenges to food security issue. How to solve this problem? The only option is to expand vertically to balance the equation, food = people. Hybrid rice, as it has the capability to increase yield by 15-20% more than even the best HYV, can be an answer for vertical expansion. Vertical increase in yield can meet the food demand of expanding population. There is a gradual development of hybrid rice cultivation in our country since 2001-2002 to 2016-17. The area planted to hybrid rice in the country during Boro 2016-17 was around 0.7 Mha has contributed 3-4 MT of additional rice

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to the total rice production of the country (AIS, 2018).

Therefore, to break the present yield ceiling of semi-dwarf modern varieties, hybrid rice seems to be an attractive viable alternative if suitable parental lines and effective seed production infrastructure are developed in the public, private, or NGO sectors of the country as well as seed production units should be closely linked with its hybrid rice research units to expedite the transfer of this technology. Therefore, these experiments have been taken for selection of suitable hybrid combination for development of effective seed production ability. So the objective of the research programme was selection of suitable hybrid combination and modifications of the currently used strategies for F_1 hybrid seed production.

MATERIALS AND METHODS

The experiment was conducted at the experimental farm of Bangladesh Rice Research Institute (BRRI), Gazipur during November to May 2017-18. The soil of the experimental field was clay loam in texture having pH of 6.2. It belongs to the Chitra soil series of red brown terrace. Five cytoplasmic-genetic male sterile (CMS) lines (IR75608A, IR79156A, BRRI7A, BRRI10A and BRRI11A) and four (BRRI10R, BRRI15R, BRRI20R and BRRI31R) restorer lines were used. Twenty seed production combinations (IR75608A/RRI10R, IR75608A/BRRI15R, IR75608A/BRRI20R, IR75608A/BRRI31R, IR79156A/BRRI10R, IR79156A/BRRI15R, IR79156A/BRRI20R, IR79156A/BRRI31R, BRRI7A/BRRI10R, BRRI7A/BRRI15R, BRRI7A/BRRI20R, BRRI7A/BRRI31R, BRRI10A/BRRI10R, BRRI10A/BRRI15R, BRRI10A/BRRI20R, BRRI10A/BRRI31R, BRRI11A/BRRI10R, BRRI11A/BRRI15R, BRRI11A/BRRI20R and BRRI11A/BRRI31R) were used in this study. The seed of these parental lines were collected from Hybrid rice division of BRRI. Seeds of all genotypes were soaked separately following BRRI prescribed duration gap between A and R lines for 48 hours in clothes bag. Soaked seeds were picked up from water and wrapped with straw and gunny bag to increase the temperature for facilitating germination. The germinated seeds were sown in seed bed for raising seedlings. The land was prepared thoroughly by 3-4 times ploughing and cross ploughing followed by laddering to obtain a good puddled condition.

The experiment was laid out in a randomized complete block design (RCBD) with three replications. The unit plot size was 4m × 2m. Fertilizer were applied @ 270, 130, 120, 70, and 10 kg/ha of urea, TSP, MOP, zinc sulphate and gypsum, respectively. Total urea was applied in three installments at 15, 35 and 55 days after transplanting (DAT). One third of MOP was applied with 2^{nd}top dressing of urea. Thirty-day-old seedlings of R and A lines were transplanted @ 3-4 seedlings and 2 seedlings per hill, respectively. The row spacing maintained for R-R, R-A and A-A lines were 40, 30 and 15 cm respectively. Hill spacing for both R and A lines were maintained 15 cm. Transplanting was done on different dates as per experimental treatments. Row directions were perpendicular to wind direction. Synchronization of flowering was adjusted at different panicle initiation stages by applying 2% phosphorus solution for earliness and 1% nitrogen fertilizer solution for delay. Proper isolation was maintained through deployment of polythene barriers among the entries. Gibberellic acid (GA_3) at the rate of 220 g/ha was used to improve panicle exertion and prolong duration of floret opening and stigma receptivity. Supplementary pollination was done with a bamboo stick at peak anthesis period for 3 to 4 times maintaining an interval of 30 minutes between them. Intercultural operation, irrigation and protection measures were maintained properly. Seed yield was harvested when it reached physiological maturity stage. Randomly ten hills were selected in each plot and the data were recorded on-days to first flowering, days to 50% flowering, days to maturity, plant height, panicle length, flag leaf length (cm), number of tillers per plant, number of spikelets per panicle, number of filled spikelets per panicle, grain yield per plant, straw yield per plant, harvest index and percent out crossing rate. Data were analyzed using STAR computer software ANOVA-2 and Microsoft Excel programme 2007.

RESULTS AND DISCUSSION

The analysis of variance revealed significant differences among the tested hybrid combinations that indicated the seed production feasibility of hybrid rice combinations exist except for number of total spikelet's per panicle. It showed insignificant variation among the hybrid rice combinations under the present experiment (Table 1).

Table 2 shows the mean performance of hybrid combinations. The highest mean for plant height was found in IR75608A/BRRI20R (97.07 cm) which was followed by IR75608A/BRRI10R (96.37 cm) and IR75608A/BRRI31R (96.00 cm). The lowest mean for plant height was observed in BRRI11A/BRRI20R (80.17 cm) which was followed by BRRI10A/BRRI31R (81.33 cm).

Islam (2013) completely supported the findings of the present experiment when investigating approved hybrid rice genotypes for their seed quality assessment. The longest period for first flowering was found in IR79156A/BRRI15R (122.93 days) followed by IR75608A/BRRI15R (121.43 days) and IR79156A/BRRI10R (121.38 days),

Table 1. Analysis of variance for different characters in 20 combination rice hybrids (A × R) during Boro 2017-18.

Source of Variance	DF	Character												
		Plant height (cm)	No. of tillers /plant	Days to first lowering	Flag leaf length	Days to 50% flowering	Panicle length (cm)	No. of total grain/panicle	No. of filled grain/	Out crossing rate (%)	Days to maturity	Seed yield/plant (g)	Straw yield/plant (g)	Harvest index
Treatment (MS)	19	121.50**	5.41**	133.27**	29.95**	133.27**	3.44**	128.94^{NS}	33.68**	97.61**	136.13**	4.26**	46.29**	15.14**
Replication (MS)	2	12.11	8.96	27.75	7.10	26.96	4.72	1807.85	21.34	79.57	14.59	0.677	7.46	34.00
Error (MS)	38	0.8997	1.928	0.691	2.797	0.691	1.174	125.267	8.689	0.595	0.67	0.125	1.803	3.258
CV %		1.04	9.38	0.72	7.02	0.69	4.80	8.46	7.36	2.12	0.55	6.32	7.85	7.28

Legend: DF = Degree of freedom, NS = Insignificant and ** Significant at the 1% level of significance, CV= Co-efficient of variation.

whereas BRRI7A/BRRI31R took the shortest time (102.93 days) which was followed by BRRI7A/BRRI20R (103.60 days). The longest period for 50% flowering was found in IR79156A/BRRI15R (128.27 days) followed by IR75608A/BRRI15R (126.77 days) and IR79156A/BRRI10R (126.71 days), on the other hand BRRI7A/BRRI10R and BRRI7A/BRRI31R took the shortest time (108.27 days) which was followed by BRRI7A/BRRI20R (108.93 days). Shikder (2010) found similar results while working with exotic hybrid rice genotypes in Boro season. Rice varieties in Boro season showed great fluctuations on flowering dates. These results are in close agreement with the previous findings by Roy (2006) and Ali 2007. The highest mean number of tillers per plant was recorded in BRRI7A/BRRI31R (17.33) which was followed by BRRI10A/BRRI20R (16.33) and BRRI7A/BRRI20R (16.17). The lowest mean number of tillers per plant was observed in IR75608A/BRRI10R (12.53) which was followed by IR75608A/BRRI20R (12.77) and IR75608A/BRRI15R (12.83). Rice plant generally produces more number of tillers than panicles. Unproductive tillers or the tillers that are produced at later dates and do not produce panicles before harvest are rather wasteful process (Mamin, 2003). The above findings were also supported by Saha (1998). Yadav (2001) also found similar trend in case of significant variability for number of tillers per plant in rice. The longest flag leaf length was found in IR75608A/BRRI15R (31.37cm) which were followed by BRRI10A/BRRI20R (29.80 cm) and IR79156A/BRRI10R (25.63 cm). The shortest flag leaf length was recorded in IR75608A/BRRI10R (15.97 cm). Maximum number of panicles per plant was produced by BRRI7A/BRRI31R (14.00) which was followed by BRRI10A/BRRI31R (13.07), and BRRI11A/BRRI31R (12.47). The minimum number of panicle per plant was produced by IR75608A/BRRI15R (8.17) which was followed by IR75608A/BRRI10R (8.37). Islam (2013) somehow agreed with the present results. They found moderate number of panicle per plant with high genetic advance in percent of mean during working with developed hybrid rice genotypes. Rahman (2010) completely supported the findings of the present experiment while working with BRRI hybrid dhan2 variety for hybrid seed production.

The longest day to maturity was recorded 154.60 days in IR79156A/BRRI15R which was followed by IR75608A/BRRI15R (153.10 days). BRRI7A/BRRI10R took the shortest time (134.33 days) for maturation which was followed by BRRI7A/BRRI31R (134.67 days) and BRRI7A/BRRI20R (135.00 days). This feature indicated less influence of environment on the expression of this character. Hossain (2004) reported similar results of the present study, while working with 30 rice genotypes. Nath (2005) also supported the above findings for days to maturity in T. Aman rice varieties. The longest panicle length was observed in IR79156A/BRRI10R (24.60 cm) which was followed by IR75608A/BRRI20R (24.57 cm) and BRRI7A/BRRI10R (24.40 cm) respectively. The shortest panicle length was observed in IR75608A/BRRI10R (21.17 cm) which was followed by IR79156A/BRRI31R (21.33 cm). Bhandarkar *et al,* (2002) evaluated 52 genotypes of rice and reported high heritability for panicle length which supported the present outcomes. The highest number of total spikelets per panicle was found in genotype IR79156A/BRRI31R (148.87) which was followed by BRRI7A/BRRI10R (140.90). The lowest number of total spikelets per panicle was recorded in genotype BRRI11A/BRRI31R (119.97) which was followed by BRRI11A/BRRI20R.

Shikder (2010) completely supported the findings of the present experiment while investigating enormous exotic hybrid rice genotypes for their seed quality assessment. The highest value for percent out crossing rate (%OCR) was produced by the combination BRRI7A/BRRI31R (50.23%) which was followed by BRRI10A/BRRI10R (46.40%). The lowest value for percent out crossing rate

(%OCR) was found in the combination of BRRI7A/BRRI15R (30.30%) which was followed by BRRI7A/BRRI10R (32.47%). The highest value for straw yield per plant was recorded in BRRI7A/BRRI31R (25.50 g) which was followed by BRRI10A/BRRI10R (24.60 g) and BRRI10A/BRRI15R (23.97 g) respectively. The lowest value for straw yield per plant was found in IR79156A/BRRI31R (12.20 g) which was followed by BRRI7A/BRRI15R (13.70 g). The highest value for harvest index was found in BRRI11A/BRRI15R (28.53%) which was followed by BRRI7A/BRRI15R (28.16) and BRRI7A/BRRI10R (26.06%) respectively. The lowest value for harvest index was recorded in BRRI10A/BRRI15R (17.02%) which was followed by BRRI11A/BRRI10R (23.73%). Iftekharudduala *et al.* (2001) found low GCV and PCV with high heritability and high genetic advance in percent per mean in irrigated rice which is more or less similar to the present study.

Table 2. Mean SD and SE value of seed yield contributing character of selected approved combinations of hybrid rice.

Combination	Plant height (cm)	No. of tillers / plant	No. of panicle/ plant	Panicle length (cm)	No. of total grain/ panicle	Out crossing rate (%)	Flag leaf length (cm)	Straw yield/plant (g)	Harvest index	Days to first flowering	Days to 50% flowering	Days to maturity
IR75608A/BRRI10R	96.37a	12.53f	8.37i	21.17f	129.63	33.50h	15.97h	15.44c-e	25.55a-c	120.21b-d	125.55b-d	151.88b-d
IR75608A/BRRI15R	94.33cd	12.83ef	8.17i	22.67b-f	124.47	36.07g	31.37a	15.73c-e	24.95c	121.43b	126.77b	153.10b
IR75608A/BRRI20R	97.07a	12.77ef	8.60hi	24.57a	137.76	31.83i-k	21.77fg	14.30c-f	24.88c	119.93cd	125.27cd	151.60cd
IR75608A/BRRI31R	96.00ab	14.00c-f	9.30g-i	23.27a-e	129.83	42.40d	23.81b-f	20.00b	24.63c	118.93d-f	124.27d-f	150.60d-f
IR79156A/BRRI10R	93.33cd	14.07b-f	9.90d-i	24.60a	127.07	31.17kl	25.97b	13.97d-f	26.41a-c	121.38b	126.71b	153.05b
IR79156A/BRRI15R	94.13cd	12.93d-f	9.67f-i	21.53ef	134.63	32.83h-j	25.07b-d	16.25c	26.03a-c	122.93a	128.27a	154.60a
IR79156A/BRRI20R	92.93de	14.87b-e	10.70c-h	22.49c-f	135.27	41.07e	22.63d-g	20.67b	24.94c	120.27b-d	125.60b-d	151.93b-d
IR79156A/BRRI31R	93.87cd	13.93c-f	9.77e-i	21.33f	148.87	31.67jk	23.23b-g	12.20f	24.38c	120.93bc	126.27bc	152.60bc
BRRI7A/BRRI10R	92.90de	15.50a-c	11.33b-g	24.40ab	140.90	32.47h-j	25.63bc	15.43c-e	26.06a-c	102.93k	108.27k	134.33k
BRRI7A/BRRI15R	93.17cd	15.33a-c	12.33a-c	21.87d-f	132.98	30.30l	24.90b-d	13.70ef	28.16ab	104.60j	109.93j	136.00j
BRRI7A/BRRI20R	94.57bc	16.17a-c	12.00a-e	23.73a-c	129.89	33.60h	23.13c-g	15.63c-e	25.37bc	103.60jk	108.93jk	135.00jk
BRRI7A/BRRI31R	91.60e	17.33a	14.00a	23.43a-d	135.26	50.23a	24.60b-e	25.50a	24.29c	102.93k	108.27k	134.67jk
BRRI10A/BRRI10R	81.43gh	15.83a-c	11.67b-f	22.60c-f	129.13	46.40b	24.20b-f	24.60a	24.19c	115.55i	120.88i	147.21i
BRRI10A/BRRI15R	83.03f	15.33a-c	12.00a-e	21.60ef	132.00	37.87f	23.70b-g	23.97a	17.02d	117.07gh	122.4gh	148.73gh
BRRI10A/BRRI20R	82.67fg	16.33ab	12.17a-d	22.00c-f	138.96	35.53g	29.80a	16.13cd	23.95c	116.93gh	122.27gh	148.60gh
BRRI10A/BRRI31R	81.33gh	15.90a-c	13.07ab	22.13c-f	133.07	32.53h-j	21.77fg	14.50c-e	24.59c	116.40hi	121.73hi	148.07hi
BRRI11A/BRRI10R	82.00fg	15.20a-d	11.03b-g	21.93d-f	134.50	32.97hi	22.90c-g	14.20c-f	23.73c	117.93e-g	123.27e-g	149.60e-g
BRRI11A/BRRI15R	82.17fg	14.17b-f	10.67c-h	22.30c-f	128.80	44.80c	20.97g	19.97b	28.53a	118.93d-f	124.27d-f	150.60d-f
BRRI11A/BRRI20R	80.17h	15.27a-c	11.43b-g	21.90d-f	123.60	32.33h-k	22.77d-g	15.43c-e	24.07c	119.27de	124.60de	150.93de
BRRI11A/BRRI31R	81.67f-h	15.77a-c	12.47a-c	22.03c-f	119.97	36.67fg	22.03e-g	14.37c-f	24.34c	117.60f-h	122.93f-h	149.27f-h
Mean	89.24	14.80	10.93	22.58	132.28	36.31	23.81	17.10	24.80	115.99	121.32	147.62
SD	6.33	1.81	2.00	1.42	13.55	5.87	3.16	4.04	2.85	6.66	6.65	6.69
SE	1.415	0.405	0.447	0.318	3.030	1.313	0.707	0.903	0.637	1.489	1.487	1.496
CV%)	1.04	9.38	12.55	4.80	8.46	2.12	13.27	7.85	7.28	0.717	0.685	0.554

Legend: SD= Standard deviation (SD), SE= Standard error and CV= Co-efficient of variation.

The highest number of filled spikelets per panicle was produced by BRRI7A/BRRI31R (48.20) which was followed by IR79156A/BRRI31R (47.83) and BRRI7A/ BRRI10R (44.63) respectively. Table 3 shows the lowest number of filled spikelets per panicle exhibited by BRRI11A/BRRI31R (36.27) which was followed by BRRI10A/ BRRI15R (36.37). Almost similar result was quoted by Bidhan *et al*. (2001) who reported high heritability coupled with high genetic advance for number of filled spikelet's per panicle.

The highest value for grain yield per plant was recorded in BRRI7A/BRRI31R (8.17g) which was followed by BRRI10A/ BRRI10R (7.85 g) and BRRI11A/BRRI15R (7.68 g) respectively. Table 3 shows the lowest value for grain yield per plant found in IR79156A/BRRI31R (3.97 g) which was followed by BRRI11A/ BRRI10R (4.44 g). Similar report was presented by Shrirame and Muley (2003) who worked out high co-efficient of variability with high heritability for grain yield per plant in hybrid rice. Mishra and Verma (2002) also reported high heritability coupled with high genetic advanced for yield per plant in rice. Iftekharudduala et al. (2001) reported high variation among genotypes in respect of the trait which is similar to the present study. Roy (2006) also expressed similar agreement with the results of the present study.

Table 3. F_1 seed production potentiality of different CMS lines crossed with restorer lines.

Combination	No. of filled grain/panicle	F_1 seed yield per plant (g)
IR75608A/BRRI10R	40.40b-d	5.29c-f
IR75608A/BRRI15R	37.73cd	5.23c-f
IR75608A/BRRI20R	39.13cd	4.74e-h
IR75608A/BRRI31R	38.53cd	6.54b
IR79156A/BRRI10R	38.67cd	5.01d-h
IR79156A/BRRI15R	40.87b-d	5.71c
IR79156A/BRRI20R	40.40b-d	6.87b
IR79156A/BRRI31R	47.83a	3.97i
BRRI7A/BRRI10R	44.63ab	5.42cd
BRRI7A/BRRI15R	36.63cd	5.37cd
BRRI7A/BRRI20R	37.33cd	5.31c-e
BRRI7A/BRRI31R	48.20a	8.17a
BRRI10A/BRRI10R	38.60cd	7.85a
BRRI10A/BRRI15R	36.37cd	4.90d-h
BRRI10A/BRRI20R	41.20bc	5.07d-g
BRRI10A/BRRI31R	40.63b-d	4.72f-h
BRRI11A/BRRI10R	39.30cd	4.44hi
BRRI11A/BRRI15R	38.53cd	7.68a
BRRI11A/BRRI20R	39.37cd	4.90d-h
BRRI11A/BRRI31R	36.27d	4.63gh
Mean	40.03	5.59
SD	4.14	1.21
SE	0.926	0.271
CV	7.36	6.32

Legend: SD= Standard deviation (SD), SE= Standard error and CV= Co-efficient of variation.

Seed production feasibility of hybrid rice combination in Boro season 2017-18, BRRI7A/BRRI31R hybrid rice combination showed considerable positive significant variation over an average in respect of yield and desirable variation for earliness in maturity.

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Farmer`s Perception about Resurgence of Brown Planthopper, *Nilaparvata Lugens* (Stål) in Bangladesh

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ABSTRACT

Studies were conducted on resurgence of brown planthopper (BPH), *Nilaparvata lugens* (Stål) and its possible management through a survey in six different regions (viz Tanore, Rajshahi; Niamatpur, Naogaon; Nachole, Chapai Nawabganj; Sadar, Dinajpur; Tarash, Sirajganj and Trishal, Mymensingh). Farmer's perception of BPH resurgence and its management was more or less similar in different regions with some exception. About 60% farmers were able to identify BPH and 40% farmer could identify the pest problem at the later stage of the infestation when burning symptom was visible in patches. All the respondent farmers (100%) relied on use of insecticide where the selection of insecticide as well as its application was not appropriate.

Key words: Brown planthopper, resurgence, farmer`s perception

INTRODUCTION

Insect pests and diseases are the important limiting factors of rice production in Bangladesh. Among the pests of rice, the brown planthopper (BPH), *Nilaparvata lugens* (Stål.) (Homoptera: Delphacidae) has gained major importance in several Asian countries including Bangladesh. The control of this insect pest has always been emphasized and largely relied on insecticides in most rice producing countries (Ali *et at*., 2019: Wojciechowska *et al*., 2016; Alam, 2013; Gao *et al*., 1987; Nagata *et al*., 1979) where resistant varieties are not available. In Bangladesh, a number of insecticides are being used to control this particular insect pest.

All the pesticides have different types of effect on the pest, which may lead to the differential development of the next generation of the pest. Heavy uses of broad spectrum chemicals also reduce the biodiversity of natural enemies, lift the natural control, induce outbreak of secondary pests and contaminate eco-system (Singh, 2000).

After application of insecticides, BPH resurgence was reported in Bangladesh (Alam, 2013; Alam and Karim, 1977), India (Ghosal and Chatterjee, 2018; Varadharajan *et al*., 1977, Chandy, 1979), Indonesia (Oka, 1991; Soekarna, 1979), the Philippines (Heong and Hardy, 2009), Poland (Wojciechowska *et al*., 2016) and the Solomon lslands (Stapley *et al*., 1979). Most of the hopper burned fields reported or observed in India, Indonesia, Philippines, and Sri-Lanka received insecticides before the outbreak. In insecticide trials on experiment at stations and in farmer`s fields, hopper burn commonly occurs in treated plots while untreated areas remain relatively free of infestation.

Entomologists and plant protection researchers at home and abroad have taken much attention on resurgence of insect pests after application of some insecticides (Wojciechowska *et al*., 2016; Alam, 2013). Some of the researchers (Bommarco *et al*., 2011; Flávio *et al*., 2010; Hajek, 2004; Zhang *et al*., 1988) thought that resurgence of insect pests might be happened because a number of

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natural enemies were killed by some insecticides. Some of the researchers thought that it probably resulted from stimulated fecundity of certain pests after the applications of some insecticides. International Rice Research Institute (IRRI) widely studied the resurgence of BPH population and pointed out that the cause of resurgence of BPH was that natural enemies were killed or plants which grew luxuriantly attracted pests. Another report from IRRI in 1980 indicated that 16 kinds of insecticides could result in resurgence of BPH, and suggested that it was not the principal cause of resurgence for insecticides to kill predators. Some researchers also reported the problem of BPH in China (Heong and Hardy, 2009; Gu, 1984; Gao *et al.*, 1988).

Improper methods of application of some insecticides also caused resurgence. According to IRRI report (1977), application of Furadan on crop leaf resulted in resurgence of BPH. But application of Furadan on soil didn't result in resurgence (Gao Chunxian *et al.*, 1988), because it made predators and parasites not to come into contact with insecticide and protected them. However, the reason behind the outbreak of BPH in Bangladesh is not well understood.

To find out the reasons for resurgence a survey was conducted on the farmer`s perception about brown planthopper resurgence.

MATERIALS AND METHODS

The survey was carried out at six districts of Bangladesh to study on the farmer perception about brown planthopper (BPH) resurgence in T. Aman season 2014.

There are three methods by which survey data can be gathered (Dillon and Hardaker, 1993). These are i. Direct observation; ii. Interviewing of respondents and iii. Records kept by respondents. Since the farmers of Bangladesh do not usually maintain records, the second method was followed to achieve the objectives. However, survey method is not free from drawback. The main drawback of this method is to rely on the memory of the respondents. To minimize errors, repeated visits were made to collect data and in case of any omission or contradiction the farmers were revisited to obtain the missing and/or correct information.

Selection of the study area. The areas where brown planthopper resurgence was reported in transplanted Aman season 2014 were selected for survey. A lot of news were published in several local and national newspaper of Bangladesh about the resurgence of brown planthopper (Table 1). On the basis of severity of attack and the communication facilities, six upazilas of six districts namely: Tanore, Rajshahi; Niamatpur, Naogaon; Nachole, Chapainawabganj; Tarash, Sirajganj and Trishal, Mymensingh were selected.

Period of survey. The survey was done in T. Aman, during the period from October to November 2014, when the rice crop was at booting to harvesting stage.

Selection of farmers. Farmers who cultivate irrigated rice in the dry and intermediate zones and favourable rainfed rice in the wet zone were selected for the survey. A total of 180 farmers were selected for collecting data to fulfil the objective. About 30 farmers, selected at random, were interviewed in an upazila of each district.

Survey instrument/questionnaire. In conformity with the objectives of the study, a preliminary questionnaire was designed for collecting data from the selected farmers. The draft questionnaire was pre-tested with a few sample farmers of the study areas. Thus, some parts of the draft questionnaire were improved, rearranged and modified in the light of the actual and practical experiences gained from the pre testing. The questionnaire was finally developed in a simple manner, so that accurate information could be obtained without repetition and misunderstanding.

Data collection. The survey was designed to describe the sociodemographic profile of rice farmers in the selected districts, record the agronomic and pest management practices in T. Aman 2014 (July to December 2014), and obtain detailed information about farmers' knowledge and attitudes on insect pests and natural enemies of rice and their use of pesticides. Their knowledge in traditional pest control methods was also inquired. Detailed information on the use of insecticide such as product name, manufacturer, group, technical grade (a. i. %), frequency and time of application and doses of insecticide were recorded.

Date processing. The collected data were coded, summarized and processed for analysis. Data were also verified to eliminate possible errors and inconsistencies. The first step was taken to scrutinize the data of each and every schedule to find out any inconsistency or omission in the data collection and to avoid irrelevant information.

Statistical analysis. After completing the pre-tabulation task, actual tabulation work was started. Processed data were transferred in excel worksheet. Simple statistical analysis, such as percentage, mean, standard deviation (SD), coefficient of variation (CV), standard errors (SE) were determined for the interpretations of the findings of the study.

RESULTS

Farmer's Knowledge about identification of brown planthopper (BPH)

Table 2 presents of farmers, knowledge about identification of BPH. Among the six districts, the highest number of farmers, able to identify the brown planthopper was found in Sirajganj (Tarash) and the lowest was found in Mymensingh (Trishal). In Sirajganj 80% farmers told that BPH is a serious pest of rice and 20% farmers had no knowledge about BPH. In Mymensingh the knowledge level of the farmer about BPH was very poor, which was just opposite scenario of Sirajganj. About 80% farmers had no knowledge of BPH in that surveyed area of Mymensingh. In other four districts, above 50% farmers were efficient in identifying the pest brown planthopper.

Table 1. List of local and national newspapers those published the news of BPH resurgence in 2014.

Newspaper	Date of publication	Title
Alokito Bangladesh	16.11.2014	*Rajshahite dhan khete poker akromon*
Janakantha	16.05.2014	*Sugandhi atoper khete pokai biborno*
Sonar Desh	18.11.2014	*Tanore chini atob dhane current poker akromon*
Jugantor	14.10.2014	*Barendro anchole aman khete karant poker akromon*
Bonik Barta	26.10.2014	*Poker akromone dishahara dinajpurer krishak*
Daily Sangram	24.10.2014	*Dinajpur o Nilphamarite poker akromone krishekra dishahara*
Daily Naya Digonta	24.10.2014	*Dinajpur o porshai dhankhete current poka: krishak dishahara*
Daily Prothom-Alo	29.10.2014	*Dinajpure current poker akroman koiksho acre aman dhan nosto*
Daily Sanbad	13.11.2014	*'Gach foring' niontrone trisale nana uddug*
Doinik Sodas sangbad	13.11.2014	*Aman dhane badami gach foring*
Doinik Bishsar Mukhopatro	13.11.2014	*Aman dhane badami gach foring akromon: potirodhe trisala squard goton*
Amar Desh	8.11.2014	*Mymensinghe dhan khete poker akromon: aman utpadon ordhake neme ashar asonka*
Doinik Jahan	8.11.2014	*Bivinno upazilai poker akromon aman phosolar bapok khoti*

Table 2. Ability of farmers of different areas in identifying brown planthopper.

Location		Identifying ability of respondent farmers	
District	Upazila	Able to identify (%)	Unable to identify (%)
Rajshahi	Tanore	66.67	33.33
Naogaon	Niamatpur	63.33	36.67
Chapainawabganj	Nachole	76.67	23.33
Dinajpur	Sadar	60	40
Sirajganj	Tarash	80	20
Mymensingh	Trishal	20	80

- Mean value of 30 farmers in each location

Farmer`s understanding about the infestation of brown planthopper

In the survey area, farmers understood the infestation of BPH by some parts of the land were burnt, the presence of insects at the base of the plant and both. The highest number of farmers were found in Mymensingh (76.67 %) who understood the infestation of brown planthopper as some parts of the land were burnt and the lowest number was in Sirajganj (13.33%). In case of insects present at the base of the plant, the highest number of farmers was found in Dinajpur (50%) and the lowest was in Mymensingh (20%). In both cases, 43.33 % farmers of Sirajganj was found to understand the infestation of brown planthopper and only 3.33% farmers were couscious about it in Mymensingh (Table 3).

Brown planthopper management information

In all the survey areas, 100% farmers used chemical insecticides in controlling brown planthopper. No farmer was found to manage the brown plant hopper by using cultural, biological or any other methods.

Determination of insecticide selection in controlling BPH

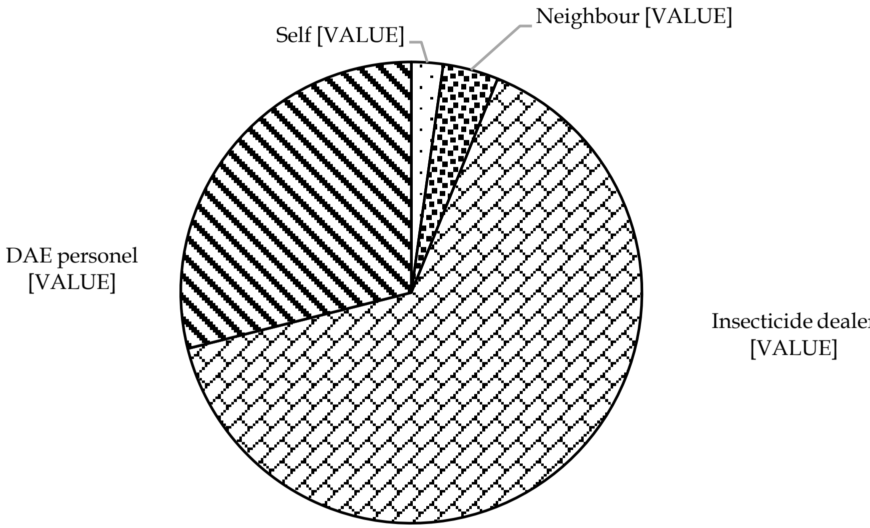
Selection of insecticide by the farmer for managing BPH was varied greatly. Farmers used four different ways such as self, neighboring farmer, insecticide dealer and agriculture officer/DAE personal to select insecticide. In surveyed area 64.94% farmers selected the insecticide by insecticide dealer and only one fourth farmers (28.89%) selected the insecticide with the help of agricultural officer/DAE personnel (Fig. 1). Only 2% farmers selected insecticide by their own decision and about 4% selected by the advice of neighboring farmer (Fig. 1).

Table 4 presents the details of insecticide selection by the farmers of different regions. In Mymensingh, the highest number of farmers (83.33 %) selected insecticide with the help of insecticide dealer in contrast it was the lowest (40.00 %) in the Sirajganj district. But in case of insecticide selection with the advice of agriculture officer/DAE personal, the highest percentage of farmers (53.33%) was recorded in Sirajganj district and the lowest (13.33%) was in Naogaon and Mymensingh.

Table 3. Farmer's perception (%) about the infestation of brown planthopper.

Location		Judgment of BPH attack		
District	Upazila	Burn symptom in patches (%)	Presence of BPH at the base of the plant (%)	Both (%)
Rajshahi	Tanore	50.00	43.33	6.67
Naogaon	Niamatpur	50.00	33.33	16.67
Chapainawabganj	Nachole	20.00	46.67	33.33
Dinajpur	Sadar	40.00	50.00	10.00
Sirajganj	Tarash	13.33	43.33	43.33
Mymensingh	Trishal	76.67	20.00	3.33

- Mean value of 30 farmers in each location.



- Fig. 1. Influence of different stakeholders on the insecticide selection by farmers.

Table 4. Influence of stakeholders on farmers insecticide selection decision to manage brown planthopper in different areas.

Location		Decision of insecticide selection			
District	Upazila	Self (%)	Neighbor Farmer (%)	Insecticide dealer (%)	DAE personnel (%)
Rajshahi	Tanore	3.33	3.33	73.33	20.00
Naogaon	Niamat-pur	3.33	6.67	76.33	13.33
Chapai Nawabganj	Nachole	-	-	66.67	33.33
Dinajpur	Sadar	3.33	6.67	50.00	40.00
Sirajganj	Tarash	3.33	3.33	40.00	53.33
Mymensingh	Trishal	-	3.33	83.33	13.33

- Mean value of 30 farmers in each location

Insecticide application decision as followed by farmers for BPH management

Among the surveyed farmers larger portion (62.78 %) sprayed insecticide when BPH population was over 50 insects per plant and 19.45 % farmers sprayed insecticide when the population level 30 – 50 insects per plants. Only 4.49% farmers applied insecticide before economic threshold level and 13.34% at the time of economic threshold level (Fig. 2).

Table 5 presents time of decision about insecticide application in different areas. The highest number of farmers (16.67%) applied insecticide before economic threshold level (ETL) in Dinajpur district. No farmer was found in the district of Rajshahi, Naogaon, Chapai Nawabganj and Mymensingh to follow the insecticides application before ETL. The farmers of Sirajganj followed ETL in comparatively larger percentage (46.67%) and it was minimum (6.67%) in Rajshahi and Chapai Nawabganj. Insecticide applications at the population level 30-50 BPH/plant was 26.67% in Dinajpur and Sirajganj and 10.00% in Naogaon district. Higher percentage of farmers (80.00%) in Rajshahi and Naogaon sprayed insecticide when the population of insect was over 50 per plant and the lowest percentage (16.67%) followed in the district of Sirajganj.

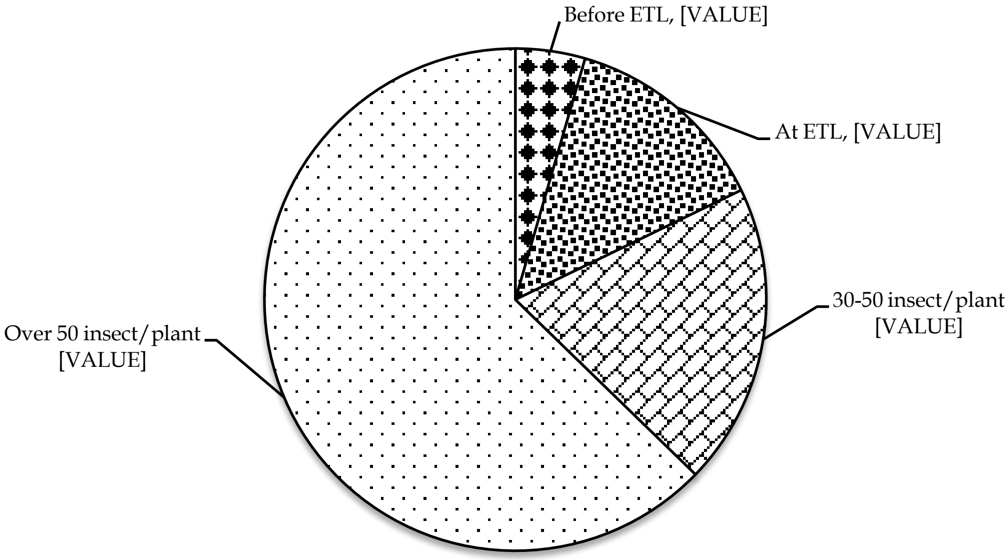


Fig. 2. Farmer's opinion about the insecticide application decision based on level of brown planthopper attack.

Dose of insecticides practiced by farmers to manage the BPH infestation.

Most of the farmers (44.45%) in the surveyed areas sprayed insecticide at sub-lethal dose and only 20% of farmers used to spray at recommended dose (Fig. 3). In the district of Dinajpur, the highest percentage of farmers (70%) used sub-lethal dose and it was the lowest (26.67%) in Mymensingh (Table 6). Use of over dose was also the highest practice of the farmers of Mymensingh (63.33%) and the lowest was in Dinajpur (10%). Comparatively higher percentage of farmer of Sirajganj (43.33%) sprayed the insecticide at recommended dose.

Table 5. Farmer`s practice of insecticide application in six districts based on level of brown planthopper attack.

Location	Level of BPH attack			
District	Before ETL (%)	At ETL (%)	30-50 insect/plant (%)	Over 50 insect/plant (%)
Rajshahi	-	6.67	13.33	80.00
Naogaon	-	10.00	10.00	80.00
Chapai Nawabganj	-	6.67	16.67	76.67
Dinajpur	16.67	10.00	26.67	46.67
Sirajganj	10.00	46.67	26.67	16.67
Mymensingh	-	-	23.33	76.67

- Mean value of 30 farmers in each location.

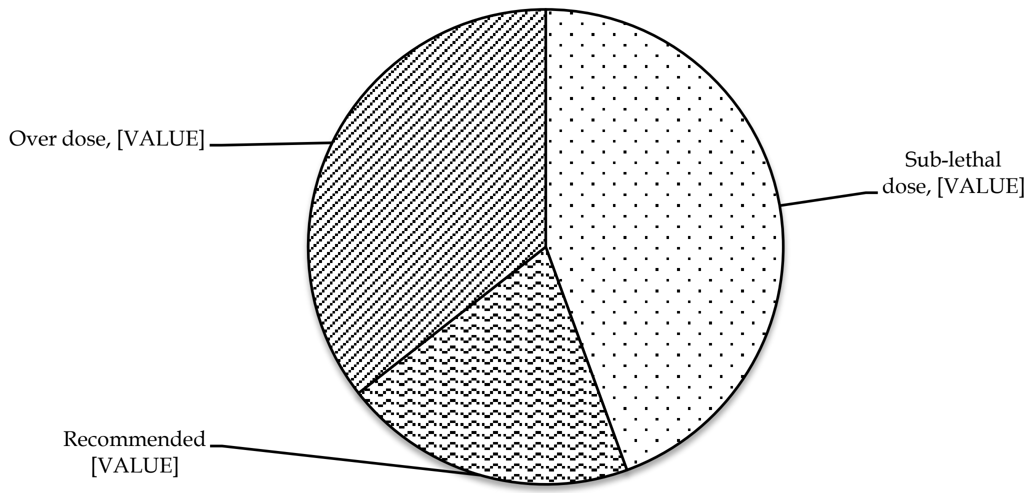


Fig. 3. Farmer`s opinion about insecticide application dose to control brown planthopper in the field.

Spray coverage of insecticide as practiced by farmers in controlling BPH Figure 4 presents the spectrum of plant coverage. A large percentage (59.45%) of farmers used to spray insecticide in controlling brown planthopper at top spectrum, 31.11% farmers followed to cover lower spectrum and only 9.44% farmer sprayed insecticide at both spectrum for the management of brown planthopper.

Table 6. Opinion of farmers of six locations on the insecticide dose used against brown planthopper.

Location		Different dose of insecticide		
District	Upazila	Sub-lethal (%)	Recommended (%)	Over (%)
Rajshahi	Tanore	56.67	13.33	30.00
Naogaon	Niamatpur	33.33	10.00	56.67
Chapai Nawabganj	Nachole	50.00	23.33	26.67
Dinajpur	Sadar	70.00	20.00	10.00
Sirajganj	Tarash	30.00	43.33	26.67
Mymensingh	Trishal	26.67	10.00	63.33

- Mean value of 30 farmers in each location.

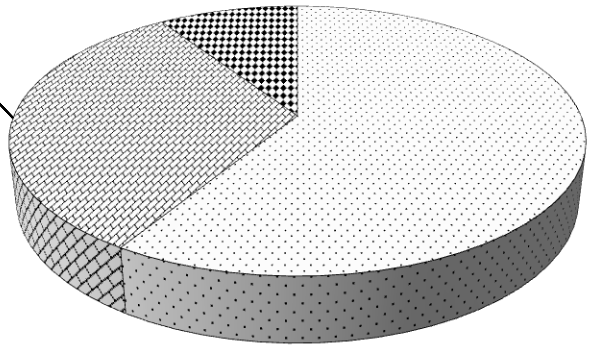


Fig. 4. Spectrum of plant coverage in application of insecticide by the farmer`s in controlling BPH.

Insecticides used in different locations for controlling BPH. Table 7 presents the insecticide molecule used by the farmers in the selected area. From the surveyed area, 16 types of insecticide molecules were reported to be used to control BPH. Among the six districts of six upazila Isoprocarb/MIPC (eg. Mipcin 75WP, Sopcin 75WP, Chabi 75 WP) was used in most of the time. The highest insecticide was used in Rajshahi (Tanore) and the lowest was used in Sirajganj (Tarash). In Rajshahi, Deltamethrin (eg. Decis 2.5 EC), Imidacloprid (eg. Jadid 200 SL, Imitaf 200SL, Confidor 70WG) and Lambda cyhalothrin (eg. Karate 2.5 EC, Fighter 2.5 EC, Jubas 2.5 EC, Rota, 2.5 EC) were used by the majority of farmers. The highest number of farmers of Naogaon (Niamatpur) and Chapai Nawabganj (Nachole) used Isoprocarb/MIPC (eg. Mipcin 75WP, Sopcin 75WP). Pymetrozine (eg. Pleneum 50 WG) was used by the majority of farmers of Dinajpur (Sadar). In Sirajganj (Tarash) the highest number of farmers used Imidacloprid (eg. Confidor 70WG, Beauty 200SL) and Isoprocarb/MIPC (eg. Sopcin 75WP, Chabi 75WP). The majority number of farmers in Mymensingh (Trishal) used Fenvalerate (eg. Fenfen 20 EC).

Yield loss assessment. The yield loss due to brown planthopper resurgence of the surveyed area was documented as per opinion of the farmers of different regions (Table 8). In Rajshahi, the highest yield loss (23%) was found in Chini Atop as well as BRRI dhan34 and the lowest yield loss (13.07%) was in BRRI dhan49. The highest yield loss (31.70%) was noted in BRRI dhan34 and the lowest was (18.51%) in BRRI dhan49 in Naogaon. Farmers of Chapai Nawabganj opined that the highest yield loss (31.71%) occurred in Chine Atop and the lowest (22.81%) was in Swarna. In Dinajpur, 22.81% yield loss was estimated in the Swarna and 18.90% was in BRRI dhan34. The highest (15.33%) yield loss was observed in the Swarna in Sirajganj and the lowest was in BRRI dhan49. But in Mymensingh, the highest yield loss (23.94%) was estimated in BRRI dhan49 and the lowest (15.96%) was in BINA 7.

Among the surveyed area, the highest yield loss (27.32%) was found in Chapai Nawabganj (Nachole) and the lowest (13.86 %) was in Sirajganj (Tarash). Figure 5 presents the amount of yield loss determined according to surveyed area. Fine rice variety showed more yield loss as compared to coarse rice variety.

Table 7. Pattern of common insecticides use in different locations.

Insecticide group	Rajshahi (Tanore)	Naogaon (Niamatpur)	Chapai Nawabganj (Nachole)	Dinajpur (Sadar)	Sirajganj (Tarash)	Mymensingh (Trishal)	Average
Acetamiprid	10.00	6.67	3.33	3.33	-	-	3.89
Acephate	3.33	3.33	6.67	3.33	-	6.67	3.89
Imidacloprid	50	23.33	13.33	46.67	53.33	10	32.78
Cartap	6.67	3.33	6.67	3.33	-	-	3.33
Chlorpyrifos	16.67	23.33	20.00	10.00	3.33	10.00	13.89
Cypermethrin	23.33	13.33	3.33	3.33	-	10	8.89
Deltamethrin	56.67	40.00	30.00	-	-	3.33	21.67
Fenvalerate	-	-	-	-	-	56.67	9.45
Isoprocarb/MIPC	33.33	53.33	50.00	46.67	86.67	10	46.67
Lambda cyhalothrin	53.33	40.00	10	23.33	-	20	24.44
Pymetrozine	26.67	26.67	43.33	73.33	3.33		28.89
Thiamethoxam	3.33	13.33	3.33	20		3.33	7.22
Phenthoate	-	-	-	-	-	30.00	5.00
Abamectin (1%) + Acetamiprid (3%)	23.33	30.00	36.67	-	-	-	15.00
Chlorpyrifos (50%) + Cypermathrin (5%)	30.00	13.33	23.33	20.00	-	6.67	15.56
Thiamethoxam (20%) + Emamectin Benzoate (10%)	10.00	13.33	23.33	30.00	-	-	12.78

- Mean value of 30 farmers in each location.

Table 8. Farmer`s opinion on the yield loss in different rice varieties due to brown planthopper infestation.

District	Variety	Land (ha)	Expected Yield(ton)	Gained Yield(ton)	Yield Loss(ton)	% Yield Loss
Rajshahi	Swarna	30	180	143.42	36.58	20.32
	BRRI dhan34	15	52.5	40.34	12.16	23.16
	BRRI dhan49	15	82.5	71.71	10.78	13.07
	BINA 7	8.44	40.51	34.05	6.46	15.92
	Chini Atop	8	28	21.51	6.49	23.17
Naogaon	Swarna	15.28	91.68	73.05	18.62	20.32
	BRRI dhan34	15.28	53.48	36.53	16.95	31.70
	BRRI dhan49	15.28	84.04	68.68	15.56	18.51
Chapai Nawabganj	Swarna	20	120	92.63	27.37	22.81
	BRRI dhan34	20	70	50.80	19.20	27.43
	Chini Atop	8.13	28.46	19.43	9.03	31.71
Dinajpur	Swarna	9.72	58.32	45.02	13.30	22.81
	BRRI dhan34	53	185.50	150.44	35.05	18.90
Sirajganj	Swarna	6	36	30.48	5.52	15.33
	BRRI dhan34	6.18	21.63	18.47	3.16	14.62
	BRRI dhan 49	12	66	59.16	6.84	10.30
	BINA 7	6	28.8	24.56	4.23	14.72
	Ranjit	16	96	82.23	13.77	14.34
Mymensingh	BRRI dhan34	7.3	25.55	19.63	5.92	23.17
	BRRI dhan49	30	165	125.50	39.50	23.94
	BINA 7	5	24	20.17	3.83	15.96

- Mean value of 30 farmers in each location

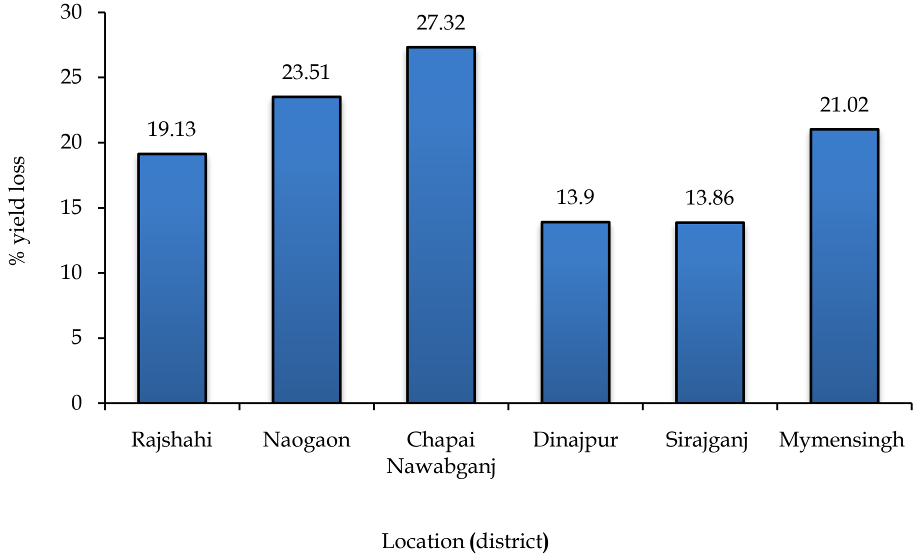


Fig. 5. Average yield loss as estimated by the farmers in different surveyed area in T. Aman season (N=30).

DISCUSSION

Knowledge of farmer about identification of BPH is an important factor for management of BPH resurgence. In surveyed area, 61.11% farmers were able to identify BPH and 38.89% farmers were unable to identify. So there is a lacking about the identification of the pest. In ability of two-third of the farmers could be considered as an important reason of failure for the management of BPH.

Regular monitoring of BPH population is of great importance for management issue as the pest can build its population in very short period of time. Although monitoring helps the farmer to identify the brown planthopper infestation in early stage, 75% farmers of the survey area monitor their field occasionally and only 17.78% farmers practiced monitoring at regular interval. BPH outbreak in the surveyed area is assumed to be due to lack of frequent monitoring. Therefore, identification of initial level of BPH attack and its damage is very much useful for the farmer to manage it successfully. Data on farmers understanding about the infestation of brown planthopper showed that 41.67% farmers identified the infestation of brown planthopper when some parts of the land were burnt, 39.44% farmers identified when presence of insects at the base of the plant and 18.89% farmers identified it is one of the by both conditions. This inability of identifying the damage level or presence of insects in early stage is one of the causes of crop loss due to devastating attack of BPH.

The useful practice of BPH management in all the survey areas was the sole reliance on the use of insecticides. All the farmers (100%) depended on insecticide to manage the BPH problem. No mechanical or cultural practice such as light trap, sweep net was used by the respondent farmers in the surveyed area. Although the pest is supposed to be managed by using different management approaches but in practice only pesticide was used against it.

Respondent farmers in the surveyed area used insecticides of different groups to manage the BPH during T. Aman 2014. Among them Isoprocarb/MIPC (eg. Mipcin 75WP, Sopcin 75WP, Chabi 75 WP), Deltamethrin (eg. Decis 2.5 EC), Imidacloprid (eg. Jadid 200 SL, Imitaf 200SL, Confidor 70WG, Beauty 200SL), Lambda cyhalothrin (eg. Karate 2.5 EC, Fighter 2.5 EC, Jubas 2.5 EC, Rota 2.5 EC), Pymetrozine (eg. Pleneum 50 WG), Fenvalerate (eg. Fenfen 20 EC) were used by maximum number of farmers. It was evident from the list that many of the insecticides were not recommended against BPH.

Most of the farmers (65%) selected the insecticides to manage BPH as per the advice of insecticide dealer. The selection of insecticide through the dealer might have misled the farmers in BPH management. As dealers always motivate the farmers to buy a product which is more profitable for him rather than a recommended one. Only 28.89% farmers in the surveyed area selected insecticide by the help of the agricultural officer/DAE personal. It was clear from the survey data that high dependency on dealer in selecting pesticide aggravated the problem of BPH resurgence.

The farmers sometimes do not have ability to pay the cost of insecticide instantly by cash. They frequently collect the pesticide from the dealer living close to his vicinity with the agreement to pay after the harvest. This system might have limitations to select proper insecticide.

Application of only insecticide could be useful in successful control of BPH but it should be applied with right product and dose following right time and method. Insecticide application time is the key factor to manage its infestation. To manage the BPH infestation properly farmers need to apply the insecticide at economic threshold level (ETL). But in the surveyed area, 82.23% respondent farmers applied the insecticide after ETL. Only 17.83% applied the insecticide at ETL or before ETL. Heinrichs *et at.* (1982) reported the timing of insecticide application ultimately governs BPH resurgence (Heong and Schoenly 1998).

Dose is an important factor to manage the BPH problem. Most of the farmers (44.45%) in all the surveyed areas sprayed insecticide at sub-lethal dose and the lowest number of farmers (20.00%) sprayed at recommended dose. Most of the farmers did not have the facilities for application of pesticides for which they depend on a professional spray man. Sometimes the professional spray man wants to cover more areas in short period of time rather giving proper concentration to the right dose and coverage at lower spectrum of plants. Use of low dose or sublethal dose contributes significantly in the development of resistance and thereby resurgence (Bottrell and Schoenly, 2012; Way and Heong, 1994; Heinrichs and Mochida, 1984; Chelliah, 1979).

Knowledge on the ecology of pest is necessary to manage a pest. As BPH prefers shady and humid environments for which they are mainly present at the lower spectrum of the plant. Spray of insecticide should thoroughly cover the lower spectrum. But in practice, it is revealed from the farmer's interview that most of the farmers (59.45%) sprayed insecticide at the top spectrum and only 32.22 % sprayed their insecticide at lower spectrum of the plant. Coverage of top spectrum application of insecticide failed to reach the body of brown planthopper. That`s why application of pesticide did not control the pest rather caused higher crop damage.

Among the surveyed area, the highest yield loss (27.32%) was found in Chapai Nawabganj (Nachole) and the lowest (13.86 %) was found in Sirajganj (Tarash). The yield loss of Rajshahi (Tanore), Naogaon (Niamatpur), Mymensingh (Trishal) and Dinajpur (Sadar) were 19.13%, 23.51%, 21.02% and 13.90% respectively. Although none of the cultivated varieties in different areas was resistant or tolerant to BPH but information generated through farmer's interview indicated that fine rice variety showed more yield loss compare to coarse rice variety.

CONCLUSION

Farmers of different regions of the country have lack of knowledge on brown planthopper and its management. That is why the outbreak of BPH in different regions has been increasing day by day. To manage this detrimental pest, awareness should be developed among the farmers.

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Incidence of Major Insect Pests and Natural Enemies in Three Rice Growing Seasons of Bangladesh

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ABSTRACT

Incidence of insect pests and their associated natural enemies was investigated from July 2017- June 2018 at six locations (Gazipur, Rajshahi, Barishal, Sonagazi, Rangpur, Cumilla) of Bangladesh to identify their major occurrence period as well as their incidence in three rice growing seasons, (Aus, T. Aman, and Boro). Among the tested locations, marked differences were found in the composition of insect pest and natural enemies. Higher number of pest population was found at Gazipur with 80,000 individuals for insect pest and 40,000 individuals for natural enemies. At least one peak for major insect pest and natural enemies suggested their specific occurrence period across the locations. Among the insect pests, major peak of GLH was found at Gazipur and Rajshahi during T. Aman season with 4,000 individuals for each location. In contrast, BPH population was as high as 10,000 individuals for Gazipur in October during T. Aman season. Additionally, it was high at Rajshahi in October and November with around 2,000 individuals of BPH. For WBPH, one major peak was found in October at Gazipur and Rajshahi with 10,000 and 2,000 individuals respectively. For YSB, it was higher at Rajshahi in October with over 6,000 individuals during T. Aman season. Moreover, one major peak also observed in Barishal with over 2,000 individuals in November. Among natural enemies, CDB population was observed mainly at three locations in between October and November with 900 individuals for Gazipur, 400 individuals for Rajshahi and 200 individuals for Barishal during T. Aman season. In contrast, for STPD population, two major peaks were found in Barishal with 6,000 and 5,000 individuals in December and March respectively during Boro season. For GMB population, it was observed at Gazipur in November with more than 20,000 individuals during T. Aman season whereas Rajshahi had around 2,000 individuals in the same month. However, higher incidence of GLH, BPH, and WBPH at Gazipur and Rajshahi suggested availability of insect pests during T. Aman season. In contrast, higher YSB incidence at Barishal and Rajshahi indicated their abundance in those areas. On the other hand, incidence of natural enemies at Gazipur indicated presence of greater biological control compared with other locations. In future, this information could serve as a reliable source in strengthening rice pest monitoring services as well as effective pest control in Bangladesh.

Keywords: Insect pest, incidence, natural enemies, rice (*Oryza sativa* L.)

INTRODUCTION

Bangladesh has three overlapping rice growing seasons in a calendar year, namely Aus, T. Aman, and Boro. Firstly, Boro is corresponding to dry season (November to May) while T. Aman is representative of wet season rice (July to November). In contrast, Aus season falls in between Boro and T. Aman, which extends from April to July (Shelly *et al.*, 2016). As a result, rice is cultivated throughout the year that favours higher population growth of major insect pests of rice as well as their natural enemies (Khan, 2013; Rahman *et al.*, 2017). In general, the fauna which are harmful to rice plant and cause economic loss in paddy fields are termed as insect pests of rice while the fauna which acts as biological control agents of those harmful insect pests are known as beneficial insects (Khan, 2013). These beneficial insects have been categorized as predators and parasitoids, collectively known as natural enemies. Additionally, about only 15% of the insects in the rice field are herbivores (pest), while the remaining 85% constitutes detritivores, neutral, beneficial,

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decomposers etc. (Williamson, 1998, Kiritani, 2006, Win *et al.*, 2011).

However, common insect pests of rice include green leaf hopper (GLH), brown plant hopper (BPH), white backed plant hopper (WBPH), and yellow stemborer (YSB). Generally, they also differed from each other in terms of nature of damage in the paddy fields. For instance, both nymphs and adults of GLH feed by extracting plant sap and adult spread the viral disease tungro. In contrast, BPH cause orange-yellowish leaves before turning brown and dry and this is a condition called hopper burn that kills the plant. Both nymphs and adults of WBPH suck phloem sap causing reduced vigour, stunting, yellowing of leaves and delayed tillering and grain formation. YSB feed upon tillers and causes dead hearts or drying of the central tiller, during vegetative stage; and causes whiteheads at reproductive stage. On the other hand, natural enemies play a greater role in biological control of harmful insect pests. Carabid beetle (CDB), staphylinid beetle (STPD) and green mirid bug (GMB) have been reported as biological control agents of rice pests (Rice Knowledge Bank, 2019; BRKB, 2019).

Generally, rice growers do not apply insecticides in proper doses or appropriate chemical to control those insect pests. This often led to severe reduction of natural enemies. Population dynamics of insect pest and natural enemies in different rice growing seasons could help us to understand incidence pattern of major insect pest as well as their natural enemies which could facilitate biological control rather than chemical control. Moreover, incidence of insect pests and abundance of their natural enemies vary greatly depending on climate and crop growing conditions of each location.

In previous studies, considerable variation of insect pests and natural enemies were observed across multiple locations of Bangladesh (Anonymous, 2016, Ali *et al.*, 2019a). Further investigation is required to observe their abundance and incidence pattern in relation to rice growing seasons. Thus, present study was undertaken to investigate incidence of major insect pest and natural enemies in three rice growing seasons, Aus, T. Aman, and Boro.

MATERIALS AND METHODS

Rice insect pests and their natural enemies were monitored using light trap across six locations of Bangladesh including Gazipur, Cumilla, Barishal, Rajshahi, Sonagazi and Rangpur. Light trap with certain modifications were incorporated in accordance with essential requirements. The trap had four parts i.e. collecting chamber, funnel shaped lid, light source and a lid from the top to protect from unexpected showers. The light source was a 100W normal electrical bulb, 200 cm above the ground. The light trap (BRRI, Gazipur, Bangladesh) was constructed in 1973 and has been used since then for monitoring insect pests and natural enemies of rice pests (Ali *et al.,* 2014). Trapped insect pests and natural enemies were collected every day, recorded and deposited along with monthly total tallies for July 2017 to June 2018.

RESULTS AND DISCUSSIONS

Total pest population in the tested locations

Among the tested locations, marked differences were found in the composition of insect pest and natural enemies (Fig. 1). Firstly, Gazipur had higher number of pest population followed by Rajshahi and Barishal. For Gazipur, pest population consisted of more than 80,000 insect pest individuals with around 40,000 individuals of natural enemies. In case of Rajshahi, it was approximately 55,000 individuals for insect pest and 10,000 individuals for natural enemies. But, Barishal

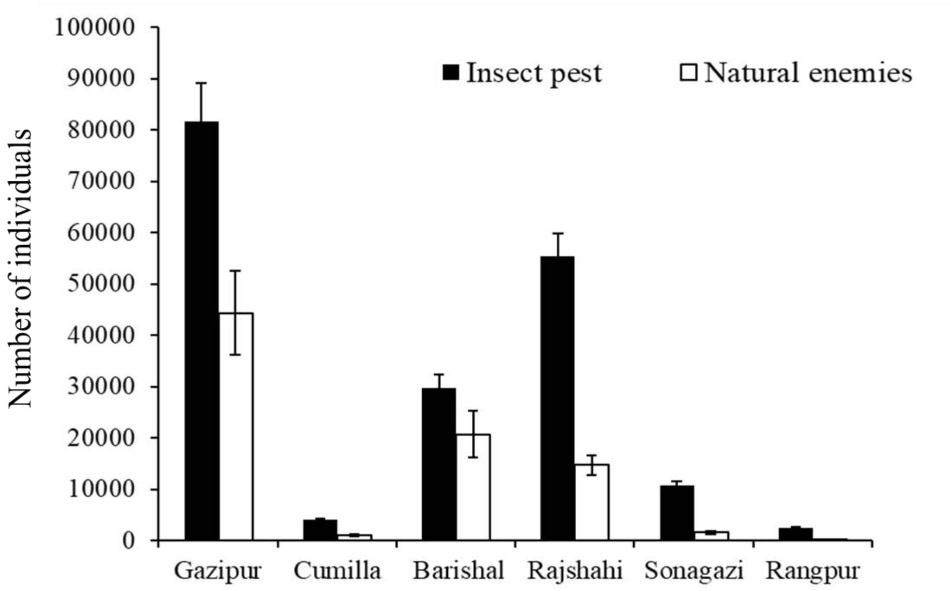

Fig. 1. Bar represents total number of insect pest and natural enemies (mean±SD) from July 2017 to June 2018.

Note: Insect pests include total number of individuals of green leafhopper, white leafhopper, orange headed leafhopper, zigzag leafhopper, brown planthopper, white-backed planthopper, yellow stem borer, dark headed borer, pink borer, gall midge, rice leafroller, caseworm, grass hopper, short horn grasshopper, long horn grasshopper, long horn cricket, mole cricket, field cricket, swarming caterpillar, rice hispa, rice bug, small brown planthopper and scotinophora bug. natural enemies include carabid beetle, ladybird beetle, staphylinid beetle, green mired bug, damselfly, spider, ear wig, tiger beetle, elaterid beetle, dragon fly, and ground beetle.

had nearly similar composition with around 30,000 individuals for insect pest and 20,000 individuals for natural enemies. Compared to above three locations, smaller amount of pest population was present in Cumilla, Sonagazi, and Rangpur during the study period with less than 10,000 individuals for each location.

Incidence of major insect pests in different locations

For GLH, two peaks were observed during the pest monitoring period July 2017 to June 2018 (Fig. 2A). First peak was found at two locations in October with around 10,000 individuals for Gazipur and around 2,000 individuals for Rajshahi. However, a second peak was observed at the end of April for Gazipur with less than 1,500 GLH individuals. No major peaks were found for GLH population in the remaining locations.

For BPH population, major peak was found in October for Rajshahi with more than 6,000 individuals while November for Barishal with around 2,000 individuals (Fig. 2B). In case of WBPH population major peak was found for three locations in October for Gazipur and Rajshahi while November for Barishal with same number of individuals (Fig. 2C). Like BPH, both Gazipur and RS Rajshahi had one peak in October with a WBPH population around 10,000 and 2,000 respectively (Fig. 2C). For YSB, Rajshahi and Barishal showed two major peaks at different times for each location (Fig. 2D). It was found in October and May for Rajshahi with around 6,000 and 3,200 YSB individuals respectively. In case of Barishal, two peaks were observed in November and March with 2,200 and 1,000 YSB individuals respectively.

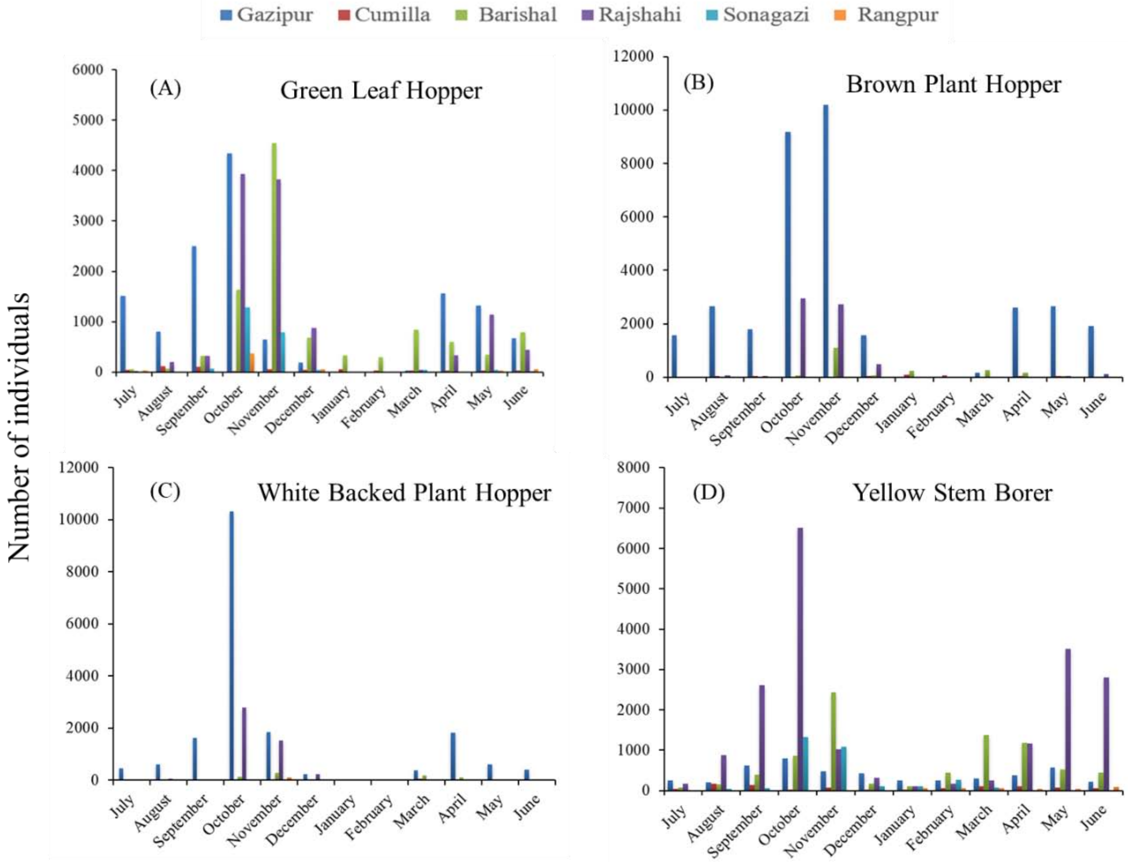

Fig. 2. Incidence of major insect pests including green leafhopper, brown plant hopper, white backed planthopper and yellow stem borer individuals from July 2017 to June 2018 across six locations namely Gazipur, Cumilla, Barishal, Rajshahi, Sonagazi, and Rangpur.

Distributions of natural enemies in different locations

For CDB, major peaks were found at three locations, Gazipur, Rajshahi and Barishal (Fig. 3A). In Gazipur, peaks were found in November and May with around 900 and 400 CDB individual, respectively. For CDB population, Rajshahi had major peaks in October while March for Barishal with 400 individuals. Furthermore, Cumilla had one peak with around 200 individuals in February.

For STPD population, major peaks were found at Barishal in December at Barishal with 6,000 individuals whereas around 3,000 individuals for Gazipur in the same month (Fig. 3B). Rajshahi had major peak in March with around 1,000 individuals. For GMB, one major peak was observed at Gazipur with more than 20,000 GMB individuals in November (Fig. 3C).

Fluctuations of major insect pests in three rice growing seasons

In Aus season, there was less incidence of GLH in the observed locations (Fig. 4a). Less population was observed only at Gazipur in May and July with 1,200 and 1,500 individuals respectively. In T. Aman season, one major peak was found at three locations in different months. Gazipur and Rajshahi had around 4,000 individuals in October while over 4,000

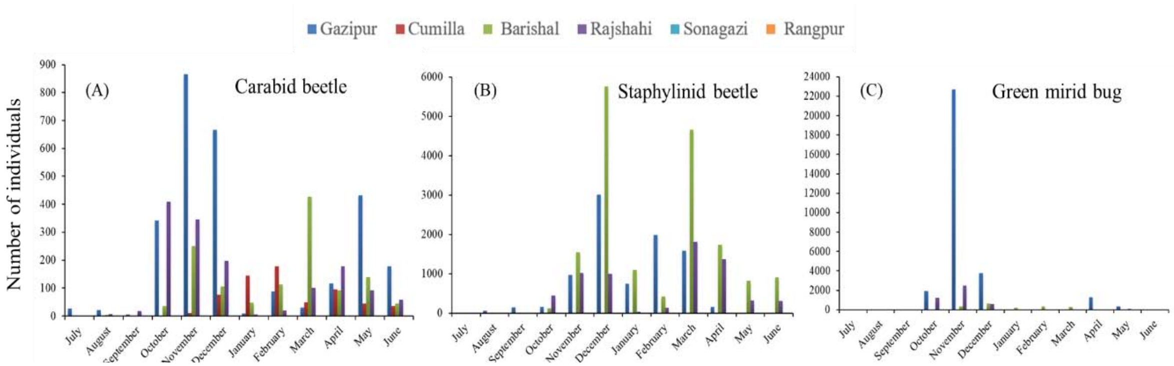

Fig. 3. Incidence of major natural enemies including **c**arabid beetle, **s**taphylinid beetle, and **g**reen mirid bug individuals from July 2017 to June 2018 across six locations namely Gazipur, Cumilla, Barishal, Rajshahi, Sonagazi, and Rangpur.

individuals for Barishal in the month of November. Like Aus, less incidence of GLH was found in the Boro season with less than 1,000 individuals in the observed locations. Among the locations, incidence of BPH was less in the Aus season (Fig.4a). Among all locations, Gazipur had presence of BPH individuals with a static manner throughout the season. In the same location, BPH population was as high as 10,000 individuals in T. Aman season in the month of October and it increased sharply in November. Similarly, it was high at Rajshahi in October and November with over 2,000 individuals. There was no incidence of BPH population at other locations. Like Aus, incidence of BPH population was less among evaluated locations in the Boro season.

There was no incidence of WBPH population in Aus season (Fig. 5b). In T. Aman, one major peak was observed in October at Gazipur and Rajshahi with 10,000 and 2,000 individuals respectively. Like Aus, there was no incidence of WBPH in Boro season. In Aus, higher incidence of YSB was found at Rajshahi in May with around 3,500 individuals (Fig. **5**b). In T. Aman, one major peak was observed in the same location with over 6,000 individuals in October. Moreover, one major peak also observed in Barishal with over 2,000 individuals in November. In Boro, one major peak was observed with 1,000 individuals in Barishal and Rajshahi in March and April respectively.

Fluctuations of major natural enemies in three rice growing seasons

In Aus season, CDB population was present only in Gazipur with around 400 individuals. In T. Aman, one major peak was observed at three locations in between October and November with 900 individuals for Gazipur, 400 individuals for Rajshahi, and 200 individuals for Barishal. In Boro season, CDB population was present among the locations with certain fluctuations throughout the time period. One major peak was found at Gazipur in December and at Barishal in March with 700 and 400 individuals respectively.

In Aus season, there were few incidences of STPD population in the observed locations (Fig. 6). It was present at Rajshahi and Barishal in the month of May and June with less than 1000 individuals. In T. Aman, similar incidence of STPD was found at Gazipur, Rajshahi, and Barishal in the month of November with same number of individuals. In Boro season, the population of STPD varied greatly across the locations. Two major peaks were found in Barishal with 6,000 and 5,000 individuals in the month of December and March respectively. Similarly, Gazipur and Rajshahi had two major peaks in December and February for Gazipur, and December and March for Rajshahi. The population varied between 1,000-3,000 individuals at those locations.

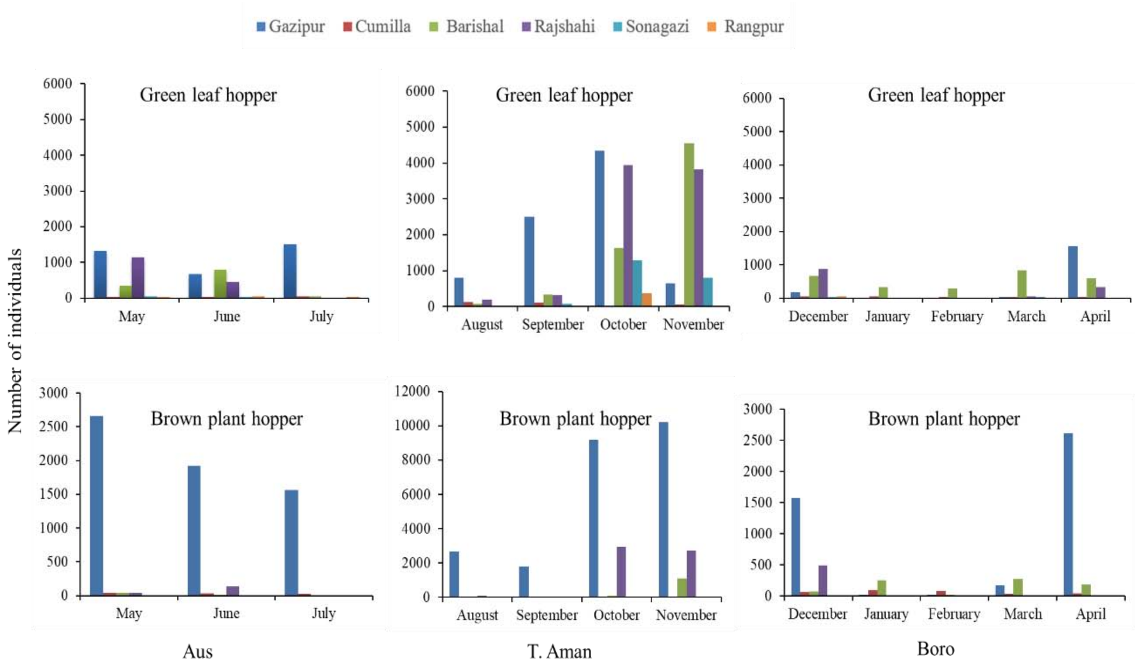

Fig. 4. Incidence of major insect pest in three rice growing seasons Aus, T. Aman and Boro. Data from May to July represent Aus, May to July represent T. Aman, and December to April represent Boro season.

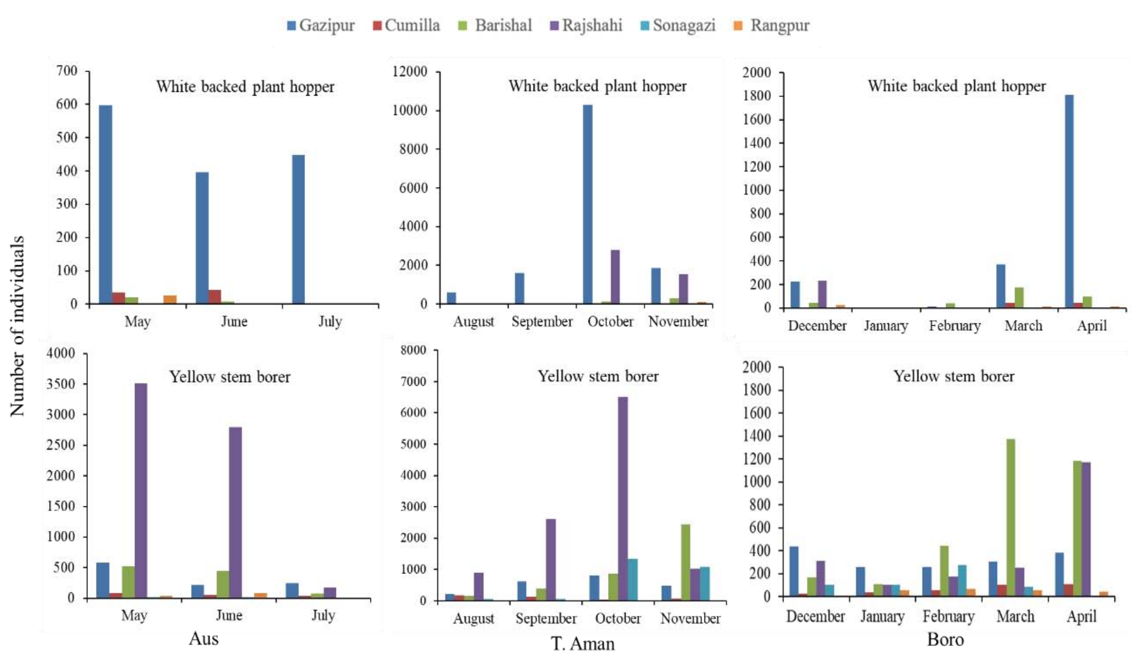

Fig. 5. Incidence of major insect pest in three rice growing seasons Aus, T. Aman and Boro. Data from May to July represent Aus, May to July represent T. Aman, and December to April represent Boro season.

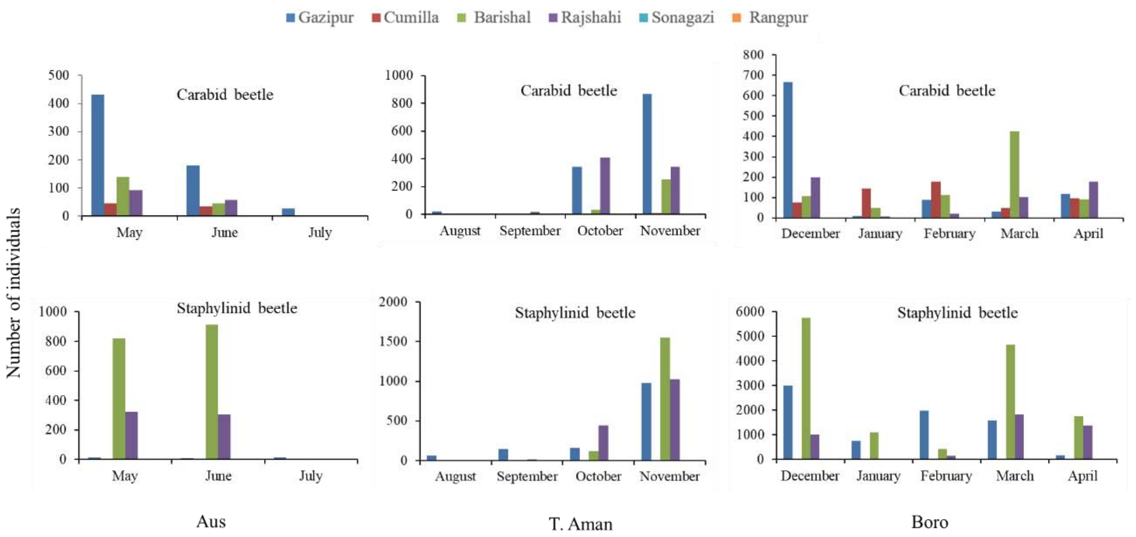

Fig.6. Incidence of major natural enemies in three rice growing seasons Aus, T. Aman and Boro. Data from May to July represent Aus, May to July represent T. Aman, and December to April represent Boro season.

In Aus season, GMB incidence was only observed at Gazipur and Rajshahi in May with 380 and 100 individuals respectively. In T. Aman season, unusual pattern of GMB incidence was observed at Gazipur in November with more than 20,000 individuals. In comparison, Rajshahi had around 2,000 individuals on the same month. In Boro, one major peak was observed at Gazipur in December with around 4,000 individuals. Similarly, Rajshahi and Barishal had incidence of GMB in the same month with less than 1,000 individuals.

DISCUSSIONS

Presence of higher number of pest population (insect pest and natural enemies) in three locations, Gazipur, Barishal, and Rajshahi suggested possibility of pest outbreak in above locations. Later, occurrence period of major insect pests (GLH, BPH, WBPH, and YSB) and natural enemies (CDB, STPD, and GMB) were described based on three rice growing seasons. These findings enable us to figure out the incidence pattern of major insect pests of rice in different locations which could help us to take location specific control measures against major insect pests.

In this study, the total pest population varied greatly from location to location which clearly indicate that incidence of pest population depends on environmental factors. Moreover, presence of natural enemies was coupled with presence of insect pests. For example, Gazipur had 40,000 individuals of natural enemies, which is nearly half of the total insect pests (Fig. 1). These results indicate existence of biological control of insect pest under natural field condition. Similar trend was observed in Barishal. But, Rajshahi had fewer number of natural enemies compared to total insect pests which indicates less existence of natural control in the paddy fields. In previous reports, major incidence of insect pests and natural were also found at three locations, Gazipur, Rajshahi, and Barishal (Anonymous 2016).

In Gazipur and Rajshahi, GLH had major occurrences in October whereas it was November for Barishal (Fig.2). In case of BPH and WBPH, it was found in Gazipur and

Rajshahi during same period of the calendar year. These results indicate that incidence of GLH, BPH, and WBPH occurred at the same time. However, incidence of YSB was much different from above three insect pests. It was higher in number at Barishal and Rajshahi with 6,000 individuals on October and 2,200 individuals on November. These results clearly indicate that incidence of YSB occurred in Rajshahi and Barishal at different times with greater number of YSB population in Rajshahi. In the reporting year from 2013- 2017, it was also observed that GLH, BPH, and WBPH population are always higher for Gazipur while YSB population showed major occurrence in Rajshahi (Anonymous 2016).

Among natural enemies, CDB, STPD, and GMB were abundant in major three locations. Higher incidence of CDB was found in Gazipur followed by Rajshahi, Barishal and Cumilla. Similarly, STPD population was also high in Gazipur, Barishal and Rajshahi and their occurrences were observed at different periods. These results indicate the presence of natural enemies in above locations which could have significant role in biological control of harmful insect pests of rice. However, GMB population was abundant at Gazipur in November only. These results suggested the existence of fewer GMB populations across locations. Like insect pests, higher incidences of natural enemies were also found at Gazipur with a major peak for GMB at Gazipur (Anonymous 2016).

In the present study, comparison of pest population incidence among rice growing seasons enables us to discuss availability of insect pests and natural enemies in observed locations. Moreover, occurrence of location specific pest population incidence supported the benefit of present study in crop protection programme. During T. Aman season higher incidence of GLH, BPH, and WBPH was found in Gazipur and Rajshahi. Thus, insect pest monitoring and control measures should be strengthened in T. Aman season to minimize the pest damage in those areas. In case of YSB, we observed different scenario in the observed locations. Major occurrences of YSB took place in Rajshahi with higher number of YSB population in all rice growing seasons. In addition, similar trend was also observed in Barishal, mostly in T. Aman and Boro season. Thus, crop protection measures in Barishal should include effective control measures against YSB to minimize the crop loss.

Among natural enemies, CDB and GMB were present in higher number at Gazipur across all the rice growing seasons (Fig. **6**). However, major occurrences were observed in T. Aman season. These results clearly indicate possible occurrence of biological control and existence of natural harmony in respect of pest control in rice. Thus, pesticide use should be avoided in possible cases to maintain this ecological balance in every rice production system. Thus, it could help in facilitating biological control in the crop fields. Through conserving natural enemies, a recent example of implementing ecological approaches in Bangladesh suggested reduction of production costs and chemical inputs in the rice ecosystems which could reduce pest infestations in the paddy fields (Ali *et al.*, 2019b). Thus, this information about natural enemies could help us in developing on farm eco-friendly approaches to control major insect pests of rice by reducing chemical usage.

CONCLUSIONS

In this study, higher number of population in Gazipur, Rajshahi, and Barishal suggested higher incidence of insect population in the rice growing period. Frequent peaks for major insect pests and natural enemies in a specific month suggested incidence of insect population in both the seasons. Among three rice growing seasons, T. Aman had higher incidence of insect pest and natural enemies across the observed locations. Additionally, presence of higher number of insect pest in October indicated most favourable time of pest emergence in the calendar year. Moreover, fluctuations of natural enemies among the growing seasons indicated possibility of biological control against major insect pests. In future, location specific population study in multiple years could enable us to find and discuss existing relationship between major insect pests and natural enemies.

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Development of Drought Tolerant Rice Variety BRRI dhan66 for Rainfed Lowland Ecosystem of Bangladesh

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ABSTRACT

A newly released drought tolerant rice variety BRRI dhan66 suitable for rainfed lowland ecosystem of Bangladesh is an improvement over existing drought tolerant rice varieties. The variety has satisfactorily been passed in the proposed variety trial conducted in the farmers' field. As a result, National Seed Board (NSB) approved this variety for commercial cultivation in the wet season (T. Aman) in 2014. It has modern plant type with 120 cm plant height and matures in 110-115 days. The important feature of this variety is higher drought tolerance during reproductive stage. It can produce 4.5-5.0 t/ha grain yield without irrigation during reproductive stage. It can produce satisfactory yield when soil moisture remains <20% and perch water table depth is more than 70-80 cm from the surface. The seed size of the variety is 24 g with intermediate long bold grain. It has long, wide and erect flag leaf with deep green colour. It is highly promising as a drought tolerant rice variety for cultivation in the drought prone area, which helps farmers' to get rid of huge economic loss and is contributing in sustaining food security.

Key words: Drought, wet season, BRRI dhan66, reproductive stage, perch water table, soil moisture

INTRODUCTION

Rice is the staple food for more than three billion people in Asia, where more than 90% of the world's rice is produced and consumed (Li and Xu, 2007). It is grown worldwide in 154 million hectares (m ha) and more than 45% of the area is in rainfed ecosystems, where yields are seriously affected by drought (IRRI, 2002). According to Ricepedia report, about 60 million hectares of rainfed lowlands supply about 20% of the world's rice production. The rice yield in these ecosystems is very low, 1.0–2.0 t ha^{-1} and is unstable due to erratic and unpredictable rainfall. With the changing climate, drought is becoming one of the major problems among other stresses which would affect rice production severely.

Drought is the most important source of climate-related risk for rice production in rainfed areas (Pandey *et al.*, 2007). Drought affects about 100,000 hectares (250,000 acres) of land in Bangladesh particularly in Barind Tract and other northern districts during July to September period. To maintain food security, development of drought tolerant varieties are needed for drought-prone Barind Tract and other areas. The drought tolerant rice varieties have also economic significance to other districts that are known as drought hot spots – Kushtia, Magura, Chuadanga and Jashore, where rain is scanty and unpredictable during the last week of September and in October when rice needs water critically. Appropriately rice is grown in 27 million hectare of land worldwide in upland condition also facing draught stress. To counter this climate vulnerability, it is necessary to breed new rice cultivars with elevated drought tolerance.

Drought mitigation, through development of drought-tolerant rice varieties with higher yields suitable for water-limiting environments will be a key work to raise rice production and ensure food security to three billion people in Asia. The progress in genetic improvement of rice for water-limiting environments, however, has been slow and

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limited (Evenson and Gollin, 2003) due to poor understanding of the inheritance, mechanisms of tolerance and lack of efficient techniques for screening breeding materials for drought tolerance (Khush, 2001). Characterization of drought environment, matching phenology, high potential yield and inbuilt drought tolerance are vital for successful crop production in water-limiting conditions. Drought types, particularly timing and intensity, are important in determining specific plant traits required to improve drought resistance. Drought stress induces a series of complex responses beginning with stress perception, signal transduction and manifestation of responses at the cellular, physiological, and developmental levels. The set of responses observed depends upon the crop stage, severity and duration of the stress. When evaluating the usefulness of traits to increase grain yield, it is important to consider phenological development, which has an overriding effect on the grain yield under water limiting condition (Fukai and Cooper, 1995). The reproductive development in plant is highly vulnerable to water deficit (Saini and Westgate, 2000). Yambao and Ingram (1988) reported yield reduction upto 70% upon imposing drought for 15 days at panicle initiation stage, and 88% and 52% reduction when stressed at flowering and grain filling stage respectively. Stress imposed during panicle initiation can delay or completely inhibit flowering, through inhibition of floral induction and development (Saini and Westgate, 2000). Within this period two sensitive peaks have been reported, one being the period around pollen mother cell meiosis and tetrad break up and the second is anthesis to initial stage of grain development. Pollen formation in rice is highly vulnerable to drought stress (Nguyen and Sutton, 2009). Stress at meiotic stage causes pollen sterility, failure of pollination, spikelet death or zygotic abortion, but female fertility is affected only under extreme stress.

Conventional breeding has been based on observed selection for yield. Most of the high yielding varieties– IR36, IR64, MTU1010, BR11, Swarna and Samba Mahsuri are grown in rainfed areas are preferred by the farmers due to their yield potential but are not tolerant to drought. These varieties give high yield during non-drought years, but there is drastic reduction when moderate drought appears and collapse completely in severe drought stress (Kumar et al., 2008). Other varieties which show some degree of resistance to drought reported from plateau region of Eastern India. Nam Sagui 19 is one of the important parental lines in breeding programme. Some of the successful cases of direct selection for grain yield under drought have been reported at IRRI (Kumar *et al.,* 2008; Venuprasad *et al.,* 2009). This breakthrough resulted in the development of several promising breeding lines for the rainfed lowland and upland (Mandal *et al.,* 2010; Verulkar *et al.,* 2010). Some of the varieties of rice for grain yield under drought conditions have been also released through direct selection those are Sahbhagidhan (India), Sukha dhan-1, Sukha dhan-2 and Sukha dhan-3 (Nepal), BRRI dhan56 (Bangladesh), Sahod ulan-3, 5, 6, 8 and Katihan-8 (Philippines), Tarharra 1 (Nepal). These varieties perform well under drought as well as favourable years.

Multilocation testing of elite breeding lines has also allowed a better understanding of the genotype×environment (G×E) interactions related to grain yield under reproductive-stage drought. In general, it has been observed that a majority of these lines perform best in their specific environments. A majority of these varieties were released in specific countries where they turned out to be the best performers. However, lines IR74371-70-1-1 and IR74371-54-1-1 were released under three different names in India, Bangladesh, Nepal, Philippines and Nigeria respectively- showing the stability of performance of these lines across environments. Regardless of the complexity of grain yield under reproductive-stage drought, lines selected under managed dry-season field experiments at IRRI were able to perform well in different countries. The success of this breeding programme pointed the adaptability of lines across regions in shallow lowland environments of different countries, and this validates the earlier prediction that G×E interactions can be handled more accurately within the different topography (shallow lowland, medium lowland, or deep lowland) in the rainfed ecosystem (Kumar *et al.*, 2012).

The main objective of this study is to evaluate agronomic parameters of a drought tolerant rice variety BRRI dhan66 under controlled and natural condition and it's suitability for drought prone rainfed lowland rice ecosystem. The multi-location yield trials in multiple years demonstrated that BRRI dhan66 is more drought tolerant rice variety than existing one.

To release IR82635-B-B-75-2 as a drought tolerant variety BRRI dhan66, the yield and other parameters were observed which has been discussed very intensively in this study.

MATERIALS AND METHODS

BRRI dhan66 is an outcome of a single cross between two advanced breeding lines IR78875-176-B-2 and IR78875-207-B-3 with a hope to develop a drought tolerant rice variety in International Rice Research Institute (IRRI). The pedigree of BRRI dhan66 is IR82635-B-B-75-2. The fixed line was introduced from IRRI in 2010 and advanced yield trials were conducted in the different drought prone areas of Bangladesh until 2013.

The promising line was subjected to advanced yield trial (AYT) to evaluate specific and general adaptability with standard check BRRI dhan56 in on-station condition of nine regional stations of BRRI in randomized complete block (RCB) design with three replications in T. Aman 2011. After proper yield evaluation this material was subjected to advanced lines adaptive research trial (ALART) to evaluate specific and general adaptability with standard check BRRI dhan56 in the farmers' field condition in T. Aman 2012 conducted by Adaptive Research Division (ARD) of BRRI. This genotype was tested for different physico-chemical properties, cooking qualities and best planting time, disease-insect reactions under natural condition were found out. Plant height, tillering ability were recorded from the ten random plants excluding border rows. Growth duration was counted from seedling to 80% grain maturity. Grain yield data was taken from 10 sq-m sample plot in each replication. In T. Aman 2013, IR82635-B-B-75-2 (BRRI dhan66) was evaluated by the National Seed Board of Bangladesh (NSB) in the nine locations of farmers' field of Bangladesh under field trial named proposed variety trial (PVT). Finally after proper evaluation the NSB team recommended IR82635-B-B-75-2 as a superior genotype in respect to drought tolerance for release as BRRI dhan66 in 2014.

RESULTS AND DISCUSSION

Table 1 shows the agro-morphological characteristics of BRRI dhan66. It has intermediate plant height and lodging tolerance. BRRI dhan66 has deep green, erect, long and wide flag leaf which facilitates maximum solar light uptake. The advanced yield trial of BRRI dhan66 with check variety BRRI dhan56 was conducted in five locations of Bangladesh. BRRI dhan66 showed the maximum yield (4.61 t/ha), followed by BRRI dhan56 (Table 1) in 2011. Importantly, BRRI dhan66 gave the highest (305) panicle/m^2 than BRRI dhan56 (286). The 1000 grain weight of BRRI dhan66 showed significant variation with BRRI dhan56. High yield is one of the prime objectives in developing modern rice varieties. BRRI dhan66 showed higher yield than the other breeding lines under drought condition in T. Aman 2011 season. One of the reasons of higher yield of BRRI dhan66 was due to its genetic potentiality of higher drought tolerance capacity than BRRI dhan56.

IR82635-B-B-75-2 (BRRI dhan66) and check variety BRRI dhan56 were evaluated in 8 locations (Gazipur, Natore, Jhinaidah, Joypurhat, Kushtia, Rajshahi, Chapai Nawabgonj, Naogaon) in the farmers' field of Bangladesh in 2012. Table 2 shows the result. The highest grain yield was found for BRRI dhan66 (5.70 t ha^{-1}) followed by BRRI dhan56 (5.10 t ha^{-1}) in Joypurhat. The result visualized the higher yield potentiality of BRRI dhan66 over the check genotype. On average BRRI dhan66 yielded 0.51 t ha^{-1} higher than BRRI dhan56. The genotype was almost disease free in some locations. The plant stature of the variety made the line lodging tolerant. Growth duration was found two days longer than the check variety BRRI dhan56. Farmers preferred BRRI dhan66 for better yield, shorter growth duration and importantly lodging tolerance as well as higher drought tolerance.

Table 3 shows performance of the IR82635-B-B-75-2 (BRRI dhan66) at on farm trial, T. Aman. IR82635-B-B-75-2 (BRRI dhan66) was evaluated by the National Seed Board (NSB) of Bangladesh in T. Aman 2013 season under on farm condition. The highest yield of the genotype was found 4.94 in Lalmonirhat followed by 4.82 t/ha in Rangpur and 4.73 t ha^{-1} in Rajshahi. The grain yield indicated that the variety could produce more yield against drought stress. On average BRRI dhan66 produced 4.02 t ha^{-1} yield whereas BRRI dhan56 produced 3.23 t ha^{-1} yield. In other words, BRRI dhan66 produced 0.79 t ha^{-1} more grain yield than BRRI dhan56 (Table 3). According to soil moisture and perch water table depth status BRRI dhan66 is more drought tolerant rice variety than BRRI dhan56 (Figs. 4 and 5). Growth duration of BRRI dhan66 was ranged from 107 days in Chapai Nawabganj to 117 days in Gazipur depending on the agro climatic situation in the T. Aman season. Mean growth duration of the variety was found 113 days which is three days longer than the check variety BRRI dhan56.

Table 1. Morphological and agronomical characters of the proposed variety, T. Aman 2011.

Designation	Plant height (cm)	Growth duration (day)	Panicle per m^2	1000 grain weight (gm)	Grain Yield (t ha^{-1})					
					Gazipur	Rangpur	Nilphamari	Lalmonirhat	Kurigram	Mean
IR82635-B-B-75-2 (BRRI dhan66)	120	114	305	25	4.9	4.3	4.8	4.6	4.5	4.6
BRRI dhan56 (ck)	115	111	286	23	4.4	4.1	3.2	4.9	4.4	4.2

Table 2. Performance of the proposed variety at different zonal trials, T. Aman 2012.

Designation	Plant height (cm)	Growth duration (day)	Grain yield (t ha^{-1})								
			Gazipur	Natore	Jhinaidah	Joypurhat	Kushtia	Rajshahi	Chapai Nawabganj	Naogaon	Mean
IR82635-B-B-75-2 (BRRI dhan66)	118	111	4.88	4.51	5.10	5.70	5.42	5.21	5.14	5.66	5.20
BRRI dhan56 (Ck)	116	108	4.48	4.23	4.35	5.10	4.79	4.39	5.11	5.10	4.69

Table 3. Performance of the proposed variety at on farm trial, T. Aman 2013.

Location	IR82635-B-B-75-2 (BRRI dhan66)		BRRI dhan56 (Check variety)		LSD (0.05)	Remarks
	Growth duration (Days)	Grain yield (t/ha)	Growth duration (Days)	Grain yield (t ha^{-1})		
Rajshahi (Godagari)	113	4.11	115	3.19	0.631	Significantly higher
Rajshahi (Tanore)	114	4.73	111	3.82	0.565	Significantly higher
Chapai Nawabganj (Gomostapur)	107	2.51	106	1.48	0.452	Significantly higher
Naogaon (Pursha)	111	4.07	107	3.31	0.392	Significantly higher
Naogaon (Neamotpur)	113	2.58	109	1.94	0.364	Significantly higher
Rangpur (Sadar)	114	4.82	111	3.93	0.615	Significantly higher
Nilphamari (Sadar)	113	4.31	109	3.78	0.416	Significantly higher
Lalmonirhat (Sadar)	114	4.94	110	3.91	0.715	Significantly higher
Dinajpur (Fulbaria)	113	3.86	110	2.95	0.456	Significantly higher
Kushtia (Sadar)	108	4.10	107	3.80	0.412	Not significant but higher
Gazipur (Sadar)	117	4.17	115	3.46	0.213	Significantly higher
Mean	113	4.02	110	3.23		

BRRI dhan66 showed tolerance to major diseases and insects under the natural field condition of Plant Breeding Division (Table 4). The variety showed bacterial infestation score 3, meaning it is more or less tolerant to bacterial blight. The variety is found moderately tolerant to sheath blight disease (Table 4). The variety is also tolerant to stemborer for the dead heart and white head symptoms count. BRRI dhan56 also showed similar symptoms.

BRRI dhan66 produced optimum and higher yield when it was transplanted in first week of August and growth duration was 128 days. If it was transplanted in third week of August then it produced 5.06 t/ha with 122 days growth duration and other transplanting dates were not suitable for BRRI dhan66. So the perfect date of transplanting ranged from first week of August to third week of August (Table 5).

Table 4. Reaction of the proposed variety against major diseases and insects under natural field condition.

Designation	BB	ShB	DH	WH
IR82635-B-B-75-2 (BRRI dhan66)	3	3	1	1
BRRI dhan56 (ck)	3	3	1	1

BB = Bacterial Blight, ShB = Sheath Blight, DH = Dead Heart, WH = White Head Disease and Insect severity scale (0 – 9)

Table 5. Effect of planting time on yield (t/ha) and growth duration (in the parenthesis) of the proposed variety.

Designation	Date of transplanting					
	21 July	6 August	20 August	4 September	20 September	5 October
IR82635-B-B-75-2 (BRRI dhan66)	4.38 (129)	5.68 (128)	5.06 (122)	4.06 (118)	2.53 (111)	0.682
BRRI dhan56 (ck)	2.82 (120)	2.88 (115)	3.28 (113)	2.88 (109)	2.69 (103)	0.701

Distinguishing characters of the candidate variety IR82635-B-B-75-2 (BRRI dhan66) compared to the check variety BRRI dhan56 are penultimate leaf pubescence of blade, anthocyanin colouration of lemma and palea, anthocyanin coloration of lemma and palea below apex, lemma anthocyanin colouration of apex, panicle length, number of effective tillers in plant, maturity duration (Table 6).

At 50% heading date time only 0.5% off-type was observed for both the lines. It indicated that the candidate variety IR82635-B-B-75-2 is uniform according to International Union for the Protection of New Varieties of Plants (UPOV) standard.

In the test plots of two consecutive seasons trials, no remarkable variation and segregation were noted which implied the stability of the candidate varieties.

It was observed that BRRI dhan66 was more drought tolerant due to it's long root. The root length of BRRI dhan66 was 61.0 cm where the root length of check variety BRRI dhan56 was 58.0 cm. The grain weight per plant is also more than the check variety (Table 7). The leaf is deep green and plant is stronger under both controlled and natural drought stress condition (Figs. 1, 2 and 3).

Table 6. Distinctness between IR82635-B-B-75-2 (BRRI dhan66) with check variety BRRI dhan56.

Characteristic	BRRI dhan56 (Check variety)		IR82635-B-B-75-2 (Proposed variety)		Remark
	Code	State	Code	State	
Penultimate leaf pubescence of blade	1	Absent	5	Medium	Distinct
Anthocyanin coloration of Lemma & Palea	5	Medium	1	Absent	Distinct
Anthocyanin coloration of Lemma & palea below apex	5	Medium	1	Absent	Distinct
Lemma anthocyanin coloration of apex	3	Weak	1	Absent	Distinct
Panicle length	5	Medium	7	Long	Distinct
Number of effective tillers in plant	7	Many	5	Medium	Distinct
Time of maturity	3	Early	5	Medium	Distinct
Grain wt. of 1000 fully developed grains (at 12%)	5	Medium	7	High	Distinct

Table 7. Evaluation of proposed variety under controlled drought condition, BRRI, Gazipur, T. Aman 2012-13.

Designation	Root length (cm)	Grain wt. (g) /Plant		%Sterility	
		Stress	Control	Stress	Control
IR82635-B-B-75-2 (BRRI dhan66)	61.0	15.51	44.0	64.2	10.9
BRRI dhan56 (ck)	58.0	14.3	43.6	63.3	18.2

Fig. 1. Front view of IR82635-B-B-75-2 (BRRI dhan66) with BRRI dhan56 screened under controlled drought condition in BRRI.

Fig. 2. BRRI dhan66 under rainfed condition.

Fig. 3. BRRI dhan66 under natural drought condition.

During T. Aman 2013, soil moisture status of the experiment field, with proposed variety BRRI dhan66 and check variety BRRI dhan56, was observed very low (15-10%) during reproductive stage under controlled drought condition in BRRI (Fig. 4). Perch water table depth was obtained at below 30-35 cm from soil surface in the experiment field of proposed variety BRRI dhan66 with check variety BRRI dhan56 under controlled drought condition in BRRI (Fig. 5). In T. Aman 2011, ground water table depth (cm) of field at reproductive stage in Alimganj, Paba, Rajshahi was below 20-80 cm from soil surface and soil moisture was 6-10% (Figs. 6 and 7). So, it was proved that BRRI dhan66 has higher drought tolerance.

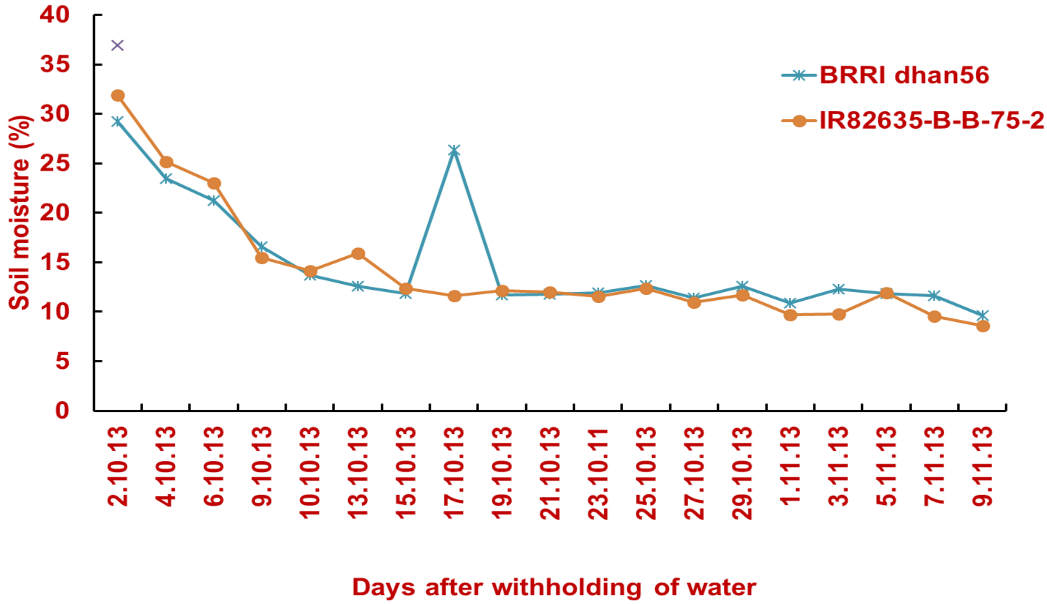


Fig. 4. Soil moisture status of proposed variety BRRI dhan66 with check variety BRRI dhan56 under controlled drought condition in BRRI, 2013.

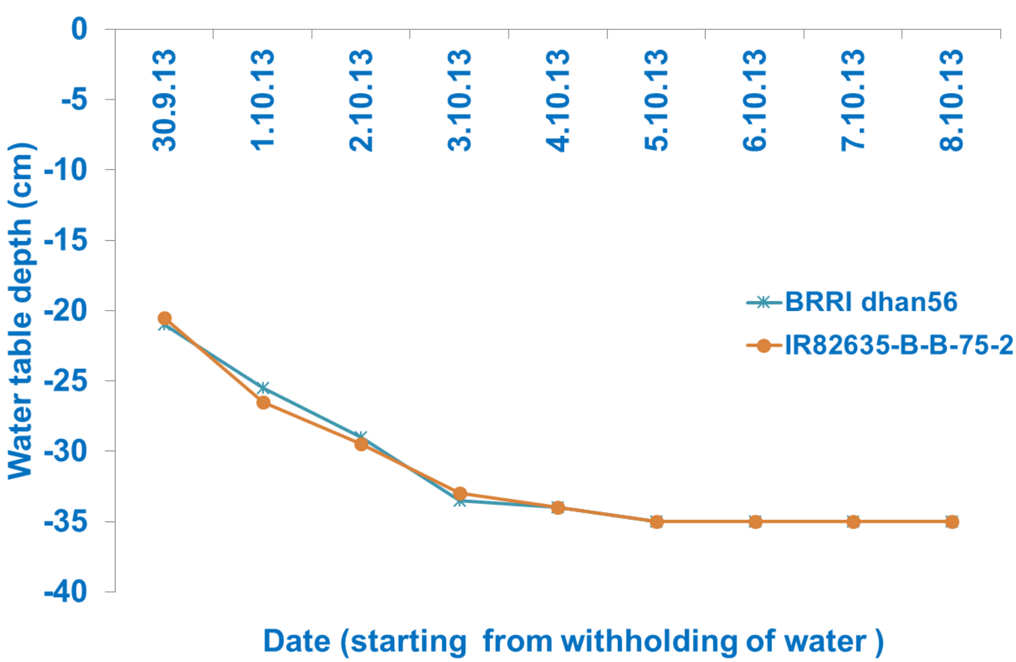
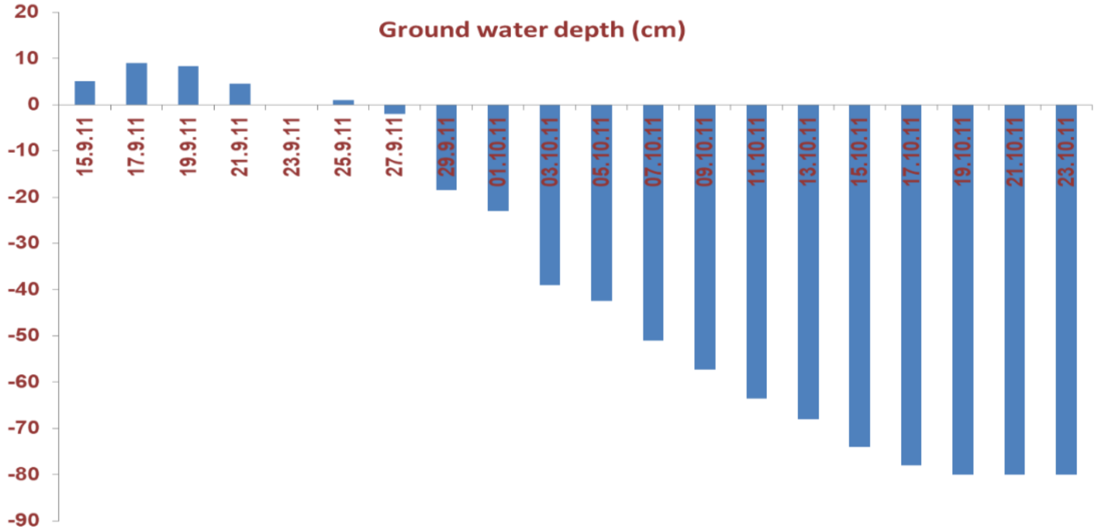


Fig. 5. Perch water table depth status of proposed variety BRRI dhan66 with check variety BRRI dhan56 under controlled drought condition in BRRI, 2013.



* 21 rainless days

Fig. 6. Ground water table depth (cm) of proposed variety at reproductive stage in Alimganj at Paba upazila in Rajshahi, T. Aman 2011.

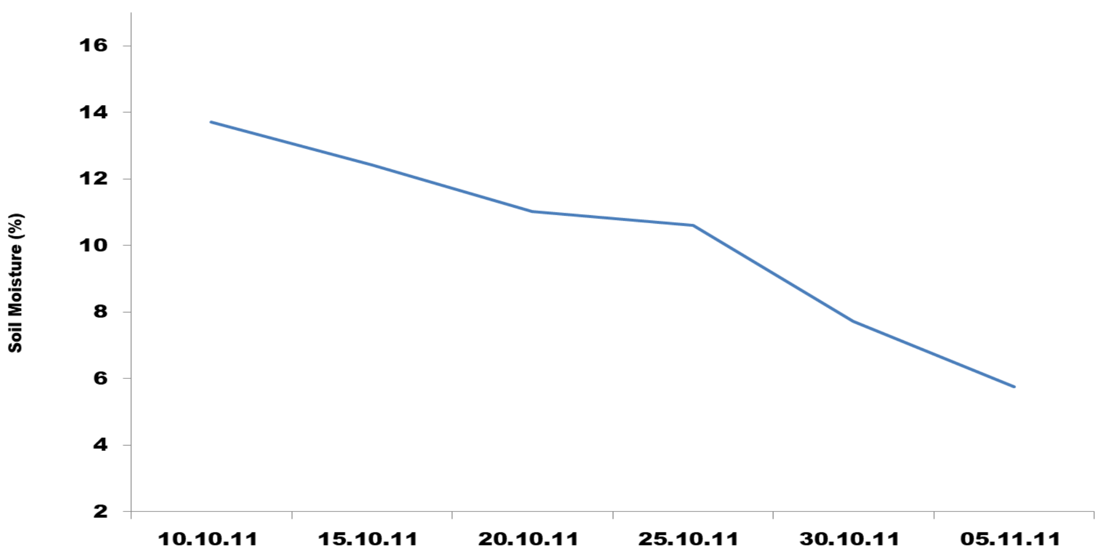


Fig. 7. Soil moisture (%) of proposed variety at reproductive stage in Alimganj at Paba upazila in Rajshahi, T. Aman 2011.

BRRI dhan66 has medium bold grain having length-breadth ratio of 2.7 which is similar with BRRI dhan56. The milling outturn of the variety was 65.6% with the head rice recovery 59.2% which was better than the other varieties (Table 8). But BRRI dhan66 has 10.8% protein where BRRI dhan56 has 8.4% protein. Table 8 presents the physicochemical properties of BRRI dhan66 indicating the grain characteristics of BRRI dhan66. Figure 8 shows the paddy and husked rice of BRRI dhan66 and BRRI dhan56.

Table 8. Physicochemical properties of BRRI dhan63.

Designation	Milling yield (%)	Head rice yield (%)	Decorticated grain				ER*	Protein (%)	Amylose (%)
			Length (mm)	Breadth (mm)	L/B Ratio	Size and shape			
IR82635-B-B-75-2 (BRRI dhan66)	65.6	59.2	6.0	2.2	2.7	Medium bold	1.4	10.8	23.0
BRRI dhan56 (Ck)	66.0	57.7	6.1	2.2	2.7	Medium bold	1.3	8.4	23.0

*ER: Elongation ratio

Fig. 8. Comparative view of paddy and husked rice of BRRI dhan66 and BRRI dhan56.

CONCLUSION

Drought tolerant HYV at reproductive phase in rainfed lowland rice ecosystem is highly demanding. BRRI dhan66 can give 0.5-1.0 t ha^{-1} more yield than BRRI dhan56 under drought prone environments of Bangladesh. Adaptability tests of this variety under multi-location trials in the farmers' field showed satisfactory performance with respect to grain yield and some yield contributing parameters. It is anticipated that this drought tolerant rice variety will contribute to the national gross domestic product (GDP) and also alleviating poverty from drought prone northern region of Bangladesh and thus will contribute in sustaining food security.

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Development of High Yielding Deep Water Rice Variety BRRI dhan91 for Semi Deep Flooded Ecosystem of Bangladesh

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ABSTRACT

Deep water rice ecosystem represents the flood-prone rice ecosystem where rice plant requires elongation ability to reach the surface with a certain amount of plant height to withstand in stagnant flood water condition. Low yield potentiality of locally adapted deep water cultivars limits the total rice production in the country. In present study, efforts were made to evaluate the suitability and adaptability of newly developed high yielding deep water breeding line BR10230-15-27-7B and control variety Fulkori under semi deep water ecosystem of farmer's field condition in three consecutive years. At six locations, water depth varied from 60 to 140 cm under semi deep water ecosystem. In 2016 and 2017, mean yield of the line ranged between 2.9 to 3.1 t ha^{-1} while 1.7 t ha^{-1} for the local control variety Fulkori. However, around 1.0 t/ha yield advantage was found for the newly developed breeding line. Thus, the higher yield potentiality of the breeding line under 140 cm water depth conditions suggested its suitability under shallow flooded environments. During final evaluation in 2018, larger variation was observed in terms of grain yield ranging from 1.1 to 3.8 t ha^{-1} for the line while 0.4 to 1.7 t ha^{-1} for the control variety when evaluated under actual deep water areas. This result also supported that this line have greater potentiality under shallow flooded condition. In addition, the breeding line exhibited similar plant height with at least six days earliness compared to the control variety. Finally, National Seed Board (NSB) approved this line as variety and designated as BRRI dhan91 for broadcast Aman (B. Aman) season. In future, this new rice variety could help the local rice growers to cultivate modern high yielding rice variety in shallow flooded environments. BRRI dhan91 also showed better performance for tallness with lodging tolerance, submergence tolerance and moderate elongation ability under shallow flooded conditions.

Key words: Deep water rice, BRRI dhan91, new rice variety

INTRODUCTION

Rice is the staple food for more than three billion people in Asia, where more than 90% of the world's rice is produced and consumed (Li and Xu, 2007). Asian cultivated rice (*Oryza sativa* L.) holds a unique position among domesticated crop species in that it is both a critical staple food and the first fully sequenced crop genome. Rice is consumed as a grain almost exclusively by humans, supplying 20% of daily calories for the world population (World Rice Statistics, FAOSTAT).

Deep water rice ecosystem represents the flood-prone rice ecosystem where stagnant flood water occurred in a depth usually exceeds 100 cm and continues for longer period of time ranging from more than 10 days to five months (Maclean *et al.* 2002). However, this rice required elongation ability to reach the surface, such as the one found in floating rice up to five m length. Deep water rice was cultivated in the floodplains and deltas of rivers such as the Ganges and Brahmaputra of India and Bangladesh, the Irrawaddy of Myanmar, the Mekong of Vietnam and Cambodia, the Chao Phraya of Thailand, and the Niger of West Africa (Bouman *et al*. 2007). This rice has been classified into two types based on stature and depth of water: (i) traditional tall, and (ii) floating. Traditional tall

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cultivars are tall with long leaves and grown at water depths between 50 and 100 cm while floating rice is grown in 100 cm or deeper situations. Apparently, each of these types requires specific adaptive traits, which required the development of unique varieties (Lafitte *et al.* 2006).

In Bangladesh, deep water rice covers an area of 0.48 million ha where cultivation of transplant Aman rice is limited by high level of water depth throughout the growing season (BBS, 2006, Ahmed *et al.* 2016). In Bangladesh, most of the deep water rice is floating type where the depth of water can exceed 4 m (Ahmed *et al.* 2016). Though DWR is cultivated in small areas with low yield, attention should be given to develop high yielding deep water rice to maintain stable rice production (Ahmed *et al.* 2016). There are two categories of deep water areas: shallow deep and deep. Flooding depth exceeding 100 cm categorised as deep water and flooding depth less than 100 cm categorised as shallow deep flooded areas. BRRI emphasized to develop tall deep water rice varieties having submergence tolerance and moderate level of stem elongation suitable for shallow deep flooded areas.

In this regard, many advanced breeding lines of DWR have been developed by Bangladesh Rice Research Institute (BRRI) for semi-deep water ecosystem where level of water depth is relatively low. Thus, the present study was undertaken to evaluate the agronomic performances of newly developed breeding line BR10230-15-27-7B across shallow flooded ecosystem of Bangladesh.

MATERIALS AND METHODS

Plant materials. BRRI dhan91 is an outcome of a single cross between two breeding lines Tilakkachari/BRRI dhan41 with a hope to develop a semi deep water submergence tolerant rice variety in Bangladesh. The pedigree of BRRI dhan91 is BR10230-15-27-7B. The crossing was done in 2009 and fixed line was developed through hybridization followed by modified bulk and pedigree selection. BRRI developed advanced breeding line BR10230-15-27-7B and local deep water rice variety Fulkori were used for this study.

Growing conditions of paddy fields. Field trials were performed under shallow flooded areas followed by Randomized Complete Block (RCB) design with three replications in three consecutive seasons, B. Aman 2016, 2017 and 2018. In B. Aman 2016 season, the field trials were conducted at Goainghat, Sylhet; Sibpur, Habiganj; Jatra-pasha, Habiganj and Gopalganj. In B. Aman 2017 season, the field trials were conducted at Goainghat, Sylhet; Sibpur, Habiganj; Jatra-pasha, Habiganj; Nagorpur, Tangail; Natore and Gopalganj. In B. Aman 2018 season, the field trials were evaluated at Bhanga, Faridpur; Moksudpur, Gopalganj; Sadar, Manikganj; Singair, Manikganj; Ghior, Manikganj; Balikhal, Habiganj; Sadar, Tangail; Homna, Cumilla and Shibbari farm, BRRI Gazipur. Land was well prepared in semi-dry conditions. Seeding was done in between first week of May to first week of June in each year. Unit plot size was 5 x 5 m^2 and spacing of 20 cm was maintained between two lines and continuous seed sowing was done in a line. The seed rate was 35 kg/ha (30-40 seeds per meter line or 130-150 seeds per square meter based on seed germination percentage). For seeding, farrow was created in soil and seeds were placed in 2-2.5 cm depth and covered by soil. Fertilizers were applied @ 150, 100, 70, 60 and 10 kg/ha Urea, TSP, MoP, Gypsum and $ZnSO_4$ respectively. Full dose of TSP, Gypsum and $ZnSO_4$ were applied as basal; Urea was top dressed in 2-3 split depending on flood water depth: 1^{st} at about 35 DAS (days after seeding), 2^{nd} at about 55 DAS (before flood water comes) and at 15-25 cm water depth condition (about 75 DAS). When flood water or stagnant water depth was more than 50 cm, urea application was avoided.

Evaluation of agronomic traits. Plant height, growth duration and yield were recorded in accordance with standard system. Growth duration was counted from date of seeding to 80% grain maturity date. Grain yield was estimated from 10 square meter sample plot for each replication.

Screening for submergence and elongation. Materials were raised in trays and 21-day-old seedlings were submerged in submergence tank of BRRI for 12 days. Then, water was drained out and plants were kept for recovery. After seven days of recovery, the plant was scored for submergence tolerance and elongation based on standard evaluation system of rice from 1(best) to 9 (poor) scores.

RESULTS AND DISCUSSION

In 2016, the breeding line BR10230-15-27-7B was evaluated across four locations. In general, plant height, growth duration and yield were selected as key trait to make comparison in between the line and the control variety Fulkori (Table 1). The mean plant height was 179 cm for the line and 183 cm for the control variety. This result indicates that newly developed breeding line have similar plant height, which have higher benefit to survive in shallow flooded areas where flood water or stagnant water reaches comparatively higher water depth. Moreover, the mean growth duration was 155 days for the line and 165 days for the control variety. This result also clearly indicates that the newly developed line is 10 days earlier than the control variety. The grain yield of the line BR10230-15-27-7B was at least 1.0 t higher compared to the control variety Fulkori for all locations. Among the locations, the highest grain yield was observed at Gopalganj with 3.4 t/ha for the line. The mean yield was 3.1 t ha^{-1} for the line and 1.7 t ha^{-1} for the control variety.

In 2017, the breeding line BR10230-15-27-7B was evaluated across six locations (Table 2). The mean plant height was 177 cm for the line and 185 cm for the control variety Fulkori. For growth duration, it was 153 days for the line and 168 days for the control variety. This result also clearly indicates that the newly developed line is 15 days earlier than the control variety. The grain yield of the line BR10230-15-27-7B was at least 1.0 t ha^{-1} higher compared to the control variety Fulkori for all locations. Among the locations, the highest grain yield was observed at Jatra-pasha, Habiganj with 3.4 t ha^{-1} for the line. However, the mean yield was 2.9 t ha^{-1} for the line and 1.7 t ha^{-1} for the control variety. Additionally, water depth was recorded in this year and it varied from 60-140 cm among the observed locations. This result supported that newly developed line BR10230-15-27-7B has potentiality to produce higher grain yield even under higher water depth.

In 2018, the breeding line BR10230-15-27-7B was evaluated across nine locations and two times evaluation was made by National Seed Board team in vegetative stage and reproductive stage, respectively.

Among the locations, the growth duration of the breeding line ranged from 148 to 173 days while 149 to 181 days for the control variety (Table 3). The mean growth duration was 156 days for the line BR10230-15-27-7B and 162 days for the control variety Fulkori. This result also clearly supported the results of the previous years and the line was six days earlier than the control variety. Although, the growth duration of both line and the control variety was unexpectedly high at Homna, Cumilla due to early seeding.

Among the locations, the grain yield of the breeding line ranged from 1.1 to 3.8 t ha^{-1} while 0.4 to 1.7 t ha^{-1} for the control variety (Table 3). The mean grain yield was 2.4 t ha^{-1} for the line and 1.0 t ha^{-1} for the control variety. However, the large variation in grain yield over the evaluated locations suggested that one rice variety have different potentiality across deep water rice areas. Additionally, this variation greatly depends on available water depth in those particular areas in the cultivated season and one specific variety is not suitable for all the deep water areas. Thus, the evaluated line was recommended for shallow flooded areas because it showed consistency in grain yield at these conditions (Tables 1 and 2).

Furthermore, the line has moderate lodging tolerance, moderate elongation ability, strong stem, erect and long flag leaf, deep green leaves and no leaf senescence at maturity which facilitates maximum solar light uptake to give high yield (Fig. 1). Due to the presence of awn in Fulkori the grain appearance of BR10230-15-27-7B was also satisfactory compared to the control variety (Fig. 2).

In B. Aman 2018 season, BR10230-15-27-7B and Fulkori were given a water pressure under artificial submerged conditions (12 days) with 80 cm water depth to evaluate the performance in aspect of elongation ability, submergence tolerance and survivability. Fulkori showed poor performance for submergence tolerance (score 9), but showed better elongation ability (score 2). BRRI dhan91 (BR10230-15-27-7B) showed better for both submergence tolerance (score 3), as well as showed moderate elongation ability (score 3) for its best flood adaptation under shallow flooded conditions (Table 4).

Table 1. Performance of the line, BR10230-15-27-7B and the control variety, Fulkori in Broadcast Aman 2016.

Designation	Mean plant height (cm)	Mean Growth duration (day)	Yield ($t\ ha^{-1}$) at different locations				Mean Yield ($t\ ha^{-1}$)
			L1	L2	L3	L4	
BR10230-15-27-7B	179	155	2.9	3.0	3.2	3.4	3.1
Fulkori	183	165	1.8	1.7	1.9	1.6	1.7

L1 = Goainghat, Sylhet   L2= Shibpur, Habiganj   L3 = Jatra-pasha, Habiganj   L4 = Gopalganj

Table 2. Performance of the line, BR10230-15-27-7B and the control variety, Fulkori in Broadcast Aman 2017.

Designation	Mean plant height (cm)	Mean growth duration (day)	Yield ($t\ ha^{-1}$) at different locations						Average Yield ($t\ ha^{-1}$)
			L1	L2	L3	L4	L5	L6	
BR10230-15-27-7B	177	153	3.2	2.5	3.4	2.9	3.1	2.5	2.9
Fulkori (ck)	185	168	1.7	1.6	2.1	1.7	1.8	1.4	1.7
Water depth (cm)	-	-	60	65	90	120	140	130	

L1 = Goainghat, Sylhet, L2= Shibpur, Habiganj, L3 = Jatra-pasha, Habiganj, L4 = Nagorpur, Tangail, L5 = Natore, L6 = Gopalganj

Table 3. Performance of the line, BR10230-15-27-7B and the control variety, Fulkori in Broadcast Aman 2018.

Location	BR10230-15-27-7B		Fulkori	
	Growth duration (days)	Grain yield ($t\ ha^{-1}$)	Growth duration (days)	Grain yield ($t\ ha^{-1}$)
Bhanga, Faridpur	149	3.5	153	1.3
Moksudpur, Gopalganj	151	1.1	155	0.4
Sadar, Manikganj	150	2.2	157	1.7
Singair, Manikganj	152	3.8	164	1.0
Ghior, Manikganj	148	2.1	155	1.4
Balikhal, Habiganj	162	1.6	167	0.6
Sadar, Tangail	154	2.6	162	1.2
Homna, Cumilla	173	2.2	181	1.1
BRRI Gazipur	151	2.1	149	0.7
Mean	156	2.4	162	1.0

Table 4. Elongation ability, submergence tolerance and survival of BR10230-15-27-7B and Fulkori under artificial submerged conditions (12 days), Broadcast Aman 2018.

Genotype	Survival %	Submergence tolerance score (1-9)	Stem elongation (%)	Elongation score (1-9)
BR10230-15-27-7B	72	3	63	5
Fulkori	0	9	85	2

Score 1 for the best and 9 for poor.

Distinguishing characters of the candidate variety BR10230-15-27-7B (BRRI dhan91) compared to the check variety Fulkori are leaf colour, flag leaf: attitude of the blade, panicle: number of the effective tillers per plant, spikelet: colour of the tip of lemma, spikelet: awns in the spikelet, leaf senescence: penultimate leaves are observed at harvest and other distinct special (Table 5). The base of the stem of BRRI dhan91 was much stronger (Fig. 1) than Fulkori Fig. 2 and it showed lodging tolerance in rainfed condition.

However, adaptability tests of the line BR10230-15-27-7B under multi-location trials in the farmers' field showed satisfactory performance in terms of grain yield in three consecutive seasons. Finally, after proper evaluation the NSB team recommended BR10230-15-27-7B as a superior genotype in respect to semi deep water tolerance for release as BRRI dhan91 in 2019. Furthermore, BRRI dhan91 could be used as a breeding material for its tallness with strong stem, submergence tolerance and moderate level of stem elongation ability.

Fig. 1. BR10230-15-27-7B having tallness, strong stems and lodging tolerance

Fig. 2. Grain appearance of the local control variety Fulkori and breeding line BR10230-15-27-7B

Table 5. Distinctness between BR10230-15-27-7B (BRRI dhan91) and check variety Fulkori.

Characteristic	BR10230-15-27-7B (BRRI dhan91)		Fulkori (Check variety)		Remark
	Code	State	Code	State	
Leaf colour	3	Dark Green	2	Green	Distinct
Flag leaf: attitude of the blade	1	Erect	3	Intermediate or Semi-erect (30-45^0)	Distinct
Panicle: number of the effective tillers per plant	7	Many	5	Medium (6-10)	Distinct
Spikelet: colour of the tip of lemma	3	Brownish	2	Yellowish	Distinct
Spikelet: awns in the spikelet	1	Absent	5	Present	Distinct
Leaf senescence penultimate leaves are observed at harvest	1	Late and slow	9	Early and fast	Distinct
Other distinct special (if any)		The base of the stem is much stronger than Fulkori. It has tolerance to lodging with 180 cm height		The base of the stem is very weak than proposed variety. It might lodge in the face of strong winds.	Distinct

At 50% heading date time, no off-type and no segregation in flowering behaviour was observed. It indicated that the candidate variety BR10230-15-27-7B is uniform according to union for the protection of New Varieties of plants (UPOV) standard. In the test plots of three consecutive years/seasons trials-no remarkable variation and segregation in respect with any traits was noted - which imply the stability of the candidate varieties.

CONCLUSION

In multi-location yield trials, performances of the breeding line BR10230-15-27-7B showed higher benefits both for growth duration and grain yield. Finally, it was released as a new rice variety as BRRI dhan91 for cultivation in shallow flooded areas based on its superior performances in NSB trials compared to control variety Fulkori. It is expected that if this variety can be cultivated in semi deep water areas of Bangladesh total rice production will be increased. In future, the new semi deep water rice variety could secure stable rice production in the country through inclusion of more areas under modern rice cultivation. BRRI dhan91 could be used in crossing programme for improvement of tallness with strong stem, submergence tolerance and moderate level of stem elongation ability.

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Photosensitive Rice (*Oryza sativa* L.) Varieties under Delayed Planting as an Option to Minimize Rice Yield Loss in Flood Affected T. Aman Season

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ABSTRACT

Photosensitive rice varieties have higher advantages in delayed planting. The present study was undertaken to figure out the degrees of delayed planting and evaluate the performance of six modern Aman rice varieties (BR11, BR22, BR23, BRRI dhan46, BRRI dhan54) against three sets of delayed planting. Each rice variety showed considerable variations for plant height, days to panicle initiation, flowering and maturity. BR22, BR23, and BRRI dhan54 showed a drastic reduction in days to panicle initiation and varied from 65 to 58 days, 69 to 60 days, and 62 to 55 days respectively, while it varied from 76 to 80 days for the control variety BR11. Similarly, days to flowering of BR22 and BRRI dhan54 showed a gradual decrease following different planting time and varied from 92 to 86 days, and 83 to 77 days respectively, while it varied from 109 to 107 days for the control variety BR11. For the above traits, BRRI dhan44 and BRRI dhan46 showed a moderate reduction depending on the three sets of planting time. Grain yield of BR22, BR23 reduced at the third set with a value ranging from 5.8 to 5.0 t/ha, 6.1 to 5.1 t/ha respectively, while BRRI dhan54 showed consistency in grain yield with a range from 5.3 to 5.2 t/ha. In contrast, grain yield of remaining rice varieties ranged between 5.7 to 4.5 t/ha for BRRI dhan46, 6.2 to 3.9 t/ha for BRRI dhan46 while severe reduction for the control variety BR11 with a range from 4.4 to 2.0 t/ha was observed. In conclusion, BRRI dhan54 was found more suitable rice variety in delayed planting compared with other photosensitive rice varieties. In future, BRRI dhan54 could be used as benchmark rice variety in a special rice breeding programme designed for delayed planting.

Key words: Delayed planting, photosensitive rice, physiological growth, grain yield

INTRODUCTION

Rice is grown worldwide with broad variation in photoperiod which affects the planting time and the growth in respective areas (Izawa *et al.* 2007; Song *et al.* 2007). In Bangladesh, rice cultivation is practiced throughout the year which has been mainly divided as Aus, Aman, and Boro (Parsons *et al.* 1999; Shelly *et al.* 2016). Aman rice is grown in the wet season when most of the rainfall come about. Sometimes heavy rainfall and sudden increase in water flow from the upstream of the main rivers causes the late flooding. In this situation, Aman plantation is seriously impaired due to the inundation of floodwater in the main rice field as well as damage to the seedbed. Furthermore, Bangladesh is the most vulnerable country for climate change. In recent times, the country is experiencing more extreme climate conditions such as an irregular pattern of rainfall in the monsoon, drought and high temperature during summer.

For a long time, farmers of Bangladesh are practicing the cultivation of photosensitive rice varieties after the recession of floodwater. These photosensitive Aman rice varieties are transplanted in the late season from August to September. Their sensitivity to flowering occurs in October or November depending on the planting time. These varieties mostly include Bangladeshi local rice varieties. Although, Bangladesh Rice Research Institute (BRRI) has developed some high yielding photosensitive rice varieties such as BR22,

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BR23, and BRRI dhan46 which have also become popular among the rice growers. However, further study is needed to characterize the features of seasonal variation concerning the transplanting time, growth stages and yield of modern rice varieties. It requires a certain temperature for the phonological events of rice plants like panicle initiation, flowering, panicle exertion and maturity, and these are much governed by the planting date during T. Aman season. The fluctuation from optimum planting time might be responsible for incomplete and irregular panicle exertion, increased spikelet sterility (Yoshida 1981). In general, T. Aman rice is planted from 15th July to 15th August. Sometimes transplanting is delayed due to the physical and socioeconomic factors. Moreover, flash floods affect 24% of rainfed lowland Aman rice areas, mainly at the seedling stage. The unpredictable rainfall often delays Aman transplanting in Bangladesh (Iftekharuddaula *et al.* 2015).

Aman season is a rain-fed season, which means that the onset of the season entirely depends on the starting of the monsoon. In recent times, the climatic change affects the season tremendously; sometimes the season is shifted mainly due to no rainfall at the starting of the season or heavy rainfall at mid or late of the season prompted to flood causing serious damage. Considering the above facts, if the season is shifted towards late then there might be a risk of cold injury during reproductive development of weak or moderately photo-sensitive varieties. In such conditions, strong photo-sensitive varieties are suitable for cultivation and numerous studies have been performed using both the local and modern Aman rice varieties of Bangladesh (Ali *et al.* 1993; Halder *et al.* 1995; Roy *et al.* 2003). In this context, BRRI has so far developed several strong photosensitive rice varieties (BR22, BR23, BRRI dhan44, BRRI dhan46 and BRRI dhan54), among these BR22 and BR23 are suitable for late or delayed planting. However, information regarding the effect of low temperature in case of delayed plantation in the T. Aman season is not adequate. Therefore, the present study was under taken to figure out the degrees of delayed plantation and evaluate the performance of six modern Aman rice varieties (BR11, BR22, BR23, BRRI dhan46, BRRI dhan54) against three sets of delayed planting in T. Aman season.

MATERIALS AND METHODS

Plant materials

BRRI has so far developed five photosensitive rice varieties namely BR22, BR23, BRRI dhan44, BRRI dhan46 and BRRI dhan54 along with BR11 as control were selected to execute the experiment.

Growing rice plants in the field

The experiment was carried out in the research field of the Plant Physiology Division located at BRRI Gazipur, Bangladesh during T. Aman 2017. Three different planting time including 30th August, 6th September and 13th September were considered as three sets of delayed planting and designated as 1st set, 2nd set, and 3rd set respectively. Seedlings were raised in the ideal seed beds and uprooted for transplanting at five leaves stage. By following planting dates, seedlings were transplanted in well puddle paddy soils. The experiment was laid out in a split plot design with three replications. Three sets of transplanting dates were placed in the main plots and varieties in the sub-plots. The unit plot size was designed 2.5 m X 2.0 m followed by 20 cm × 20 cm spacing. Fertilizer doses were applied as urea, triple super phosphate, muriate of potash, and gypsum @ 80-50-50-10 kg per hectare for N, P_2O_5, K_2O and S respectively. Full doses of triple super phosphate, muriate of potash, and gypsum were incorporated at the time of final land preparation while urea was applied in three equal splits at 15, 30 and 45 days after

transplanting.
During the growing period, intercultural opera tions were carried out as necessary.

Evaluation of agronomic traits

Data on plant height, days to panicle initiation, days to flowering, days to maturity were recorded in the suitable growth stages of rice varieties. For yield estimation, the whole plot was harvested and grain yield of each plot was recorded accordingly.

Data analysis

Data analyses were performed using Statistical Tool for Agricultural Research (STAR), version 2.0.1, developed by International Rice Research Institute (STAR, 2013).

RESULTS

Variation in major agronomic traits

The plant height of all rice varieties showed significant changes based on three sets of delayed planting except for BRRI dhan54 (Tables 1 and 2). Among the varieties, it was reduced drastically for BR22, BR23, BRRI dhan44, and BRRI dhan46 with a value between 122.3 to 95.7 cm, 132.2 to 106.2 cm, 132.0 to 112.8 cm, 136.0 to 106.9 cm respectively. In case of BRRI dhan54, it changed from 113.1 to 104.3 cm and varied only in the third set of treatment. But, the plant height of control variety BR11 was not changed significantly and varied between 109.1 to 105.8 cm. For days to panicle initiation, significant variation was observed among three sets of delayed plantations (Tables 1 and 2). In case of BR22, BR23, and BRRI dhan54, it reduced drastically following three different planting times and varied from 65 to 58 days, 69 to 60 days, and 62 to 55 days respectively. Conversely, it was longer in the third set for BRRI dhan44 and BRRI dhan46 and varied from 72 to 63 days, and 68 to 63 days respectively. Among three sets of delayed planting, it was observed significantly longer for the control variety BR11 at the third set of planting time and varied from 80 to 76 days. Like panicle initiation, significant variation was observed for days to flowering among three sets of delayed plantations (Tables 1 and 2). Flowering time of BR22 and BRRI dhan54 showed a gradual decrease following different planting times and varied from 92 to 86 days, and 83 to 77 days respectively. But BR23 and BRRI dhan44 showed opposite fashion for days to flowering with longer time for first set and third set respectively, and it varied from 98 to 93 days for BR23 and 92 to 101 days for BRRI dhan44. However, BRRI dhan46 and the control variety BR11 had a similar tendency of flowering time with a significant difference only in the second set and it varied from 93 to 90 days for BRRI dhan46 and 109 to 107 days for BR11. Different patterns of days to maturity were found among evaluated rice varieties based on three sets of planting time (Tables 1 and 2). For BR22, it was reduced only in the third set from 121 to 116 days. BR23 and BRRI dhan44 showed a gradual increase in maturity time and it was significantly higher at the third set, with a range from 125 to 120 days, and 133 to 118 days respectively. For BRRI dhan46, it was shorter in the second set and longer in the third set with a value from 123 to 117 days. In comparison, BRRI dhan54 showed a gradual decrease in maturity over delayed planting with a range from 107 to 100 days. Days to maturity of BR11 decreased at the second set and had a similarity between the first set and third set with a range from 140 to 138 days. The grain yield of evaluated rice varieties showed significant variation based on the three planting times (Fig. 1). BR22, BR23, and BRRI dhan46 had a significant reduction in yield at the third set with a value from 5.8 to 5.0 t ha^{-1}, 6.1 to 5.1 t ha^{-1}, and 5.7 to 4.5 t ha^{-1}, respectively. But BRRI dhan44 showed a gradual decrease in grain yield with the value ranging from 6.2 to 3.9 t ha^{-1}. In comparison, BRRI dhan54 showed consistency in grain

Table 1. Analysis of variance for the tested traits against three sets of planting dates.

Trait	Sum of squares		Mean square		F value		*P* value	
	Genotype	Sets	Genotype	Sets	Genotype	Sets	Genotype	Sets
df	5	2	5	2	5	2	5	2
Plant height (cm)	2271.72	3088.11	454.34	1544.05	67.95	230.93	0.0000	0.0000
Days to Panicle initiation	2034.98	122.25	406.99	61.12	362.39	54.43	0.0000	0.0000
Days to Flowering	3926.00	73.00	785.20	36.50	743.87	34.58	0.0000	0.0000
Days to maturity	6065.64	64.92	1213.12	32.46	2010.20	53.79	0.0000	0.0000
Yield (t/ha)	29.13	15.93	5.82	7.96	37.76	51.62	0.0000	0.0000

df: degree of freedom

Table 2. Agronomic traits of tested rice varieties based on three sets of delayed planting (different dates of sowing and transplanting).

Traits	Set	Rice variety					
		BR22	BR23	BRRI dhan44	BRRI dhan46	BRRI dhan54	BR11
Plant height (cm)	1	122.3±4.5a	132.2±2.5a	132.0±3.0a	136.0±1.6a	111.1±0.9a	109.1±2.8a
	2	105.5±0.b	119.7±1.5b	120.7±3.7b	123.0±2.6b	113.1±1.0a	107.3±3.0a
	3	95.7±5.6c	106.2±1.3c	112.8±4.5c	106.9±4.2c	104.3±4.6b	105.8±2.2a
Days to Panicle initiation (day)	1	65.0±1.0a	69.0±1.0a	67.0±1.0b	67.7±1.5a	62.0±1.0a	76.0±1.0b
	2	61.0±1.0b	64.0±1.0b	63.0±1.0c	63.0±1.0b	57.0±1.0b	77.0±1.0b
	3	58.0±1.0c	60.0±1.0c	72.0±1.0a	67.0±1.0a	55.0±1.0c	80.0±1.0a
Days to Flowering (day)	1	92.0±1.0a	98.0±1.0a	92.0±1.0b	92.0±1.0a	83.0±1.0a	109.0±1.0a
	2	89.0±1.0b	93.0±1.0b	91.0±1.0b	90.0±1.0b	79.0±1.0b	107.0±1.0b
	3	86.0±1.0c	93.0±1.0b	101.0±1.0a	93.0±1.0a	77.0±1.0c	109.0±1.0a
Days to maturity (day)	1	121.0±0.0a	120.0±0.0c	118.3±0.5c	121.3±0.5b	107.0±0.0a	140.0±0.0a
	2	121.0±1.0a	122.0±0.0b	121.0±1.0b	117.3±0.5c	102.0±1.0b	138.0±1.0b
	3	116.0±1.b	125.0±1.0a	133.3±0.5a	123.0±1.0a	100.0±1.0c	140.0±1.0a

Note: Data represent mean ± s.d. of each rice variety in each set of treatment. The mean value of each variety among multiple sets was compared by Tukey's Honest Significant test.

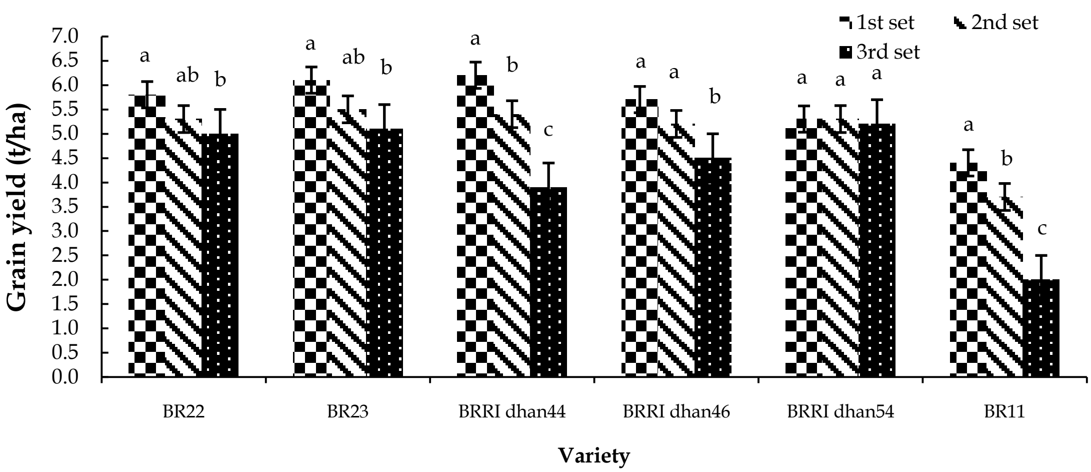

Fig. 1. The yield of five photosensitive rice varieties and the control rice variety BR11 in three sets of delayed planting during the Aman season.

Note: The bars over the column indicate standard deviation for each set and the mean value of each variety among multiple sets was compared by Tukey's Honest Significant test at 0.05 level.

yield over three sets of different planting time with a range between 5.3 to 5.2 t ha^{-1}. Like BRRI dhan44, the control variety BR11 had a gradual decrease in grain yield depending on planting time with the value ranging from 4.4 to 2.0 t ha^{-1}.

Relationship between sowing date and grain yield

Among the tested varieties, BR11 produced low yield even in 1st set of sowing. The Rate of yield decrease(-0.174) was maximum in the case of BR11 which indicated that it is not suitable for delayed planting (Fig. 2). On the other hand, BRRI dhan44 and BRRI dhan46 produced moderate yield (more or less 5.0 t ha^{-1}) till 2nd set of sowing. Rate of yield decrease of BRRI dhan44 and BRRI dhan46 were -1.66 and -0.087 respectively. BR23, BR22 and BRRI dhan54 produced moderate yield for all sets of delayed plantation and rate of yield decrease were -0.069, -0.058, -0.008 respectively. Among the varieties rate of yield decrease was minimum for in case of BRRI dhan54.

DISCUSSIONS

Significant variation was observed in all the traits (plant height, panicle initiation, days to flowering, days to maturity, and grain yield) depending on three sets of delayed planting in the T. Aman season (Tables 1 and 2). However, variation among photosensitive varieties enabled us to discuss the underlying causes and impacts of environmental factors. Time of transplanting directly influences the growth and yield contributing characters of rice (Islam *et al.* 1999). Sometimes transplanting in optimum time is not possible due to untimely rainfall or delayed recession of floodwater.

At first, drastic reduction of plant height in all photosensitive rice varieties indicated that vegetative growth is dependent on the existing photoperiod. In contrast, the plant height of control variety BR11 was not changed based on three sets of planting dates. In this study, we observed significant changes in days to panicle initiation among the tested rice varieties. BR22, BR23, and BRRI dhan54 had a dramatic reduction in days to panicle initiation compared to BR11. These results supported that these varieties are strongly photosensitive while BR11 is a weakly photosensitive rice variety. Moreover, a moderate reduction of BRRI dhan44 and BRRI dhan46 indicated moderate photosensitivity in those varieties. Among strongly photosensitive varieties, a gradual decrease of days to flowering was observed mostly in BR22 and BRRI dhan54 except for BR23. Although they had a similar pattern of panicle initiation based on three sets of planting time. Probably, this has been influenced by environmental factors such as low temperature (Fig. 3). Generally, spikelet sterility of rice is affected by low temperatures during panicle development and these changes happen according to its physiological status during sensitive stages (Shimono *et al.* 2007).

On the other hand, flowering time is affected by both genetic factors and environmental cues (Putterill *et al.* 2004; Verhage *et al.* 2014). In the present study, days to flowering increased over time in the case of two photosensitive varieties (BRRI dhan44 and BRRI dhan46) which indicates that their flowering is delayed due to low temperature. Generally, flowering should be promoted in short-day conditions but it was delayed because of low temperature. Thus, variation in days to flowering supported the idea that flowering of some photosensitive rice varieties delayed because of low temperature in the Aman season. It was also observed for two rice varieties, BRRI dhan46 and BRRI dhan31 where four transplanting dates were considered to study the effect of low-temperature stress influenced by date of transplanting (Nahar *et al.* 2009). In future, these results need to be confirmed in separate studies. In between two moderate

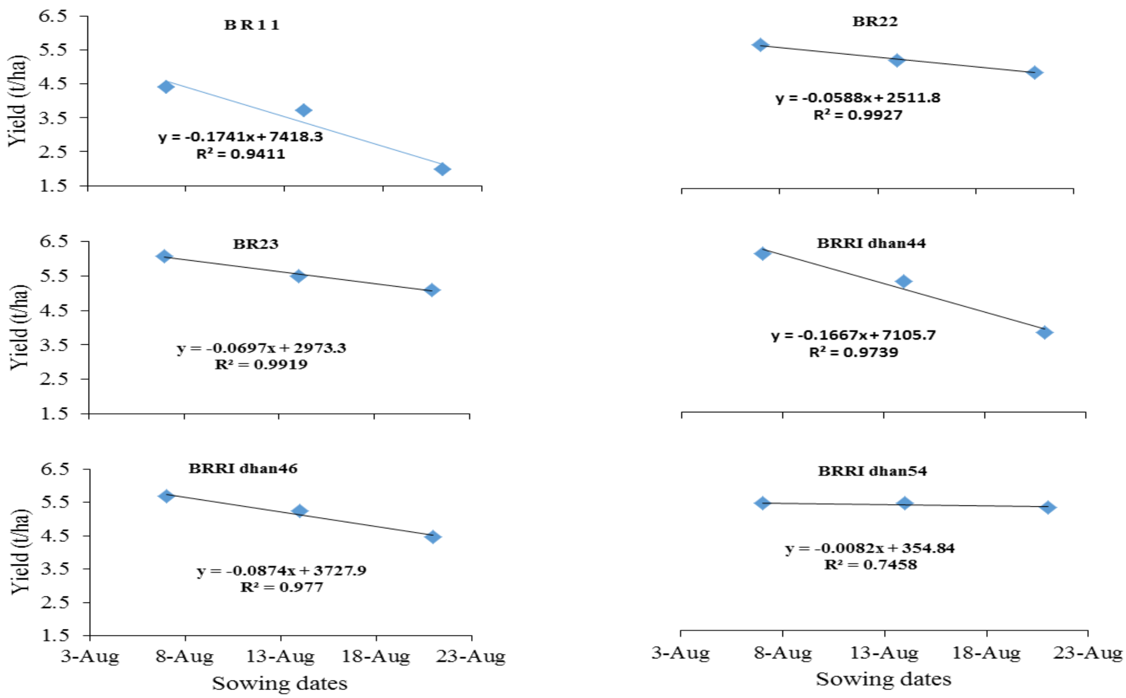

Fig. 2. Relationship between sowing dates and yield of six rice varieties in Aman season.

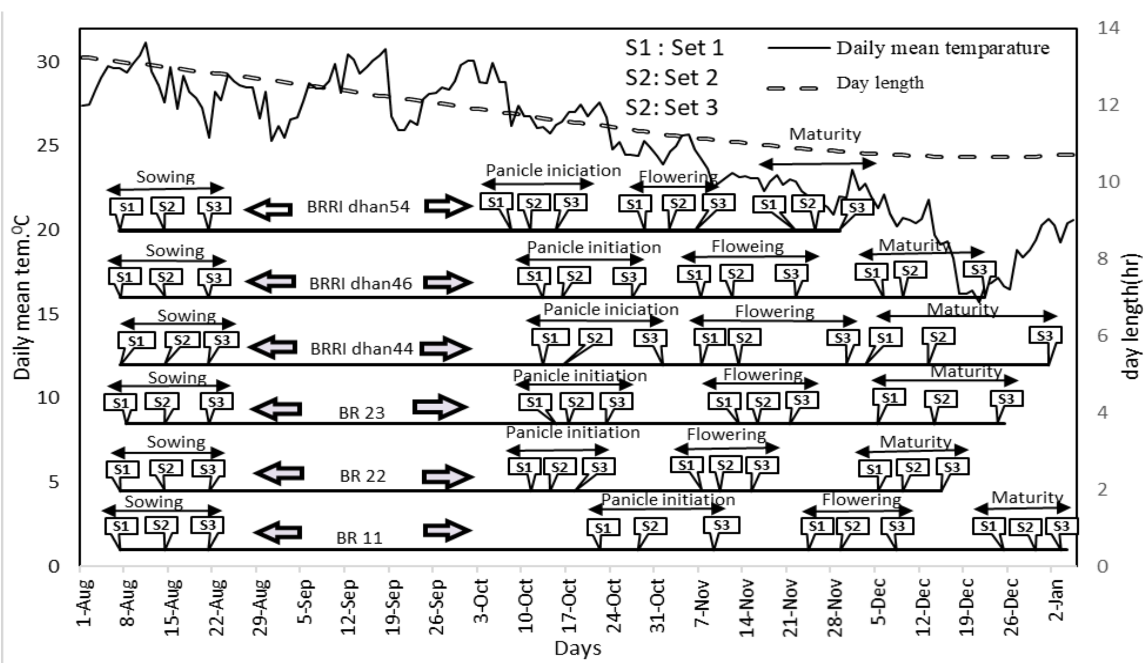

Fig. 3. Different growth stages (panicle initiation, flowering, and maturity) of each rice variety in relation to daily mean temperature (°C) and day length (hr) during the Aman season.

photosensitive rice varieties, BRRI dhan46 performed better while both the reproductive and ripening phases of BRRI dhan44 were extended due to low temperature, which is an undesirable trait in the delayed plantation. For days to maturity, both strong and moderate photosensitive rice varieties showed remarkable differences depending on planting time. Among strongly photosensitive rice varieties, BRRI dhan54 showed a gradual decrease in maturity time in case of BR22 and BR23 for a certain period. Similarly, the maturity of BRRI dhan44 and BRRI dhan46 was decreased only at the third set. These results indicate that BRRI dhan54 has higher benefits in delayed transplantation because of the decrease in growth duration over time. It has been reported that photosensitivity and thermosensitivity are especial traits in late planting and rice varieties showed a wide range of maturities in response to late planting. Besides, late maturing rice varieties exhibit a considerable reduction in growth duration compared with early and intermediate maturing varieties (Yabuta *et al.* 2010; Yasumoto *et al.* 2017).

Among the tested rice varieties, we also observed marked differences in grain yield depending on three sets of planting time. Grain yield of BRRI dhan54 did not differ significantly rather it showed consistency in case of delayed plantation. This result indicates that BRRI dhan54 has higher potentiality in a delayed plantation without any significant reduction in grain yield. In case of moderate photosensitive rice varieties, BRRI dhan46 showed superior performance in grain yield, which was further supported in comparison of days to panicle initiation and flowering. In previous studies, reduction in grain yield and days to maturity were found when the comparison was made among BR11, BR22, BR23 and Nizersail in relation to different planting dates (Ali *et al.* 1993). Moreover, the grain yield of the control variety BR11 was reduced drastically based on three sets of planting time, which indicates that weakly photosensitive rice has little or no benefit in delayed plantation. Furthermore, the relationship between sowing dates and grain yield supported that BRRI dhan54 has higher potentiality compared with other rice varieties.

CONCLUSION

Among the three sets of delayed planting, significant variation of evaluated agronomic traits indicated the presence of higher variability in performances of existing Aman rice varieties. Along with suitable agronomic performances, the strongly photosensitive rice varieties BR22, BR23, and BRRI dhan54 showed greater benefits in terms of grain yield when compared with moderately photosensitive rice varieties BRRI dhan44, and BRRI dhan46. Besides, the consistent grain yield of BRRI dhan54 suggested higher suitability of this rice variety in terms of vegetative growth and yield across delayed planting areas as well as in flood-affected areas of Bangladesh.

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Estimation of Rice Yield Loss Using a Simple Linear Regression Model for Bacterial Blight Disease

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ABSTRACT

Field experiment was carried out in hot and humid summer (Transplanted Aus) season to realize the yield loss of a susceptible rice variety Purbachi inoculated with bacterial blight (BB). Treatments consist of BB inoculations at different crop growth stages like maximum tillering (MT), panicle initiation (PI), booting (Bt), flowering and heading stages differently including a control (no BB inoculation). Disease severity index (DSI) was measured at 14 days after inoculation (DAI) and harvest. Data on 1000-grain-weight and yield was recorded at harvest. Significant variation on DSI was observed among different BB inoculated crop growth stages. MT, PI and Boot stage inoculations showed similar (DSI 7.1-8.0) but higher DSI than flowering and heading stages inoculation (3.2-5.3) even control (0.00) at 14 DAI. However, all the treatments showed similar DSI 9.0 at harvest. Bacterial blight can affect the grain weight to some extent although it was insignificant among the treatments (0.1-4.5%). DSI showed negative correlation with 1000-grain weight (r=-0.77*) and similarly with the yield (r=-0.97**). The yield ranged from 2.4-3.4 t/ha among the treatments. The yield loss was observed 5.8-30.4% in the BB inoculated treatments. MT, PI and Boot stages inoculation affected the yield much resulting 21-30.4% yield loss. It could be concluded that a susceptible variety can be affected with significant yield loss up to 30.4% with severe outbreak of B B. A simple regression equation Y = 4.09-0.211X(Y = Yield, X = BB severity score) is suggested for the prediction of yield loss in susceptible variety in summer season.

Key words: Rice variety, bacterial blight, disease severity, yield loss

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the staple food crops in the world, feeding about half of the world population (Anon. 2016). It is the staple food crop of Bangladesh and the symbol of food security. Worldwide 40% rice crop is lost every year due to biotic stresses including pathogen, insects and weeds (Hossain 1996). During the growing period, rice is always vulnerable to different major diseases like blast (*Pyricularia oryzae*), sheath blight (*Rhizoctonia solani*), sheath rot (*Sarocladium oryzae*), bacterial blight (*Xanthomonas oryzae* pv. *oryzae*) and tungro that affects the yield. Among the diseases, bacterial blight (BB) is one of the most serious threats to the rice crop in irrigated and rainfed areas of the world (Mew 1987). The disease BB, has been reported globally from Asia, Africa, northern Australia, the United States of America (USA) and some Latin American countries (Ronald 1997). The disease was identified first in Japan in 1884 (Tagami and Mizukami 1962) and considered as the oldest rice disease of Asia (Jeung *et al.* 2006).

In the last few decades BB of rice is considered as a major bacterial disease in Bangladesh. It is caused by a Gram-negative bacterium *Xanthomonas oryzae* pv. o*ryzae (Xoo)*. It is a vascular disease and cause systemic infection (Mew 1987). BB symptoms appear at the tillering stage and disease incidence increases with plant growth and reached peak at the flowering stage (Mew 1992). Virulent races of bacterial blight pathogen exist in tropical environment (Buddenhagen and Reddy 1971). Hot and humid environment in tropical Asia enhance the bacterial blight incidence and severity. Therefore, virulence races and disease favourable environment enhance the disease incidence and losses are thought to be significant in tropical Asia than sub-tropical (Mizukami and Wakimoto 1969, Ou 1972).

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Reports from several Asian and Southeast Asian countries indicated that crop losses could be occurred 10-20% in moderately susceptible cultivars in moderate conditions and up to 50% in very susceptible cultivars in conducive conditions due to bacterial blight disease (Ou 1985, Mew *et al.* 1993). Bacterial blight causes reduction in total dry matter, grain weight, and increase in the number of sterile grains. It also results in poor maturation as well as broken grain in milling. Generally, the extent of damage depends on the time of infection during growing period and the severity of the disease. In current years, BB incidence is increasing due to extensive use of nitrogen fertilizers in modern varieties and due to changing scenario of climate in different parts of the world including Bangladesh (Anon., 2016, Anon. 2017, Anon. 2018, Bashir *et al* 2010, Ali *et al.* 2009, Akhtar 2003). Introduction and intensive cultivation of modern varieties with high dose of nitrogen also enhances the disease severity and thereby yield loss in susceptible varieties.

The disease management strategies need to evaluate the impact of disease severity on crop yield. Evaluation of disease severity and crop loss assessment help in reliable estimation of yield loss and thereby determine the economic impact (James 1974). The yield loss varies depending on the location, season, weather conditions, rice cultivars, management factors like nitrogen and the crop stage at which the infection takes place. Therefore, estimation of yield loss under local host-pathogen-environment interrelationship condition is necessary. Further, estimation of yield loss based on the relationship of disease severity and attributed yield may provide a way or method of yield loss assessment. Field experiments were conducted in summer (Transplanted Aus) season to find the relation of BB (*Xoo*) severity at different crop stages and yield losses in the susceptible variety.

MATERIALS AND METHODS

Location, season and plant materials. The experiment was conducted in the research field of Bangladesh Rice Research Institute (BRRI) during hot and humid summer (T. Aus) season. A susceptible variety Purbachi was evaluated for yield loss estimation under artificial bacterial blight (BB) inoculation following leaf clipping method (Kauffman *et al*. 1973).

Field management. Land was prepared with four cultivations for seedling transplanting and growing. Basal fertilizers and furadan (@ 20 kg/ha) were applied following the standard recommended dose during final land preparation. Rice seedlings were transplanted at 25 days. Seedlings were planted spaced with 20 cm in rows and 15 cm in between plants in a row. Individual plot size was 3 m × 2 m. The crop was fertilized with 120 kg N/ha in three splits following BRRI recommendation (BRRI 2015). Other management practices were also followed as the BRRI recommended production practices.

Treatments and Design. Plants were inoculated at different growth stages. BB inoculation was done separately at maximum tillering (MT), panicle initiation (PI), booting (Bt), flowering (Fl) and heading stages. Therefore, there were six treatments including a control (no inoculation). The experiment was laid out in RCB design with three replications.

Isolation and culture of Bxo9 isolate. A virulent isolate of bacterial blight Bxo9 were isolated from the bacterial blight infected leaf. BB infected leaf samples were collected from the research field of BRRI. Infected samples were surface sterilized with 70% (v/v) ethanol for one minute and rinsed. Then sterilized samples were cut into small pieces of 3-4 mm in size and rinsed twice in sterilized water for 2-3 minutes. After that the leaf pieces were soaked in 5 ml sterile sterilized water for 30 min at room temperature to allow bacteria to disperse into the surrounding liquid in the laminar air flow. The water became cloudy which indicated the presence of a high number of bacteria. A loopful of the washings (bacterial suspension) was streaked onto Potato-sucrose-agar (PSA) medium and wrapped with cellophane tape to minimize the contamination risk. Plates were incubated at 30 ^{0}C in an incubator. After 48 hours, several yellowish or light-yellow watery colonies appeared on the medium of the plate. Further streaking on PSA petri plates allowed single colonies and pure cultures was obtained. Finally, single bacterial colony was cultured in a considerable number of slants and preserved at -20 ^{0}C for further use at different crop growth stages inoculation in a season.

Inoculation of Bxo9. Fresh culture of Bxo9 isolate were done again using the slant prepared and preserved earlier before inoculation in any stage of the crop. Bxo9 was grown in PSA petri plates or bottles under room temperature for 48 hours. Then distilled water was added in each petri plate/bottle and make the bacterial suspension. The concentration of inoculum was adjusted approximately 10^{8} cfu/ml. Plants were inoculated with 48 hours old culture inoculum of Bxo9 at different growth stages singly. All the plants in each plot were inoculated following leaf clipping method (Kauffman *et al.* 1973). Almost all the leaves were cut 2-3 cm from the leaf tip with scissors dipping in bacterial suspension immediate before cutting leaves.

Disease estimation and data collection. In order to estimate the disease severity, 10 plants were selected from each replicated plot following diagonal method of sampling. Disease scoring was done at 14-day after inoculation (DAI) at the time of harvesting. Disease severity index (DSI) was estimated from all infected leaves in the selected plants based on leaf lesion spread following standard evaluation system (SES)for rice (IRRI 2002). Data were recorded on fertile tiller, 1000 grain weight (g) and yield (t ha^{-1}) at the time of harvesting. The yield was taken from the whole plot. Number of effective tillers was estimated counting the number of panicles per hill from 10 randomly selected hills in a plot. Yield loss was calculated using the following formula:

$$\%\,Yield\ loss = \frac{Healthy\ plot\ yield - Diseased\ plot\ yield}{Healthy\ plot\ yield} \times 100$$

RESULTS AND DISCUSSION

Disease severity index

The disease severity index was the highest at MT stage inoculation which was similar to PI and boot stage inoculation (Table 1). Disease development in MT and PI was significantly higher than those of flowering and heading stage inoculation. The lowest disease severity was observed in control (no inoculation). Disease severity in flowering and heading stage inoculation showed similar disease spread as control. Disease severity index indicated a decreasing trend with the increase of leaf maturity with advancement of plant age at different crop stages (Fig. 1). This was due to gradual increase of lignification into the cell wall in expanded leaves which supports Reimers *et al.* (1992). However, disease severity in all the treatments including control reached to 9.0 due to severe outbreak of the disease. Natural disease incidence in control treatment starts at flowering and reached at the highest at harvesting.

Effect of bacterial blight on grain weight. The 1000-grain weight did not vary among the treatments which ranged from 22.2-23.3 g. Correlation between BB disease index and 1000-grain weight showed a negative relationship (Fig. 2). This means that there was a trend of decreasing grain weight with increase of disease severity. Grain weight pattern among the treatments indicated that BB can affect the grain weight to some extent although it was insignificant among the treatments (0.1-4.5%). The losses were more at or before boot stage inoculation (2.0-4.5%) which might indicate a considerable amount of losses as a whole throughout the country.

Table. 1. Effect of BB disease on the yield of Purbachi during T. Aus.

Crop stage of BB inoculation	BB disease index at 14d[a]	BB disease index at harvesting	1000 grain weight (g)	Yield (t ha^{-1})
MT	8.00 a	9	22.22 a	2.43 c
PI	7.77 a	9	22.85 a	2.37 c
Booting	7.13 ab	9	22.80 a	2.70 c
Flowering	5.33 bc	9	23.24 a	2.80 bc
Heading	4.27 cd	9	22.95 a	3.23 ab
Control	3.27 d	9	23.27 a	3.43 a

[a]14-day after inoculation. In a column figures with common letters did not significantly differ at the 5% level by DMRT. BB: Bacterial blight, MT: Maximum tillering (Seven days before panicle initiation), PI: Panicle initiation and Control: No inoculation

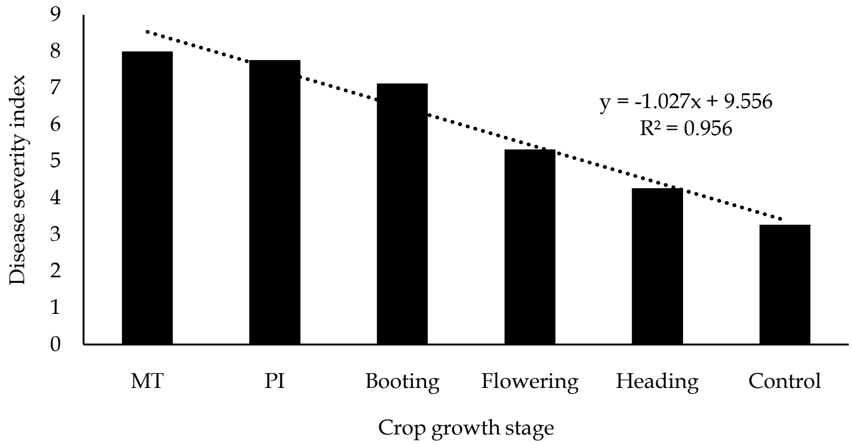

Fig. 1.Disease severity level decreases with advancement of crop stage (MT: Maximum tillering, PI: Panicle initiation, Control: No inoculation).

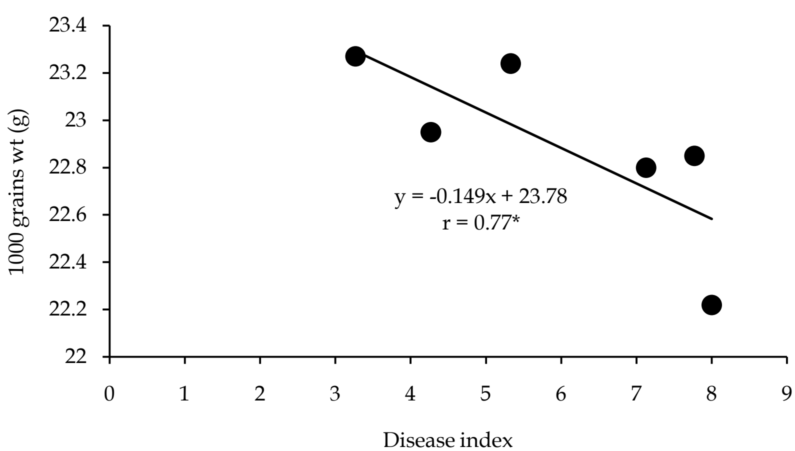

Fig. 2. 1000-grain weight of Purbachi at different disease severity levels in T. Aus.

Yield and yield loss.

The yield ranged from 2.4-3.4 t ha^{-1} among the treatments (Table 2). The highest yield was recorded in the control (3.4 t ha^{-1}) followed by heading (3.2 t ha^{-1}) and flowering (2.8 t ha^{-1}) stage inoculation with corresponding their lower disease severity. Similar yield at heading stage inoculation and control treatments were due to natural incidence of BB in control treatment occurred at heading and progress similarly until harvesting. BB inoculation in other three stages showed similar yield (2.4-2.7 t ha^{-1}) which was significantly lower than the rest of the stages. Lower yield in MT, PI and booting stages was due to higher disease severity in these stages compared to the rest of the crop stages. Crop loss assessment is often reported as percent of the yield in comparison with the control plot. The yield loss was observed 5.8-30.4% in the BB inoculated treatments (Table 2). MT to Booting stages inoculation affected the yield much resulting 21-30.4% yield loss. Whereas later stage inoculation of BB at flowering or heading resulted considerably lower yield loss.

Table 2. Prediction of yield loss on the basis of estimated yield using regression equation.

Crop stage of BB inoculation	Actual yield (t ha^{-1})	Yield loss (%)	Estimated yield (t ha^{-1})	[a]Predicted yield loss(%)
MT	2.43	29.2	2.40	30.2
PI	2.37	30.4	2.45	28.7
Booting	2.70	21.4	2.59	24.6
Flowering	2.80	18.6	2.97	13.1
Heading	3.23	5.8	3.19	6.4
Control	3.43	0.0	3.40	0.0

[a]Based on equation Y=4.09-0.211X, BB: Bacterial blight, MT: Maximum tillering (Seven days before panicle initiation), PI: Panicle initiation and Control: No inoculation

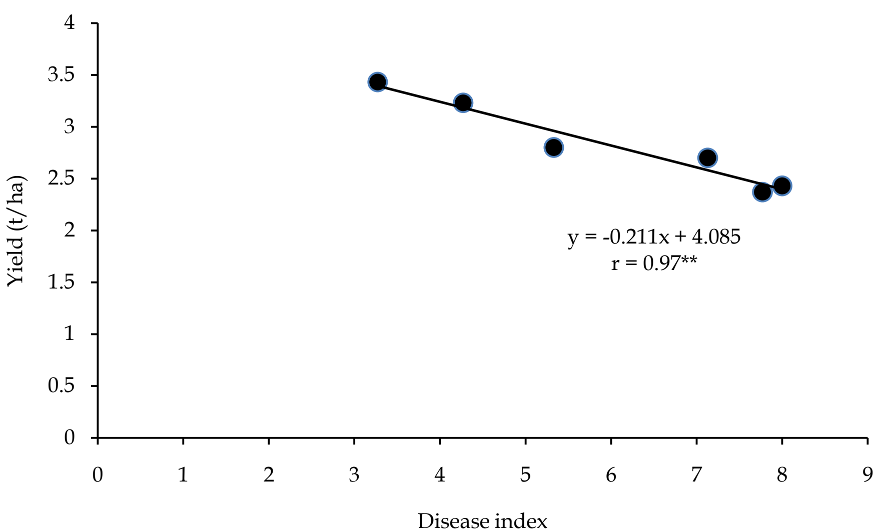

Fig. 3. Rice grain yield at different disease severity levels in Purbachi, during T. Aus.

Yield loss assessment. The yield trend indicated the increase of yield loss with higher disease severity (Fig. 3). A relationship between DSI and yield was estimated by a linear regression as Y= 4.09-0.211X (Coefficient of determination R^2=94.5 %). The equation could be expressed as $Y = a - bX$ where Y is the predicted rice yield at X level of BB severity, a is the expected yield in the absence of disease, X is the disease severity index or diseased leaf area (%) and -b is the regression coefficient that expresses the linear loss in an amount per unit area associated with specific levels of BB on susceptible rice variety (Reddy *et al.* 1979). Considering the yield loss data as a percentage of the corresponding y-axis intercept (here a=4.09), a theoretical expected rice grain yield could be attributed in absence of BB.

The estimated or predicted yield was calculated on the basis of the above equation based on a constant Y axis intercept value 4.09 (Table 2). The results showed that the predicted yield was similar to the actual yield. Similar results were also found for predicted yield loss and this predicted loss assessment was more harmonious to the disease severity. Therefore, the equation with Y axis intercept value 4.09 could be used in yield loss assessment in the BB susceptible varieties with similar yield potential. However, further studies including a considerable number of cultivars in this regard is needful for confirmation of this study.

CONCLUSION

BB inoculation at early stages (MT, PI and boot) produced the highest diseases corresponding to lower yield than the BB severity at flowering and later stages. Therefore, control measures are necessarily important when crop infected with BB at early stages. The results indicated that a susceptible variety can be affected with significant yield loss up to 30.4% with severe outbreak of BB. The suggested regression equation Y = 4.09-0.211 X could be used for the prediction of yield loss in susceptible variety in summer season.

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Diffusion of Wet Season (T. Aman) Rice Cultivars under Changed Environment in Northwest Bangladesh

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ABSTRACT

Northwestern part of Bangladesh plays an important role to supply rice for national food security. However, wet season (WS) rice cultivation in the area is highly vulnerable to moisture stress and severe pest infestation. Therefore, it is very much important to evaluate the adoption situation of wet season rice cultivars and their drivers and drawbacks of adoption in order to delineate the possible ways of rapid dissemination of modern rice varieties to cope with the existing vulnerability and minimize yield gap. Two important wet season rice-growing districts, namely Rangpur and Dinajpur were selected purposively for the study. Focus group discussion (FGD) and key informant interview (KII) were conducted using semi-structured questionnaire to gather qualitative and quantitative data for the study. In addition, structured questionnaire was used in the FGD for generating data on input use patterns, outputs and seasonal variability of yield and price of different rice cultivars for estimating costs and returns. The findings of the study reveal that farmers mainly adopted exotic WS rice cultivars to reduce unexpected yield loss due to abiotic and biotic stresses. Diffusion status of exotic cultivars was ranged between 76-85% of total WS rice area in the study locations. The drivers of widespread diffusion of exotic cultivars are stability in yield performance, compatibility to fit into local cropping systems, potentiality to recover from biotic and abiotic stresses and ensured market demand. However, farmers are dreaming for higher yield potential and more stress tolerant cultivars for fitting into two and three crops-based systems in the areas. Rice breeders may use the findings of this study to develop and disseminate suitable rice cultivars for the northwestern part of the country.

Key words: Exotic rice cultivars, adoption drivers and constraints, abiotic and biotic stresses, adaptation strategies, varietal preferences, diffusion model.

INTRODUCTION

Bangladesh is currently self-sufficient in producing its staple food rice. Northwest Bangladesh is one of the most prominent corner stones in supply chain of rice production in the country. Although dry (Boro) season (DS) irrigated rice and wet season (WS) rain-fed low land rice jointly contribute in the value chains; however, share in value chains of WS rice is largely higher than that of DS rice. Additionally, straw of WS rice is very important to household for fuel and cattle feed. The country is highly vulnerable to climate change due to its geographical location, high population density and low adaptive capacity of people (Kabir *et al*. 2016). It has been projected that extreme weather events such as drought, cyclone, heavy rainfall, flood and intrusion of saline water will be more frequent and intense under changed environment (WB, 2013). Rahman *et al.* (2017) reported that unfavourable conditions might be aggravated in developing countries like Bangladesh. Therefore, rain-fed rice cultivation, in the country particularly in its northwest part, has become highly vulnerable. On the other hand, population of this country is projected to be 215 million by 2050 and country will have to produce additional 10.8 million ton rice to meet food grain requirement of increasing population from the decreasing natural resources including arable areas (Hussain, 2011). In this

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respect, the government in its seventh five-year plan introduced vertical extension approach for food production by enhancing cropping intensity and individual crop yield in the northwest Bangladesh.

Accelerating genetic gain, location specific varieties, minimizing yield gap and curtailing adoption lag could be options to alleviate the barriers of achieving the target (Kabir, 2015). Therefore, assessing farmers' perception about climate change, their adaptation options for wet season rain-fed low land rice, drivers and drawbacks of adoption of WS rice cultivars are important. However, none of the study was found to address the issues particularly in northwest Bangladesh where farmers adopted some exotic modern rain-fed low land rice cultivars entered in the frontier regions of Bangladesh from India through cross border seed exchange between farmers. The area coverage of the exotic cultivars in comparison to that of indigenous ones was very high in the northwest Bangladesh. Reasons behind adoption lag of indigenous/modern varieties are not always very clear. However, it is needed to disseminate these indigenous/modern varieties in those areas. Thus, a study to develop a diffusion model for curtailing adoption lags through in-depth evaluation of adoption status of varieties and their criteria and constraints and factors facilitated adoption deserve due attention.

Specific Objectives

Specific objectives of the study were to:

- Delineate diffusion status of wet season rice cultivars under changed environment
- Identify drivers and drawbacks of adoption of different rice cultivars
- Draw a rapid diffusion model for potential rice cultivars.

METHODOLOGY

Qualitative and quantitative data were collected from primary and secondary sources for the study. Quantitative data such as block wise adoption of different wet season rice varieties and their yield under farmers' and BRRI recommended management on demonstration plots for the last decade (2008-2018) were collected from Agriculture Office and the Department of Agricultural Extension (DAE). As the study requires detailed and in depth information about adoption of native, exotic and hybrid cultivars, two representative sub districts were purposively selected as location of case study viz Khansama of Dinajpur and Pirganj of Rangpur district where adoption of exotic cultivars in the locations were very high. Farm level data on farmers' perception of change in climate, their adaptation option for WS rice cultivation, and drivers and drawbacks of adoption of different WS rice cultivars and phenotype of dreaming WS rice cultivars were collected through focus group discussion (FGD). In total 22 FGDs were conducted in 22 unions of the selected sub-districts using an open ended pre-structured questionnaire. In total 660 key informants i.e., 10 from each of 66 blocks of 22 unions. In addition, a structured questionnaire was used in the FGD for generating data on input use patterns, price of inputs and outputs and seasonal variability of yield and price of different rice cultivars for estimating costs and returns of the rice cultivars. Furthermore, farmers were interviewed individually using a small structured questionnaire to delineate diffusion level of different WS rice cultivars in the study locations. Moreover, an expert panel interview with DAE personnel including Sub-Assistant Agriculture Officer (SAAO), Agriculture Extension Officer, Additional Agriculture Officer and Upazila Agriculture Officer were conducted in each sub-district to identify drivers and drawback of adoption of WS rice cultivars, and validate farmer's observation. Finally, an in-depth discussion was carried out with the expert panel members regarding reduction of adoption lag for the newly released potential rice cultivars. Both the qualitative and quantitative data were analyzed following descriptive statistics.

RESULTS AND DISCUSSION

Description of study location

Proportion of different farm household types in Pirganj and Khanshama is consistent with national average percentage of different farm types (BBS, 2017). Over 80% of total arable areas in the study locations are high to medium high lands, which are mostly used for two or three crops systems. Therefore, cropping intensity in the areas is largely higher (about 250%) than that of national (192%) average (BBS, 2017) (Table 1). Despite over 80% of total arable area is high to medium high land in both the locations; however, nearly half (45%) of the areas in Pirganj used for Rice-Fallow-Rice cropping pattern, indicating that non-rice crop areas are used for rice cultivation in dry season (DS) in the location. On the other hand, about 76% of total arable areas allocated for 'rice, non-rice' cropping systems (Table 2). The land topography and land use pattern clearly indicates that there are substantial opportunities for diffusion of higher yield potential short duration WS cultivars in the locations.

Table 1. Basic agricultural statistics of Khansama under Dinajpur and Pirganj under Rangpur district.

Item	Khansama	%	Pirganj	%
Agricultural household (No.):				
Landless	9,844	26.4	13,211	15.2
Marginal	11,296	30.3	26,966	31.0
Small	11,950	32.1	35,653	41.0
Medium	3,691	9.9	10,157	11.7
Large	439	1.2	900	1.0
Total	37,220	100.0	86,887	100.0
Land type (ha)				
High land	4,500	29.3	13,705	33.5
Medium high land	8,111	52.8	22,028	53.8
Medium low land	2,750	17.9	970	2.4
Low land	-	-	4,229	10.3
Total land area	15,361	100.0	40,932	100.0
Land use statistics (ha)				
Single cropped area	328	2.13	1,010	3.07
Double cropped area	5,290	34.43	21,450	65.39
Triple cropped area	9,743	63.43	8,272	25.21
Quadruple cropped area	-	-	2,068	6.30
Net cropped area	15,361	100	32,800	100
Total cropped area	40,139	-	76,998	-
Cropping intensity (%)	261	-	251	-

Source: DAE, 2017-18

Table 2. Major cropping pattern of Khansama and Pirganj upazilas.

Dominant cropping pattern	Khansama upazila		Pirganj upazila	
	Area (ha)	%	Area (ha)	%
Boro-Fallow-T. Aman	3,700	24	14,760	45
Maize-Fallow-T. Aman	1,590	10	-	-
Potato-Maize-Fallow-T. Aman	2,396	16	-	-
Wheat-Jute-T. Aman	2,150	14	-	-
Potato-Boro-T. Aman	-	-	4,920	15
Potato-Jute-T. Aman	-	-	2,296	7
Potato-Aus-T. Aman	-	-	1,640	5
Vegetables-Seedbed-Vegetables	-	-	1,320	4
Vegetables-Vegetables-T. Aman	534	3	-	-
Garlic-Vegetables-T. Aman	500	3	-	-
Wheat-Maize-T. Aman	490	3	-	-
Mustard/Potato-Vegetables-Aus-T. Aman	-	-	1,148	3.5
Major cropping pattern total	-	74	-	80

Source: DAE, 2017-18

Climate change perception and adaptation strategies

Farmers in group discussion said that they observed changes in climate particularly rise in temperature over the years, decreased spread of rainfall (no rainfall in some months), shifted delay of monsoon months about 15-25 days, unpredictable rainfall pattern, increasing extreme weather events, particularly heavy rainfall, floods and droughts. Likewise, Nishat and Mukherjee (2013) reported that the maximum (0.87 °C and 0.42 °C) and minimum (0.45 °C and 0.52 °C) temperature is observed a prominent rise in over the last few decades. Farmers observed increased infestation of insects and pest in the WS rice in the locations. Key informants reported that potentiality of performance of some rice varieties, for instance BR11 has become considerably unsustainable under changed environment due mainly to its higher proneness to pest and less tolerance to moisture stress and cold at the panicle emerging stage. Therefore, farmers undertook planned and local adaptation option including changes in rice cultivars, application of supplementary irrigation and double transplanting technique. Farmers have adopted some higher yield potential exotic cultivars, for instance Guti Swarna, Swarna5 and Mamun Swarna because of sustainable performance of the cultivars despite stress environment.

Adoption status of wet season rice cultivars

Diffusion status of exotic inbred WS rice cultivars in Khanshama was substantially dominant (range between 79-85% of total WS rice area) with an upward trend over the last decade. Among the exotic inbred cultivars, status of Guti Swarna was most dominant, however, its adoption decreased slightly to 47% in 2018 from 57% in 2008. Similarly, adoption of BRRI cultivars during the decade decreased to 8% in 2018 from 15% in 2008. In the contrary, diffusion of other exotic cultivars, in particular Mamun Swarna and Swarna5 increased notably to 32% of total area of WS rice in 2018 from 13% in 2008. Similarly, adoption of exotic hybrid cultivars increased to about 6% of total area in 2018 from only less than one percent in 2008 (Table 3). Farmers in group discussion informed that long duration cultivars, for instance Guti Swarna, BR11 and others were replaced mainly by short duration cultivar (25-30 days shorter) for instance Mamun Swarna and hybrid as well as by Swarna5 (medium slender and slightly shorter lifecycle)

Table 3. Adoption trend of wet season rice cultivars during from 2008 to 2018 in Khanshama, Dinajpur.

Variety	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Exotic:											
Guti Swarna	57.0	56.8	57.2	51.5	42.6	41.7	51.5	51.2	45.7	46.8	42.2
Mamun Swarna	12.5	14.1	12.0	14.4	19.5	19.3	16.4	17.1	19.4	19.9	18.7
Swarna5	0.3	1.5	2.6	5.3	10.0	9.9	6.9	7.7	12.3	13.3	17.2
Other Indian	9.6	7.9	9.5	11.2	10.9	12.1	5.6	5.4	3.7	4.2	6.4
All Indian	79.4	80.2	81.3	82.5	83.0	83.0	80.4	81.4	81.1	84.2	84.5
Hybrid	0.4	0.5	0.6	0.6	0.7	0.7	5.9	5.0	5.2	4.5	5.8
Indigenous:											
BR11	8.5	7.6	6.6	5.7	5.4	4.8	4.6	4.5	1.5	0.7	0.05
BRRI dhan49	6.5	6.9	7.8	6.8	6.4	6.7	4.8	5.2	4.3	3.6	2.6
BRRI dhan51	0.0	0.0	0.0	0.0	0.0	1.4	0.7	0.7	2.1	2.8	3.1
BRRI dhan52	0.0	0.0	0.0	0.0	0.0	1.4	0.9	0.9	1.9	1.6	1.8
Other BRRI	1.3	1.2	0.9	1.1	1.1	0.5	0.6	1.1	2.0	1.3	0.5
All BRRI	14.9	14.5	14.4	12.5	11.7	14.3	11.1	11.3	9.8	8.7	8.0
All MVs	96.1	96.4	97.3	96.7	96.6	98.5	98.1	98.9	98.0	98.7	99.3
LVs	3.9	3.6	2.7	3.3	3.4	1.5	1.9	1.1	2.0	1.3	0.7
Overall	100	100	100	100	100	100	100	100	100	100	100

Source: DAE, Khanshama

It is partly because of the short duration cultivars facilitate sowing of garlic and maize on time and introduce a rice crop in cropping pattern in early wet season (EWS), and partly because of potentiality of the cultivars to perform consistently across different seasonal conditions. On the other hand, farmers in the group discussion informed that adoption of BRRI cultivars decreased to 8% of total WS rice in 2018 from over 60-65% in 2000 is mainly because of their poor performance under changed climate conditions and stress environment. Table 4 presents that on average adoption of exotic inbred cultivars in 2018 was about 76% of total area of WS rice in Khanshama, which is slightly lower than that of (84%) reported by DAE (Table 3). It was found that diffusion of exotic inbred cultivars was highly dominant (ranges between 71-77% of total WS rice area of respective union) across unions in Khanshama. Among the exotic cultivars, on average adoption of Guti Swarna was higher (about 40% of total WS rice area) followed by Mamun Swarna (about 18%) and Swarna5 (about 14%). However, there were considerable variation in adoption of Guti Swarna (ranges between 19-48%), Mamun Swarna (ranges between 8-34%) and Swarna5 (ranges between 9-21%) among unions. In the contrary, on average adoption of BRRI varieties were range between 15-17% of total areas of respective union. Among BRRI varieties, BRRI dhan51 covered about 5% of total WS rice area in Khanshama followed by BRRI dhan49 (4%), BRRI dhan52 (3%). Besides, a few areas (1.5%) were covered by other BRRI varieties (BRRI dhan33, BRRI dhan34, BRRI dhan57, BRRI dhan62, BRRI dhan71 and BRRI dhan75). In addition, hybrid rice covers about 3-12% of total area of the respective union with an average of 6% of total WS rice area in Khansama.

Table 4. Union-wise adoption of different wet season rice cultivars in Khanshama, Dinajpur, 2018.

Variety/Location	Alokjhari	Angerpara	Bhabki	Goaldehi	Khamarpara	Vhervery	Overall
Exotic:							
Guti Swarna	47.7	39.5	38.8	59.0	37.2	19.1	40.2
Mamun Swarna	8.1	18.4	15.7	10.1	19.1	34.1	17.6
Swarna5	20.6	15.2	16.7	8.8	12.9	12.4	14.4
Other Indian	3.2	4.1	4.6	1.6	1.5	6.0	3.5
All Indian	79.7	77.1	75.9	79.5	70.7	71.7	75.8
Hybrid	3.3	3.9	6.6	2.9	12.1	9.2	6.3
Indigenous:							
BR11	2.8	2.6	4.8	4.5	2.3	2.3	3.2
BRRI dhan49	2.8	4.7		2.5	5.5	5.7	4.2
BRRI dhan51	5.4	5.0	5.1	5.7	3.8	4.0	4.8
BRRI dhan52	3.4	3.2	4.1	2.7	3.0	2.8	3.2
Other BRRI	1.2	1.6	1.5	1.4	1.9	1.6	1.5
All BRRI	15.5	17.2	15.4	16.8	16.5	16.3	16.3
Other MVs	0.9	1.1	1.3	0.4	0.4	1.7	1.0
All MVs	99.3	99.2	99.1	99.7	99.7	98.8	99.3
LVs	0.7	0.8	0.9	0.3	0.3	1.2	0.7
Overall	100	100	100	100	100	100	100

Source: Field survey 2018.

Farmers in group discussion and expert panel members said that key driver of adoption of Mamun Swarna and hybrid was that those short duration cultivars facilitate early planting of local variety potatoes and garlic on time for about 25% of total arable area in Khanshama. Similarly, Swarna5 (5-7 days shorter than Guti Swarna) facilitates to planting DS crops on time and its medium slender grain is one of the most preferred rice varieties for the people in Khanshama (Table 4).

Table 5 presents adoption of Indian cultivars particularly Guti Swarna which was substantially high in the areas with an increasing trend during last decade. Adoption of exotic cultivars increased to about 75% of total area of WS rice in 2018 from 52% in 2008. In the contrary, adoption of BRRI cultivars decreased to about 16% of total area of WS rice in 2018 from 34% in 2008. It was mainly because of decreased adoption of BR11 substantially due mainly to very poor performance of the cultivar in 2012. Similarly, adoption of Bina dhan7 also decreased to about 2% of total areas of WS rice from about 7% in 2008. It indicates that BR11 and Binadhan-7 were mainly replaced by Guti Swarna. Besides, some high to medium high lands went under cultivation of short duration hybrid varieties (about 5%) and slightly short duration Swarna5. On the other hand, some medium low to low lands used for cultivating submergence tolerant cultivars BRRI dha51 and BRRI dha52 (Table 3).

Farmers in group discussion and panel members of expert group discussion unanimously agreed that performance of Guti Swarna is sustainable across seasonal conditions, land types and management. Additionally, despite longer growth duration it is possible to planting as dry season (DS) crops on time after harvesting Guti Swaran if the rice is transplanted early. On the other hand, farmers informed that currently performance of BR11 is not only unsustainable (seasonal variation in yield is very high) but also the cultivar is not matured for harvesting (mild photoperiod sensitive) for timely planting of DS crops despite transplanting early. The respondents also said that environmental stresses (biotic and abiotic) tolerance and suitability for three crops-based systems was pivotal for substantial diffusion of exotic cultivars.

Table 6 shows that on average adoption of exotic inbred cultivars was about 71% of total area of WS rice, of which adoption of Guti Swarna was about 69% in Pirganj in 2018-19 which is consistent with adoption status of WS rice cultivars as reported by DAE (Table 5). On the contrary, adoption of BRRI cultivars was about 19% of total area of the Upazila. Among BRRI varieties, BRRI dhan52 was major one (about 6%) and followed by BR11 (5%), BRRI dhan51 (4%) and BRRI dhan49 (1%). Besides, a few areas (2.6%) are used for cultivating other BRRI varieties including BRRI dhan33, BRRI dhan34, BRRI dhan57, BRRI dhan62, BRRI dhan71 and BRRI dhan75. Additionally, on average 5% of total area are being used for hybrid. It is also the cases that there was a notable variation in adoption status of exotic inbred varieties (range between 64-80%) and BRRI cultivars (range between 15-25%) among the unions in Khanshama (Table 6). Farmers in group discussion and expert panel members said that variation of adoption of cultivars among unions was mainly because of variation in topography and soil types of lands and cropping systems.

Relative performance of cultivars

Figure 1 presents performance of BRRI and Indian WS rice cultivars under farmers' and recommended practice during 2008-17, in Khanshama, Dinajpur. It was observed that over the last decade per hectare yield of BRRI cultivars was lower in range between 0.54-1.03 t ha^{-1} and 0.20-0.37 t ha^{-1}, respectively under farmers' and recommended practice (demonstration plots) than that of Indian cultivars even under farmers practice. On other words, exotic inbred cultivars gave at least one ton higher yield over BRRI cultivars under farmers' practice in most years across last decade. Similarly, performance of exotic cultivars under farmers' practice was far better (per hectare about half a ton yield advantage) than that of BRRI cultivars even under recommended practice in demonstration plots. Farmers in-group discussion and extension personnel highlighted that potentiality of performing better under stress environmental condition is one of the most important driver of substantial diffusion of exotic WS cultivars in Khanshama.

Table 5. Adoption trend of wet season rice cultivars, during 2008/099-2017-18 in Pirganj, Rangpur.

Variety/year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Exotic:											
Guti Swarna	52.3	56.4	56.1	58.5	60.3	81.6	82.7	70.2	68.5	67.6	66.7
Other Indian varieties	0.0	0.4	0.8	0.0	0.0	0.0	0.0	2.8	2.8	5.0	8.2
All Indian	52.3	56.8	56.9	58.5	60.3	81.6	82.7	73.0	71.3	72.6	74.9
Hybrid	0.2	0.9	1.2	1.3	1.1	2.6	2.6	4.2	4.7	4.9	5.3
Indigenous:											
BR11	33.5	30.6	28.5	23.9	22.9	4.4	4.4	5.8	4.3	3.0	4.0
BRRI dhan49				0.3	0.3	1.0	1.0	1.2	1.8	1.6	1.2
BRRI dhan51				1.9	1.8	1.1	1.1	1.0	1.4	4.2	3.0
BRRI dhan52				2.9	2.8	3.2	3.2	4.8	5.9	5.0	4.8
Other BRRI	0.6	1.1	3.1	2.1	2.0	1.1	0.7	1.7	1.6	1.6	2.6
All BRRI	34.1	31.7	31.6	31.1	29.8	10.8	10.4	14.4	15.0	15.5	15.5
Binadhan-7	7.8	7.1	6.9	6.6	6.3	3.0	2.3	6.4	6.8	4.5	2.1
All MVs	94.4	96.4	96.5	97.5	97.5	98.0	98.1	97.9	97.8	97.4	97.8
Local	5.6	3.6	3.5	2.6	2.5	2.0	1.9	2.1	2.2	2.6	2.2
Overall	100	100	100	100	100	100	100	100	100	100	100

Source: DAE, Pirganj

Table 6. Union-wise adoption of different wet season rice cultivars in Pirganj, Rangpur, 2018-19.

	Exotic/Indian					Indigenous								
Locations/ Variety	Guti Swarna	Swarna5	Ronjit	All Indian	Hybrid	BR11	BRRI dhan49	BRRI dhan51	BRRI dhan52	Other BRRI	All BRRI	Other MVs	LVs	All
Boroalampur	63.2	3.0	4.9	71.1	6.5	5.6	1.0	4.8	5.7	2.9	20.0	1.6	0.7	100
Borodorga	64.0		3.0	67.0	5.7	7.0	1.1	1.1	6.0	0.6	15.9	8.1	3.5	100
Vedabari	68.8	1.0	10.0	79.8	0.6	2.9	0.9	7.6	4.2	0.0	15.6	2.9	1.2	100
Chaitracol	71.2	1.1	1.8	74.1	10.5	1.2	1.1	4.7	5.3	2.5	14.9	0.3	0.1	100
Chatra	72.0	1.2	1.3	74.5	3.4	4.1	1.3	4.7	7.4	4.2	21.6	0.4	0.2	100
Kabelpur	78.1	1.1	-	79.2	3.5	2.6	1.2	3.5	5.8	2.4	15.4	1.4	0.6	100
Kumedpur	73.7	-	1.5	75.2	4.8	3.8	1.1	6.3	4.4	2.3	17.9	1.5	0.7	100
Methipur	64.3	-	-	64.3	3.5	6.3	1.3	2.5	6.7	4.8	21.7	7.4	3.2	100
Madonkhali	70.7	-	-	70.7	3.5	9.4	1.0	5.1	8.1	1.0	24.7	0.8	0.3	100
Pachgachi	64.0	-	4.0	68.0	5.8	5.2	2.1	3.6	5.4	8.2	24.6	1.1	0.5	100
Pirganj	64.7	-	3.9	68.6	8.0	12.0	1.5	1.1	5.6	1.3	21.6	1.3	0.5	100
Pourasava	72.1	-	0.5	72.6	7.5	5.1	1.3	3.6	6.1	3.5	19.5	0.4	0.2	100
Ramnathpur	67.5	0.8	-	68.3	4.9	3.5	1.1	5.2	6.2	0.4	16.4	7.4	3.2	100
Roypur	67.2	0.9	1.0	69.1	2.7	5.5	0.8	4.5	5.1	3.4	19.2	6.3	2.7	100
Shanerhat	66.8	0.9	1.1	68.8	5.5	4.4	1.2	3.8	7.6	2.1	19.0	4.7	2.0	100
Tukuria	69.0	0.8	-	69.8	7.9	4.3	1.4	4.8	6.2	2.2	18.9	2.4	1.0	100
Overall	68.6	1.2	3.0	71.3	5.3	5.2	1.2	4.2	6.0	2.6	19.2	3.0	1.3	100

Source: Field Survey 2018

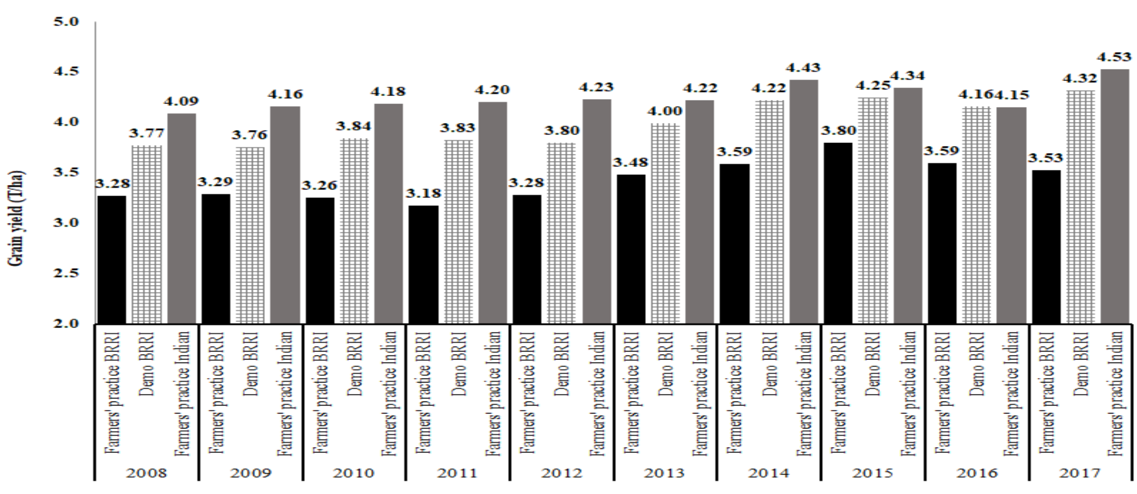

Fig. 1. Performance of BRRI and Indian WS rice cultivars under farmers' and recommended practice during 2008-17, in Khansama, Dinajpur.

Figure 2. presents performance of BRRI and Indian WS rice cultivars under farmers' and recommended practice during 2008-17, in Pirganj, Rangpur. It was observed that yield of BRRI cultivars over the last decade was lower in range between 0.38-0.53 t ha^{-1} and 0.17-0.29 t ha^{-1} respectively under farmers' practice and recommended practice than that of Indian cultivars under farmers' practice. In other words, exotic cultivars gave per hectare nearly half ton yield advantage over BRRI cultivars under farmers' practice in last decade. Additionally, performance of exotic cultivars even under farmers' practice was far better (per hectare about quarter a ton yield advantage) than that of BRRI cultivars even under recommended practice in demonstration plots. Farmers and extension personnel thought that better performance was one of the vital drivers of substantial diffusion of exotic cultivars in Pirganj.

Drivers of adoption exotic varieties in wet season

Among the adopted exotic WS rice varieties, Guti Swarna is the most dominant in both the study locations, and Swarna5 and Mamun Swarna are the second and third most dominant varieties in Khanshama (Table 7). Additionally, Ronjit is cultivated in some areas of both the locations and Garson is cultivated in some areas in Khanshama alone. Table 7 presents drivers and drawbacks of adoption of the exotic variety in WS in the study location. Adoption drivers of WS rice varieties are typified following agronomic, economic, social and environmental criteria and are discussed below.

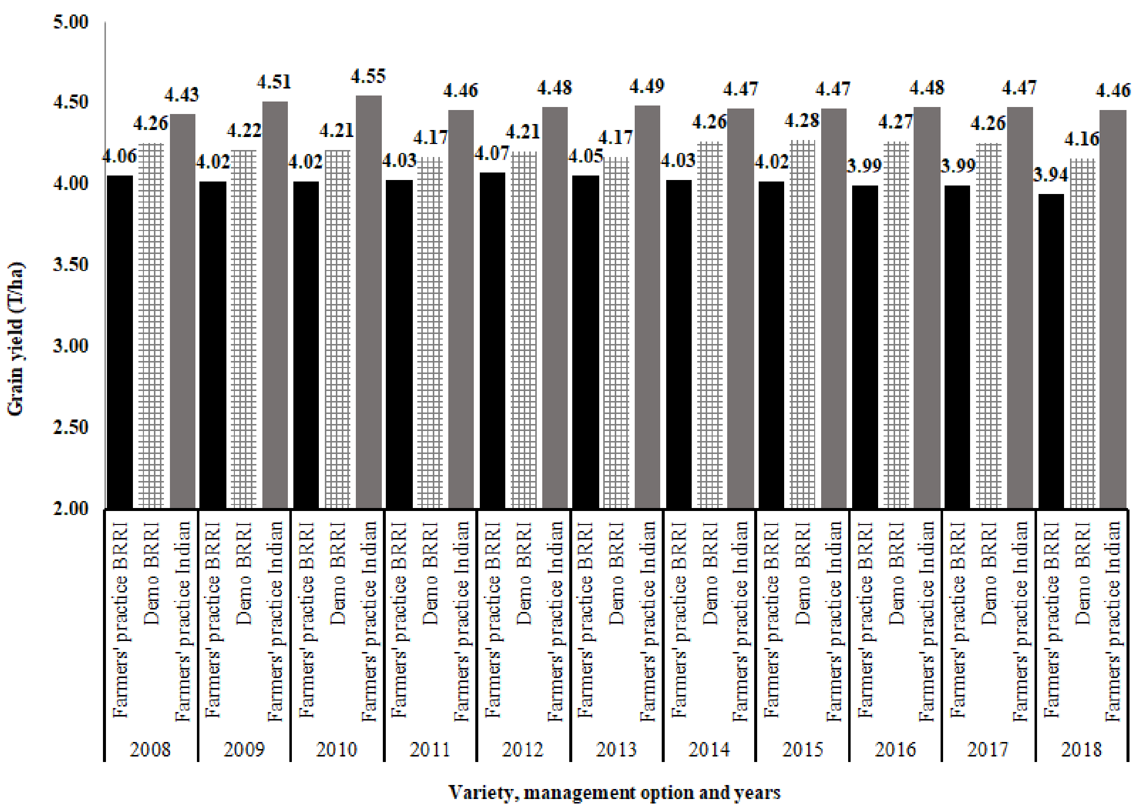

Fig. 2. Performance of BRRI and Indian WS rice cultivars under farmers' and recommended practice during 2008-2018, in Pirganj, Rangpur.

Agronomic drivers

Most farmers in group discussion said that higher yield potential than the other WS rice varieties under typical seasonal condition, and stable performance despite seasonal weather variation (e.g., heat, cold and erraticism of rainfall) was the most important driver of dominance for exotic inbred cultivars (Guti Swarna, Swarna5/Suman Swarna and Mamun Swarna) in WS. In other words, most key informants reported that the exotic cultivars were potential to produce expected yield even under the worst seasonal conditions (Table 7; Fig. 3), which was the main reason of large-scale adoption. Nevertheless, performance of BRRI varieties (BR11, BRRI dhan49 and BRRI dhan52) except the recently released ones (BRRI dhan71 and BRRI dhan75) substantially fluctuates, particularly due to moisture stress and cold before emerging panicles. For example, grain yield of exotic varieties ranges between 3.9-5.9 t ha^{-1} across different seasonal conditions (good, typical and worst) while yield of BR11, BRRI dhan49, BRRI dhan52 and BRRI dhan51 decreased to less than 3 t ha^{-1} under worst season condition in particular due to infestation of pest, moisture stress, and dew as well as mild cold at panicle emerging time. This sustainable performance of exotic cultivars is pivotal for large-scale diffusion in WS in survey areas was unanimously highlighted by both the expert panel members and key informant farmers (Table 7).

Moreover, majority of the key informants informed that exotic cultivars (Guti Swarna, Swarna5 and Mamun Swarna) not only have higher adaptive capacity to abiotic (floods, droughts and cold) and biotic (sheath blight, sheath rot, stem borer and leaf roller) stress but also, they are relatively less susceptible to some pest (BPH, tungro, ufra, ear cutter caterpillar and false smut), which are also crucial drivers for large-scale dissemination of those cultivars. Firstly, key informants reported that exotic cultivars consistently perform despite 5-7 days of natural flash flood submergence at vegetative stage as well as cold, moisture stress, heavy rain and storm at reproductive stage. In this regard, farmers said that cultivars recovered so quickly and fully from partial damage by flash flood submergence when MOP was top-dressed immediately after draining out the stagnant water from the fields, consequently reduced yield compensation.

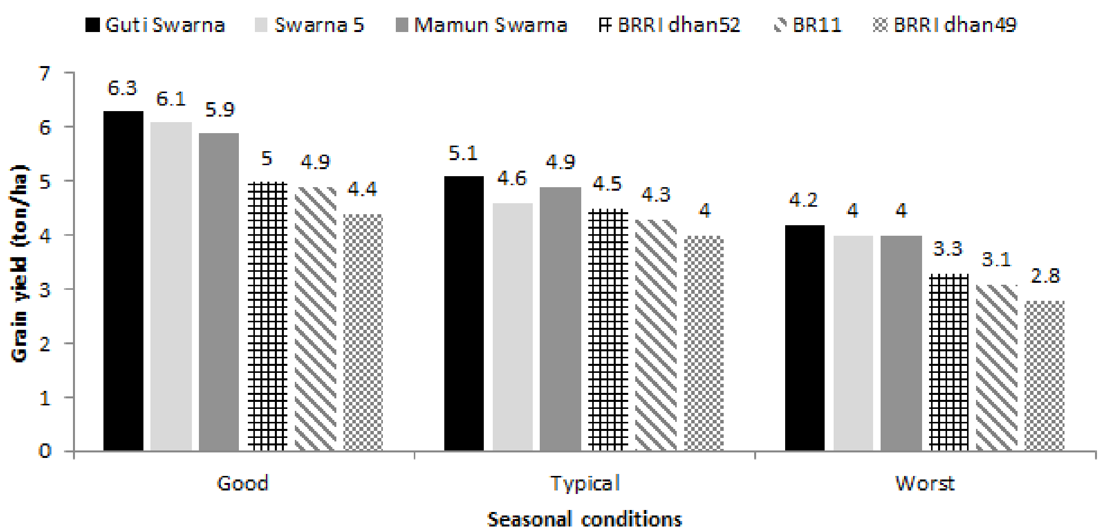

Fig. 3. Performance of different wet season rice cultivars under different seasonal conditions in study locations.

Besides, despite moisture stress and cold, panicles of those cultivars emerge quickly and fully except Swarna5, which is somewhat, drought susceptible. In the contrary, despite application of supplementary irrigation, BR11 and BRRI dhan49 and BRRI dhan52 were unable to exert panicle fully because of the beginning of winter (cold or even fall dew at night), consequently decreased yield substantially. Moreover, BR11 and BRRI dhan49 are highly vulnerable to floods at transplanting and tillering stages (Table 7).

Secondly, farmers in group discussion said that although, exotic varieties were highly prone to sheath blight and sheath rot, stem borer and leaf roller; nevertheless, they recovered from even severe infestation of such pest so quickly and fully after treatment. Farmers noted that despite complete damage of leaves, including flag leaf by the leaf roller, panicles of those exotic cultivars emerged and fills grain using nutrient reserved in the stems. On the other hand, farmers reported that erect leaves of the cultivars facilitated to pass air and temperature through the fields so that infestation of BPH was low except in Swarna5 because of its wider leaves and more vegetative growth. Therefore, despite sensitivity of those cultivars to some pests, and level of infestation exceeded economic threshold level, their performance was not affected much. Farmers informed that level of susceptibility to pest of exotic varieties was not same among them. For instance, Mamun Swarna and Swarna5 are less prone to common diseases (sheath blight and sheath rot) than even Guti Swarna and BRRI varieties. However, Mamun Swarna is susceptible to false smut but its proneness to false smut is not as severe as BRRI dhan49. On the other hand, despite treatment, performance of BRRI varieties, in particular BR11 considerably affected because of insects (BPH, gall midge, nematode, caterpillar, mealy bug and stem borer) and diseases (sheath blight, sheath rot, tungro, ufra and false smut) infestation (Table 7).

Thirdly, farmers said that exotic cultivars having higher ability to absorb shock; in particular, they could recover from re-transplanting stress so quickly. For example, Guti Swarna gets adapted within 3-4 days of re-transplanting while it takes over a weak for other varieties. Besides, despite taller plant height the cultivars are less or not prone to lodging, even if unexpected rain and storm are occurred at reproductive stage, except Mamun Swarna, which is somewhat lodging prone if transplanted in low laying areas. Expert panel members were fully agreed with farmers' observations (Table 7).

Furthermore, respondents mentioned that flexibility in planting dates, agronomic management and suitability for cultivating in different topography areas (e.g., high, medium and low land) were crucial drivers of large-scale adoption of exotic cultivars in survey locations. Firstly, the cultivars give consistent yield across different planting dates (early, optimum, delayed and extreme delayed e.g., 2-3rd week of September). Nonetheless, farmers reported that yield of BR11, BRRI dhan49 and BRRI dhan52 largely decreased under both the early and delayed transplanting dates. It can be noted that early planting crop of BRRI varieties have severe pest infestation because of excess vegetative growth while delayed transplanting crops of BRRI varieties is affected by cold, consequently decrease yield. Secondly, exotic cultivars are suitable for cultivating in different topography areas (high, medium and low land) without much compensation in yields except Swarna5, which is not so suitable for high land with no opportunity for supplementary irrigation. It addition, Guti Swarna gives substantially higher yield than the other varieties in low laying areas. In contrary, BR11 and BRRI dhan49 is only compatible for medium high land, and BRRI dhan51 and BRRI dhan52 are suitable for planting in medium low land. Thirdly, exotic cultivars perform consistently despite poor agronomic practice such as less fertilizer and pesticides application, older seedling and no weeding and supplementary irrigation application despite drought at reproductive stage. However, performance of BRRI varieties substantially varied between poor and better agronomic practice particularly their performance is highly sensitive to fertilizer dose and its application time, seedling age and supplementary irrigation (Table 7).

Besides, farmers in group discussion said that despite longer growth duration the most dominant exogenous variety, Guti Swarna was not only suitable for three crops-based systems but also compatible for planting even the early planting local variety potatoes. It is due to the photoperiod insensitive rice cultivar is matured for harvesting within the optimum planting time (before mid-November) of DS crops (potatoes, maize and garlic) if re-transplanted i.e., double transplanted 45-50 day-old seedling by mid-August. Moreover, its field duration is about 7-10 days shorter than BR11 and BRRI dhan51 and BRRI dhan52 so that farmers can plant dry season crops on time. Additionally, Swarna5 is not only compatible for three crops-based systems but also possible to harvest four crops as its life cycle is 20-25 days than Guti Swarna and 30-35 days shorter than BR11 and BRRI dhan51 and BRRI dhan52. In this respect, farmers' in the group discussion said that exotic varieties to enhance system productivity which motivates them to adopt those varieties (Table 7).

Moreover, key informants mentioned that the exotic cultivars were highly suitable for double transplanting which was also an important driver for adoption of those varieties in the extreme weather events (drought and flood prone) of northwest ecosystem. It can be noted that firstly double transplanting is an adaptation option to reduce field duration of the rice crop for facilitating optimum planting of DS crops. Secondly, it is a mechanism for stress management of cultivating rice in fields, which are not suitable for planting rice until extremely delayed planting date because of stagnant water or cultivation of early wet season rice. In addition, double transplanting has some obvious advantages including less seed requirement (only 12-15 kg/ha), pest infestation as well as higher yield (15-20%) (Table 7).

Furthermore, respondents in group discussion reported that homogeneous plant height, dark green colour leaves until maturity, ability to emerge panicle really quickly (within 5-7 days) throughout the fields at a time and golden grain colour of exotic cultivars were also important drivers for large scale adoption of the cultivars. In other words, overall physiological appearance of the rice crops throughout the life cycle is really impressive and enchanting to look at, which plays positive roles for dissemination of the variety.

Finally, some respondents said that the variety was less fertilizer responsive (only one top dress of urea) due to dark green leaves, higher number of effective tillers, long panicle with mostly filled grain (e.g., less or no sterility), higher milling outturn than that of other varieties including BRRI developed new ones were the drivers of adoption of exotic variety. Besides, taller plant height with finer straw which is a preferred feed to cattle except Mamun Swarna that has a bit rough straw, as well as availability of seed at household and less seed intensive (1-2 seedling per hill) are also driver of adoption of those cultivars (Table 7).

Economic drivers of adoption

Farmers in group discussion said that despite price of exotic cultivars such as Guti Swarna and Mamun Swarna was slightly lower (BDT 750-1,500/ton) than Swarna5 and BRRI dhan49. However, their grain (0.75 to 1.25 ton/ha) and straw yield was higher than locally available BRRI varieties, consequently give higher return. These are the key criteria for large-scale adoption of the cultivars. Moreover, key informants reported that demand of paddy of exotic cultivars was high in local market. In part it was because of higher milling outturn and higher demand of husked rice of short bold grain (Guti Swarna) and bold grain (Mamun Swarna) rice at procurement centre. It was also because of adequate supply of paddy at local markets to meet up the requirement for operating an automatic rice mill.

On the other hand, demand of husked rice of medium slender grain of Swarna5 is also higher because it is one of the most preferred grains to consumers at market. Farmers said that on average, 70-85% of total farm produce of Guti Swarna and Swarna5, and 97-99% of total farm produce of coarse grain Mamun Swarna were marketable surplus. Thus, ensured market demand is also an important consideration for widespread adoption of the exotic cultivars (Table 7).

Furthermore, majority of respondents said that exotic cultivars were economically more viable (more profitable and less risky) due to less fluctuation in yield and price across seasons. Therefore, it is less likely to give negative return of those cultivars despite seasonal weather variation (less or heavy rain, floods, heat, dew and cold). Additionally, some farmers in group discussion claimed that exotic cultivars facilitated not only to enhance intensity of land use but also increased farm income through increasing total system productivity. This economic performance is also an important driver of adoption of the cultivars (Table 7 and Fig. 4).

Social driver of adoption

Cooked rice is not only tested good to eat but also leftover rice remains fresh for eating even in the following days. Therefore, most households (65-75%) in Pirganj and some households (25-35%) in Khanshama use Guti Swarna for family consumption for 5-7 months. On the other hand, most households (65-70%) in Khanshama and some households (25-35%) in Pirjanj use Swarna5 for family for 5-7 months. Mamun Swarna is mainly cultivated for commercial purpose as rice of the coarse grain not tasted good to eat.

Additionally, higher chance of reaping expected yield (4.5 -5.5 t ha^{-1}) across seasons as well as good yield of the cultivars even under worst seasonal conditions (i.e., not less than 3.9 t ha^{-1}) boost up their confidence regarding performance of the variety. Furthermore, farmers' have no worries regarding uncertainty of emerging panicle even though prevails severe moisture stress at the beginning of winter. Finally, shorter growth duration variety, such as Mamun Swarna and even the early transplanted longer growth duration varieties, for instance Guti Swarna and Swarna5 are also matured for harvesting at food and feed scarce period. Therefore, they get higher price for grain and straw at harvesting season and allow farmers an adequate turn-around time for land preparation for establishing dry season crops on time (Table 7).

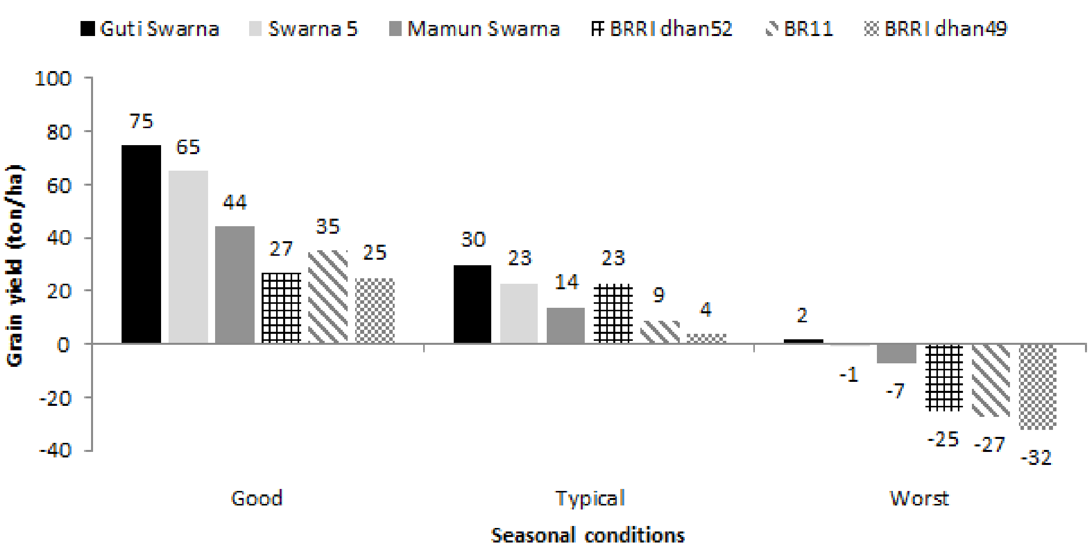

Fig. 4. Net income from wet season rice cultivars under different seasonal conditions in study locations.

Table 7. Adoption drivers of exotic cultivars in wet season in Pirganj, Rangpur and Khanshama, Dinajpur.

Adoption drivers of exotic cultivars (Guti Swaran, Swarna5 and Mamum Swarna)	Respondent (%)	
	Pirganj	Khanshama
Agronomic driver		
Consistent yield despite variation in seasonal weather and agronomic practices	100	100
Higher adaptive capacity to shocks and abiotic stress (floods, cold and droughts) except Swarna5 which is somewhat prone to moisture stress	100	100
Higher grain and straw yield than most other available varieties	85	68
Compatible for three crops-based systems, but Guti Swarna and Swarna5 are needed to transplant early for sowing DS crops on time	78	65
Not only the cultivars are able to recover from major biotic stress (sheath blight and sheath rot) but also, they are less prone to BPH, caterpillar and stem borer	72	84
Quickly emerge panicle throughout the fields at a time	100	100
Highly suitable for double transplanting which is an important adaptation strategy of farm households to climate change	88	92
Consistent performance under early, optimum, delay and even under extreme delay (2-3rd week of September) planting dates	92	84
Suitable for cultivating in different topography areas (high, medium and low land) without much compensations of yield	62	71
Less or no lodging, even if occur rain and storm at reproductive stage	96	88
Higher number of effective tillers and long panicle with mostly filled grain than that of other varieties including BRRI cultivars	76	68
Physiological appearance of the rice crops is impressive and enchanting	100	100
Require less fertilizer (one top dress of N) and seed, seed is available at home	100	100
Higher grain weight and more milling outturn than other varieties	100	100
Economic driver		
Profitable due to higher grain and straw yield, and good market price	100	100
Higher demand of paddy at local market	100	100
Commercial farm enterprise as marketable surplus (MS) of rice ranges between 70-85% of total farm produce except Mamun Swarna (97-99% of total is MS)	72	96
Less risky due to low variability in yield and price across seasons	100	92
Social driver		
Farmers have no worries regarding uncertainty of emerging panicle even though prevails severe moisture stress and beginning of winter.	100	100
Farmers cultivate exotic cultivars because of highly likely to harvest expected yield (4.5 -5.5 t/ha) despite variation in seasonal weather	100	100
Farmers' have very high confidence regarding better performance even in worst seasonal conditions (yield not less than 3.9 t/ha)	100	100
Cooked rice is not only good to eat but also leftover rice remains fresh for eating even in the following days except Mamun Swarna (not tested well)	100	100
Delicious to eat so that most farm households in Pirganj and some in Khanshama consume Guti Swarna for 5-7 months and vice versa for Swarna5	100	72
Soft straw is a preferred feed of cattle except Mamun Swarna	64	72
Environmental driver		
Consistent yield in erratic rainfall pattern and in low rainfall in post monsoon months	100	100
Consistent yield in excess dew even in the early November and commencing winter early	100	100
Tolerant to abiotic and biotic stress	92	88

Source: Field survey 2018

Environmental drivers of adoption

Farmers' perceived climate changes in erraticism of rainfall pattern and shifted delay of monsoon month causing unfavourable environment for nursery preparation and transplanting WS rice within optimum planting date. As a result, some modern varieties, such as BR11, BRRI dhan49 and BRRI dhan52 perform poorly because of delayed transplanting. However, performance of exotic cultivars, for instance Guti Swarna, Swarna5 and Mamun Swarna are consistent despite transplanting until extreme delay transplanting dates. Moreover, increased heavy torrential rainfall events, decrease rainfall in post monsoon months and excess dew even in the early November, and commencing winter early also largely impact on yields of BRRI varieties (BR11, BRRI dhan49 and BRRI dhan52). Nevertheless, performance of exotic cultivars remains consistent despite such changes in environment. Thus, indigenous WS rice cultivars were replaced by the exotic cultivars (Table 7).

Adoption drivers of less adopted cultivars in WS

Table 8 presents adoption drivers of some minor varieties in study locations. Farmers in group discussion said that key adoption driver of Binadhan-7 and hybrid was shorter life cycle of those cultivars (25-30 days) than that of the other existing cultivars. It was noted that shorter growth duration of those cultivars allowed adequate turnaround time for land preparation in order to planting local variety potatoes and garlic early (late October to mid November), and other dry season crops on time. It can be noted that yield of local variety potatoes and onion not only decreased largely but also price of those crops decreased considerably because of transplanting delay. Therefore, the cultivars facilitate to enhance both system productivity and farm income. Furthermore, farmers reported that both of the cultivars matured for harvesting food and feed scarce period giving higher return because of higher straw price and good yield under optimum planting date. It increases system productivity and farm income. However, farmers in group discussion said that large scale dissemination of the cultivars is constrained by more susceptibility to abiotic (floods and moisture stress) and biotic (pest) stress than exotic inbred cultivars. It was observed in the fields that infestation of false smut was severe in some hybrid cultivars in particular Dhanigold. Moreover, performance of both the cultivars is not satisfactory under double transplanting and with seedling age over a month old. Nevertheless, sometimes farmers were unable to maintain seedling age less than a month due to erraticism of rainfall pattern as well as it is not possible to transplanting tenderly aged seedling in medium low to low land areas because of stagnant water. Furthermore, some of the key informants said that higher rate of unfilled grain in panicle, and infestation of ear cutter caterpillar and attack of rats and birds were also severe in the early maturing rice. Finally, cooked rice of coarse grain Binadhan-7 is soft, sticky and not tasted good to eat. On the other hand, although cooked rice of some hybrid is not much sticky but become so soft shortly and not tasted good to eat. Therefore, farmers reported that the cultivars such as hybrid and Binadhan-7 are mainly cultivated for commercial purpose (Table 8).

On the other hand, farmers in group discussion said that despite Ronjit is not suitable for three crops based system due to longer growth duration as well as unable to perform well under delayed planting date. However, farmers cultivated the variety not only because of its higher potentiality to give good grain yield (3.9-5.9 t ha^{-1}) as Swarna but also give good yield in the field with stagnant water and/or in low land. Additionally, key informant said that the variety was largely less susceptible to diseases and insects than that of the others. Moreover, most of the key informants reported that price of Ronjit (BDT 1.3-1.6 Tk/kg) was higher than that of dominant Guti Swarna and its demand in market was ensured. Furthermore, some households said that the medium slender grain was tasted good to eat, and was used for cooking scented rice in the festival as well. Finally, some respondents said that the variety was potential to higher straw yield and its soft stems were preferred feed to cattle. However, despite taller plant height, the variety is not lodging prone (Table 8).

Table 8. Adoption Drivers of less adopted varieties in wet season in Pirganj, Rangpur and Khanshama, Dinajpur.

Variety		Respondent (%)	
		Pirganj	Khanshama
Binadhan-7	Adoption driver		
	Shorter life cycle (90-95 days) so that matured for harvesting food and feed scarce period, and compatible for three-crop based systems	100	100
	Give good yield under optimum and even delay planting dates	90	100
	Allows adequate turnaround time for land preparation for DS crops	100	100
	Higher number of effective tillers	70	70
	Profitable due to good yield and higher straw price	70	80
	Increase system productivity and farm income	75	80
	Adoption drawbacks		
	Give low yield for seedling age over a month	100	100
	Lower grain and straw yield potential than Swarna	100	100
	Emerge panicle gradually some after the others	90	85
	Less number of effective tillers	60	65
	Higher number of unfilled grains in the panicle	75	60
	Cooked rice is not sticky but so soft and not tasted good to eat	100	100
	High infestation of ear cutter caterpillar and attack of rats and birds	60	70
Hybrid	Adoption driver		
	Shorter growth duration than Guti Swarna (20-25 days)	100	100
	Suitable for three crops-based systems including early planting DS crops	100	100
	Matured for harvesting at food and feed scarce period	80	85
	Medium slender grain	60	55
	Profitable due to good yield and higher straw price	70	75
	Shorter plant height and strong stem so that no lodging	80	85
	Soft straw so that it is a preferred feed to cattle	60	55
	Adoption drawbacks		
	Unable to perform well under double transplanting condition	100	100
	Some give lower yield than Guti Swarna, and highly prone to sterility	55	60
	Some are highly susceptible to pest including sheath blight and false smut	40	35
	Cooked rice of coarse one is soft and sticky, so not tasted good to eat	90	95
Ronjit	Adoption driver		
	Higher grain yield potential (3.9-5.9 t/ha) as Swarna	-	100
	Gives higher yield in early and optimum planting dates	-	95
	Higher demand and price (BDT 1.3-1.6/kg) than Swarna as the medium slender grain is tasted good to eat and used for cooking scented rice	-	90
	Less disease and pest susceptible	-	80
	Perform well in the field with stagnant water in the low laying areas.	-	100
	Higher milling outturn because of thin shell	-	95
	Taller plant height but the stem is strong so that no lodging	-	100
	Higher straw yield and its soft stems are preferred feed to cattle	-	95
	Adoption drawbacks	-	
	Decreased yield in case of delay of planting while early planting one is severely affected by rat	-	100
	Longer life cycle (one week) than Guti Swarna so that not suitable for three crops-based system	-	100

Source: Field survey 2018.

Factors of decreasing or low adoption of BRRI varieties

BR11. Farmers in group discussion said that BR11 was the most dominant variety covering over about 70-75% of total area of WS rice in both the study locations until 2000 mainly because it would perform better than that of the then available cultivars. Additionally, cooked rice of coarse grain was preferred food to farm families. However, key informants said that currently adoption of the variety plunged to bottom mainly because of the variety mostly unable to perform consistently under changed environment despite better management. Farmers said that performance of the variety substantially fluctuated because of variation in seasonal weather, land types and agronomic management (sowing dates, seedling age and fertilizer rates). In this respect, farmers in group discussion said that even under slightly delayed transplanting date, the variety was unable to produce panicles fully after commencing winter or falling dew at night despite supplementary irrigation application; consequently, gave low yield. Nevertheless, farmers are mostly forced to delay in transplanting WS rice in medium low land (only where the variety perform well under favourable condition and better management) due to shifted delay of monsoon and highly likely to affected by flood at transplanting and tillering stage of early transplanting crops in the area. Farmers in group discussion said that the variety was not suitable for three crops systems. It is due to the mild photoperiod sensitive long duration cultivar does not mature for harvesting within optimum planting date of DS crops despite early transplanting. Additionally, the variety was mostly unable to perform well in high to medium high land because of its higher proneness to moisture stress. Key informant said that, yield of BR11 considerably decreased due to seedling age over a month, and inadequate (more fertilizer intensive) or untimely application of fertilizer and double transplanting. In the contrary, available exotic cultivars (Guti Swaran and Swarna5) not only gives higher yield than that of BR11 under typical seasonal condition but also consistently performs better despite variation in weather and agronomic management (Table 9 and Fig. 3).

Furthermore, farmers in group discussion said that another vital reason of decreasing adoption of BR11 was that it was not only severely susceptible to insects (BPH, gall midge, mealy bug, and stem borer) and diseases (sheath blight, sheath rot, tungro and ufra) but also mostly unable to recover from infestation of pest fully despite treatment, resulting from that largely decrease yield. This is also an important reason of decreasing the adoption of the variety. Besides, some respondents said that although tillering ability of the variety was high, while number of effective tillers was low and more unfiled grain in panicles. Finally, some key informants said that BR11 is economically less viable (less profitable and risky) because of its higher yield variability to small farm households stop cultivating the variety. Moreover, demand and price of the paddy rice at local market is low as most farm families do not prefer to eat rice of coarse grain variety (Table 9 and Fig. 4).

BRRI dhan33. Farmers in group discussion said that despite shorter growth duration, farmers stopped cultivating BRRI dhan33 as the cultivar not only gave lower yield than Binadhan-7 and hybrid but also, they did not prefer to consume coarse grain rice and its plants were highly susceptible to lodging (Table 9).

BRRI dhan49. Key informants reported that BRRI dhan49 is one of the most preferred cultivars to households for consumption, and the variety is potential to give good yield under better management and favourable weather. Additionally, price of the paddy is higher than even the Swarna5, and its life cycle is medium so that compatible for even the three crop-based systems. Furthermore, the cultivar is less or not susceptible to BPH and its straw is preferred feed to cattle. However, farmer's in-group discussion said that despite above mentioned positive criteria, adoption of the variety was low or decreasing. Firstly, because of its severe susceptibility to false smut as the disease affected both on yield and market price because of discolouration. Secondly, both grain and straw yield of the cultivar even under typical seasonal condition is not only lower than that of Swarna but also its performance largely varied across different seasonal conditions, land types and management (fertilizer dose and planting dates). Thirdly, the cultivar gave low yield in case of aged seedling and not even suitable for double transplanting because its panicles emerge within a short period of re-transplanting, consequently providing low yield. Finally, the variety is highly susceptible to leaf roller and stem borer. Besides, despite applying supplementary irrigation, panicles of the cultivar do not emerge fully after beginning of winter. Overall, farmers said that highly uncertain performance under stress environment and severe susceptibility to false smut were the root cause of not being popular of the variety (Table 9).

BRRI dhan51. Key informant reported that BRRI dhan51 had some strong positive traits including tolerant to 10-12 days of flash flood submergence, strong stem, less susceptibility to pest, medium slender grain, tasted good to eat, higher market demand and suitability for double transplanting and to some extent cold tolerant. So, this variety is potential for large scale dissemination in the flood prone ecosystem in Bangladesh. However, adoption of the variety remains low, firstly because of most areas of the study locations are under three-crop-based systems; nonetheless, neither the long duration cultivars is compatible for three crops systems nor it is potential to perform better than available exotic cultivars (Swarna). In addition, respondents said that performance of cultivars unable to out weight Swarna even in the low to medium low areas because of its less tillering ability and lower number of effective tiller (Table 9).

BRRI dhan52. Farmers in group discussion reported that despite some positive traits for instance tolerance to 10-12 days flash flood submergence, strong stem and high milling outturn adoption of the variety is low in the area. It is due to firstly; the variety gives lower yield than exotic cultivars. Secondly, the yield of the variety highly fluctuates because of seasonal weather variation as like as BR11, BRRI dhan49 and BRRI dhan52. Thirdly, the variety is highly susceptible to BPH and fungal diseases. Finally, demand of the paddy is low due to small lot of supply (Table 9).

BRRI dhan56 and BRRI dhan57. Farmers in group discussion reported that despite shorter growth duration and drought tolerance or escaping, adoption of those variety is low mainly because of availability other varieties higher yield potential short duration in particular hybrid (5.5-6.5 t/ha), Binadhan-7 and Swarna5 (4.9-5.9 t/ha). Moreover, BRRI dhan56 has bold grain so that market demand for the rice is low (Table 9).

Performance of new BRRI varieties in demonstration plots

Farmers and expert panel members have found some potentiality for diffusion of BRRI dhan66, BRRI dhan71 and BRRI dhan75 in wet season in Pirganj and Khanshama. It was due to BRRI dhan66 is potential to give higher grain and straw yield. Additionally, it is a medium long duration variety suitable for three-crop-based system. It is a medium bold grain cultivar, having good market demand, and the cultivars are to some extent stress (drought and no lodging) tolerant. Similarly, key informant said that BRRI dhan71 and BRRI dhan75 perform well i.e., gave higher grain (5.5-6.2 t ha^{-1}) and straw yield on trial plots in high and medium high land. Additionally, both are short duration so that (i) highly compatible for three crops-based systems and (ii) potential to escape moisture and cold stress. Furthermore, farmers in-group discussion anticipated that demand and price of the medium slender rice at local market will be high and cooked rice of the variety would be tasted good to eat. Finally, the variety is somewhat less susceptible to pest. However, small-scale infestation of false smut was common in the demonstration plots of both the cultivars (Table 10).

Table 9. Adoption drivers and drawbacks of some BRRI cultivars in WS in Pirganj, Rangpur and Khanshama, Dinajpur.

Variety	Adoption driver and drawback	Respondent (%)	
		Pirganj	Khanshama
BR11	Adoption driver		
	Gives higher yield under favourable conditions and better management	100	100
	Tasted good to eat	100	100
	Drawback		
	Unable to produce panicle fully despite application of supplementary irrigation if commence winter or fall dew at night	100	100
	Severely susceptible to insects (BPH, gall midge, mealy bug, ear cutter caterpillar and stem borer) and diseases (sheath blight, sheath rot, tungro and ufra)	100	100
	Poor performance under double transplanting	90	95
	Despite transplanting early, the mild photoperiod sensitive cultivar does not mature for harvesting within optimum planting time of DS crops, consequently decrease systems productivity	75	80
BRRI dhan33	Adoption drivers		
	Shorter growth duration	90	95
	Drawback		
	Grain is bold	100	100
	Highly lodging susceptible	95	90
BRRI dhan49	Adoption driver		
	Potential to give good yield under better management and congenial environment	100	100
	Price is higher than the Swarna5	100	100
	Tasted good to eat	90	90
	Compatible for three crops-based systems	80	85
	Less or no susceptible to BPH	90	84
	Drawback		
	Severely false smut susceptible.	100	100
	Demand of false smut affected paddy is low due to discolouration	90	85
	Poor recoverability from stresses (floods, droughts and cold)	80	85
	Poor performance in case of aged seedling and double transplanting		
	Susceptible to insects (leaf roller and stem borer)	85	90
BRRI dhan51	Adoption driver		
	Tolerant to 10-12 days of flash flood submergence	100	100
	Strong stem and less susceptibility to pest	80	75
	Medium slender grain and tasted good to eat	90	85
	Suitability for double transplanting and some extent tolerant to cold	80	85
	Drawback		
	Incompatible for three crops-based system due to longer life cycle	70	60
	Less tillering ability in anaerobic condition	75	70
BRRI dhan52	Adoption driver		
	Tolerance to 10-12 days flash flood submergence	80	85
	Strong stem and higher milling outturn	85	88
	Drawback		
	Susceptible to stresses (drought, cold and dew) at reproductive stage	75	72
	Susceptible to BPH and fungal disease	70	65

Source: Field Survey 2018.

Table 10. Perception of key informants about potentiality of newly released BRRI varieties based on performance of the cultivars in demonstration in Pirganj, Rangpur and Khanshama, Dinajpur.

	Adoption driver
BRRI dhan66	✓ Higher grain and straw yield potential ✓ Medium growth duration ✓ Medium bold grain ✓ Wider leaves ✓ No lodging despite taller plant height ✓ Higher straw yield ✓ Somewhat tolerant to drought
BRRI dhan71	✓ Gives good yield (5.5-6.0 t/ha) on trial plots in high and medium high land ✓ Taller plant height, gives higher straw yield, less lodging prone ✓ Shorter growth duration so that (i) highly compatible for three-crop-based systems and (ii) potential to escape moisture and cold stress ✓ Medium slender grain, good to eat and higher market demand ✓ Less pest infestation, but some false smut infestation was observed
BRRI dhan75	✓ Good yield (5.5-6.2 t/ha) on trial plots in high and medium high land ✓ Shorter life cycle so that not only highly compatible for three-crop-based systems but also potential to escape moisture and cold stress ✓ Demand and price might be higher of the slender and mild aroma grain ✓ Less pest infestation, but some false smut infestation was observed

Source: Field survey 2018

Dream variety

Farmers were asked to report biophysical and economic traits of their dream variety for WS. Thereafter, they were asked to rank the traits based on importance from 1-7 scale. Finally, they were asked to anticipate how much area could be covered by the variety in the study locations. Accordingly, key informants classified their dream varieties into two based on major cropping systems. Table 9 presents traits and their rank of dream variety for three-crop-based cropping systems for high to medium high lands. Dream cultivar with shorter field duration (110-115 days) so that allows farmers to establish DS crops early or within optimum planting date, and potential to give higher grain (6.5-6.9 t/ha) and straw yield with better quality, were ranked as first and second important traits, reported by 100% of total respondents. Key insight of most preferred traits (first and second) of dream cultivar clearly expressed that farmers do not only expect better harvest (grain and straw) from WS rice but also, they are dreaming a variety which would be potential for intensification of cropping system and enhancing total system productivity. It indicates that farmers expect better harvest from WS rice as well as fully conscious to reap full benefit of cultivating crops in the following seasons. Furthermore, farmers expect quality rice (i.e., medium slender grain with high amylose contains and cooked rice is good to eat) in order to ensure demand and higher price as well as for household consumption. It indicates that rice cultivation is not at all a subsistence enterprise; rather it has become a commercial enterprise. On the other hand, farmers also aware of yield and quality of straw (soft so that cattle prefer to eat) as rearing cattle is an important component of farming systems in the study locations (Table 11).

Multi stress tolerant and to some extent flexibility in agronomic practices to alleviate likelihood of seasonal yield fluctuation despite variation in seasonal weather (heat, extreme weather events and pest infestation) and agronomic management (planting dates, fertilizers dose and time of application), ranked as third and fourth most important traits, reported by 74-83% of total respondents. It indicates that farmers expect a consistent performance despite biotic and abiotic stress and variation in management (delay or early transplanting, higher or lower fertilizers dose with untimely application). Finally, rest of traits (5-7) of dream cultivar is mostly related to anatomy of the rice plant, reported by 48-58% of total respondents. It is expected that the cultivars should be medium tall plant height having strong stem so that no lodging despite rain in post monsoon months. Moreover, higher number of effective tillers (15-18) with homogenous growth and dark green colour erect leaves (less bushy) so that air and sunshine could pass through the fields, consequently less infested by insects and diseases. In addition, panicles of the grain should emerge so quickly at a time despite stress and long panicle with glossy golden colour grain having no sterility and higher milling outturn. The key insight of the traits of the dream variety is that farmers expected sustainable biophysical, economic and social performance of total cropping systems. Framers and extension personnel unanimously agreed that diffusion of the dream cultivars might be on average 50-60% of total area of WS rice (Table 11).

Table 12 presents traits and their rank of dream variety of wet season rice for two crops systems in medium low to low lands. It was observed (Tables 11 and 12) that phenotypes of both the cultivars for two crops system and three crops system mostly consistent except ranking in first and second most important traits. Higher yield potential and medium fields duration are ranked as first and second most important traits, reported by 100% of respondents. It is mainly because of farmers expects higher yield at the cost of allocating additional time (medium field duration) and excepting some extent poorer quality (medium coarse grain) from the two crops systems in order to equalize total productivity of both three and two crops systems. Farmers in group discussion reported that bulk supply of medium bold grain rice will be ensured its demand and fair price as medium bold grain rice has higher demand at procurement center so that large traders and millers purchase the rice at better price from even local market.

Table 11. Phenotype of dream variety of wet season for three-crop system in high to medium high lands.

Trait	Respondent (%)	Rank	Potential area (%)
Shorter field duration (110-115)	100	1	50-60% of total area of WS rice
Higher grain (6.5-6.9 ton/ha) and straw yield potential with better quality (medium slender grain, high amylose and tasted good to eat)	100	2	
Stable to perform under variable stresses	83	3	
To some extent flexible to agronomic management i.e., consistent yield despite variation in planting dates, fertilizer dose and application time	74	4	
Medium plant height with strong stem so that no lodging despite rain in the post monsoon months and emerge panicle quickly at a time	58	5	
Long panicle with glossy golden colour grain and no sterility	52	6	
Homogenous plant height, higher effective tillers (15-18) and dark green colour erect leaves (less bushy)	48	7	

Source: Field survey 2018

Table 12. Phenotype of dream variety of wet season for two crops system in medium low to low lands.

Trait	Respondent (%)	Rank	Potential area (%)
Higher grain (6.9-7.9 ton/ha) and straw yield potential with better quality (medium coarse grain, high amylose and tasted good to eat)	100	1	
Medium field duration (120-125)	100	2	40-50% of total area of WS rice.
Multi stress tolerant (pest, floods, drought and cold) i.e., potential to perform consistently despite variation in seasonal weather		3	
To some extent flexible to agronomic management i.e., consistent yield despite variation in planting dates, fertilizer dose and application time	70	4	
Medium plant height with strong stem so that no lodging despite rain in the post monsoon months and emerge panicle quickly at a time	58	5	
Long panicle with glossy golden colour grain and no sterility	52	6	
Homogenous plant height, higher effective tillers (15-18) and dark green colour erect leaves (less bushy)	48	7	

Source: Field survey 2018

Model for rapid diffusion

Key informants including famers and extension personnel said that performance of a variety in terms of yield, growth duration, biotic and abiotic stress tolerance, market demand and eating quality was the prime driver that profoundly influence adoption decision of a variety. Besides, availability of seed of the better performed variety at local market plays a crucial role in the process of dissemination of the variety. However, farmers in the group discussion reported that performance of some newly released varieties failed to meet up the farmers' expectation. On the other hand, although some varieties have performed well in the demonstration plots and farmers are willing to cultivate these; nevertheless, seed of the varieties at local level is scarce. Farmers and extension personnel said that main reason of unavailability of seed of the newly released variety at local level was the national level seed producing organization namely BADC as well as the most private seed traders mainly produced seed for most popular varieties in use to avoid risk. In this regards, BADC and private seed traders noted that lack of information regarding the location specific demand of the rice varieties for different seasons in particular demand for the newly released varieties is an important factor of continuing production of the most dominant varieties. It is also the case that BADC has limited capacity to fulfil the huge demand of rice seed for the whole country. In this regards, BADC personnel and private seed traders said that insuring availability of breeder seeds and information regarding actual variety specific demand for seed were very important to enhance adoption of the newly released potential rice varieties at farmers' fields.

Moreover, all the expert personnel (BADC, private traders, extension personnel) strongly recommended that commercial cultivation of seed by the progressing farmers could be a crucial strategy to ensure mass farmers access to quality seed to increase adoption of potential varieties to enhance production of rice for meeting the growing demand of increased population. So, identification of interested farmers for developing private seed entrepreneurship and providing training to them on seed production and storage is essential. On the other hand, expert personnel suggested that large scale demonstration of some potential variety for the selected regions instead of providing small scale trials in the whole country could create impacts in the process of diffusion of the varieties. Based on the discussion with the expert personnel and key informant's farmers following strategies could be effective to reduce adaptation lag of the newly released potential rice varieties (Fig. 5):

- Select higher yield potential and stress tolerant cultivars which are medium slender grain and compatible for existing two or three-crop based cropping pattern.

- Large scale demonstration on potential varieties in the selected regions instead of small scale demonstration on all the potential varieties in the whole country.
- Arrange field-days with participation of farmers of the entire communities along with the private seed traders to show the performance and explain them about the potentiality of the varieties.
- Identify farmers and private traders from the field day participant who are interested to produce seed of the varieties commercially.
- Provide training on seed to seed rice production package and storage of the seeds at farmers' place for marketing.
- Produce seed for 2-3 years through on farm trial in the selected trained farmers' fields could be more effective to enhance expertise of farm households which might be highly effective to develop private seed entrepreneurship at farm level.
- Develop of region and season specific rice production manual and wide spread circulation to the extension personnel and farmers.
- Develop and disseminate of modern rice production technology based applications (APPs) widely to farmers and extension personnel.
- Develop leaflet on traits of newly BRRI released varieties and its wide scale circulation to farmers, extension personnel and traders to create awareness regarding the varieties, which could enhance market demand.

Figure 5 shows that a slight modification in the traditional seed network could make the seed available of potential new cultivars at local levels. First, DAE will popularize the newly released variety to the farmers by its demonstration process. After that, DAE will estimate upazila wise demand of seed for the newly released potential rice cultivars. They will inform the requirement to BADC well ahead of commencing seed production programme for the following seasons with an assurance that DAE will make arrangement for marketing the seed through local level retailers. In this system, BADC and other seed traders will minimize market risk of multiplying new rice varieties. Besides, the farmers will get quality seed of the new varieties with reasonable market price.

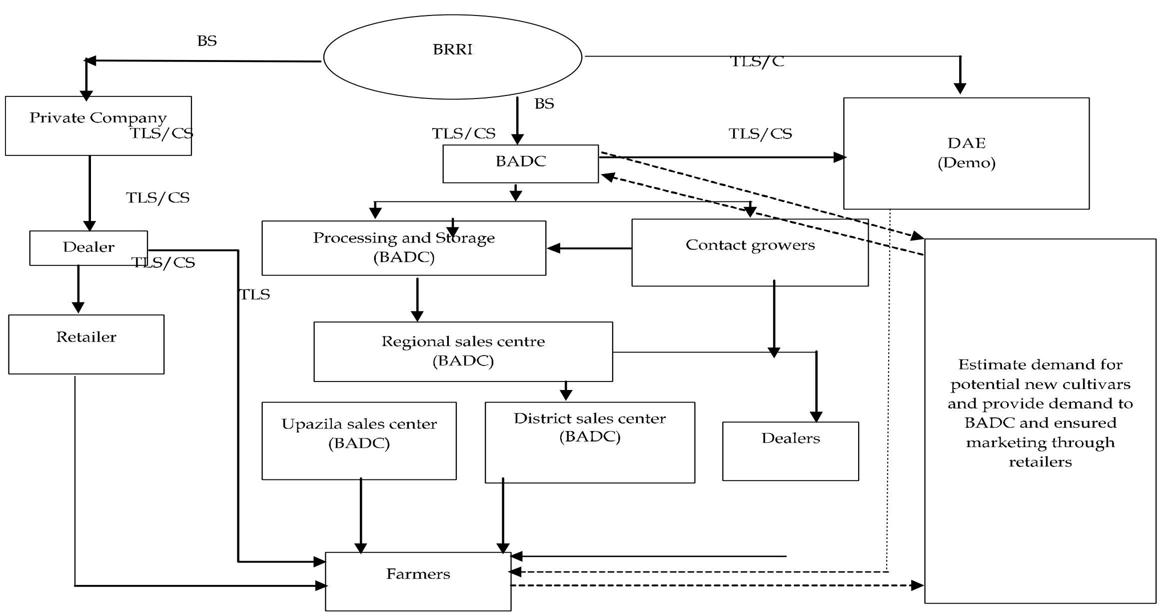

Fig. 5. Proposed modification in the existing seed network in Bangladesh.
Note: BS= Breeder seed, TLS= Truthfully leveled seed, CS= Certified seed

Proposed dissemination model

This study proposes a new seed dissemination model for rapid distribution of the newly released rice cultivars to the farm level. The model is based on concept of Seed Village in the farm level. BRRI and DAE will work collaboratively to form the seed village with their resources (Fig. 6). The DAE will go for large scale dissemination of the newly released varieties in the concerning regions. After the large scale demonstration, farmers' field day will be conducted in the farm level. The objective of the farmers' field day is to select the progressive farmers and seed traders who are willing to produce seed for this new variety.

The selected progressive farmers and traders will be provided seed to seed rice production training, support, rice production manual as well as hands on quality seed production support for producing efficient seed producer. The personnel in seed well age will be wel awer of the local centers seed production and dissemination sceneries to meet the local demand within the villages. The trained seed growers and seed traders will supply quality seed to the local seed traders and farmers. The entire system will be monitored by Seed Certification Agency (SCA), DAE and BRRI for ensuring seed quality, timely dissemination and adequate price to run the 'Seed Village' smoothly.

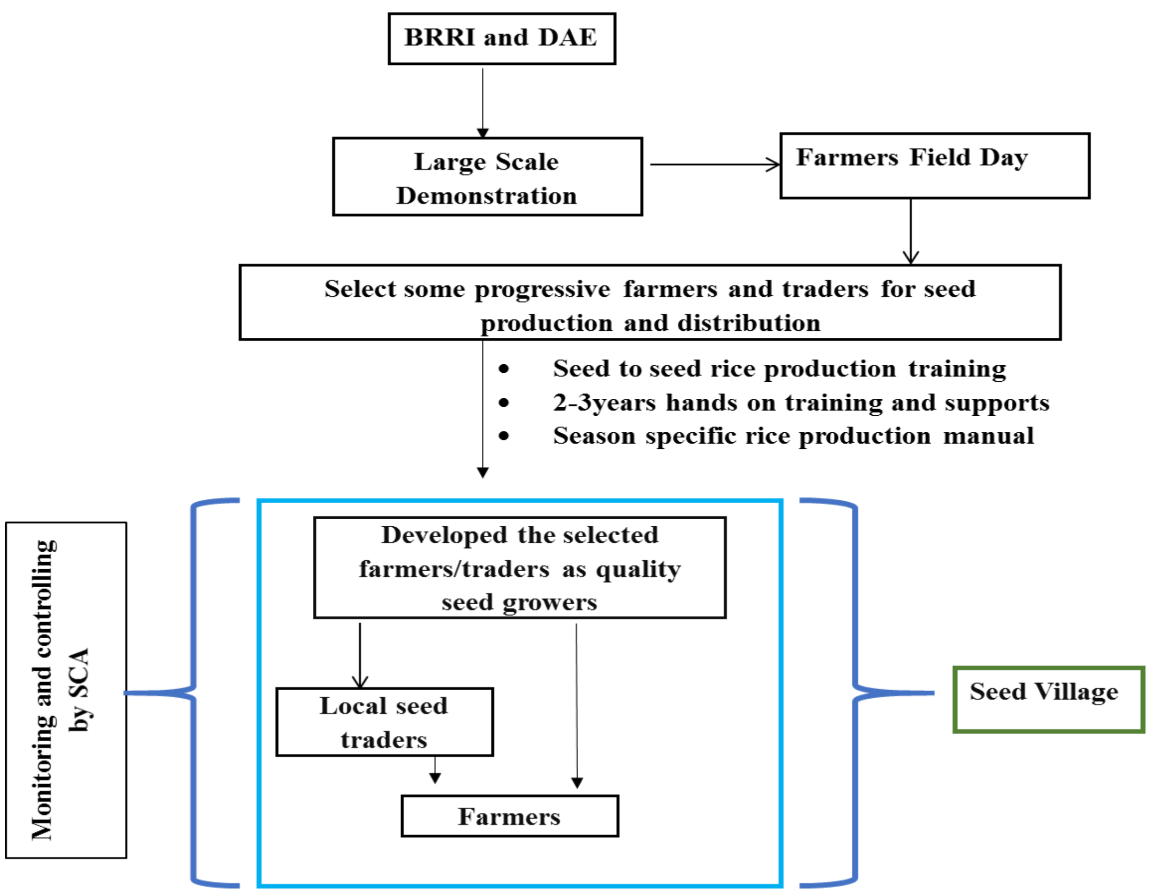

Fig. 6. Proposed model for rapid disseminations of rice cultivars to farmers fields.

CONCLUSION

Rain-fed rice is one of the worst victims of biotic and abiotic stresses in north-west drought prone ecosystem in Bangladesh. Farmers' perceived changes in climate including rising temperature, shifted delay of rainfall, erraticism of rainfall pattern and duration of winter and gravity of cold. Therefore, farmers have introduced some planned and local adaptation strategies including changes in rice cultivars, double transplanting, application of supplementary irrigation and shifting early and/or delay transplanting dates. Farmers have adopted both the indigenous and exotic wet season (WS) rice cultivars to reduce unexpected yield loss due to abiotic and biotic stresses. Diffusion status of exotic cultivars was ranged between 76-85% of total WS rice area in the study locations. The drivers of widespread diffusion of exotic cultivars included the followings: Firstly, stability in performance of the cultivars despite variation in seasonal weather conditions, agronomic management (seedling age, planting dates and fertilizer dose and application time) and land types (high medium and low land). Secondly, higher compatibility to fit into local cropping systems, and ability to recover from biotic and abiotic stresses. Thirdly, higher potentialities to perform under double transplanting technique, and steady performance despite extreme weather events (floods, droughts and cold). Finally, ability to emerge panicle really quickly (within seven days) despite moisture stress, dew, cold and even severe infestation pest, and ultimately unique appearance of rice crops across fields. In fact, exotic cultivars outweigh indigenous cultivars in terms of performance, market demand, and stress tolerance ability. Overall, sustainable performance of exotic cultivars under changed environment has boosted up confidence level of farm households to peak which is pivotal for booming diffusion of the cultivars in WS in the locations. However, farmers are looking for further better performing cultivars for replacing exotic cultivars due mainly to their higher susceptibility to pest, and taste of cooked rice. Thus, farmers are dreaming of potential cultivars for fitting into two and three-crop-based systems in the areas. The phenotype of dream cultivar for three-crop systems included shorter field duration (110-115 days) with higher grain (6.5-6.9 t ha^{-1}) and straw yield, multi stress tolerance quality rice (medium slender grain with high amylose). However, farmers expect further higher yield potential (6.9-7.9 t ha^{-1}) cultivars for two-crop system at the cost of allocating additional time (field duration, 120-125 days) along with other phenotype as dream cultivar for two crops systems. It can be noted that performance of indigenous cultivars BRRI dhan71 and BRRI dhan75 in demonstration plot is highly consistent with phenotype of three-crop systems. However, seed of the potential cultivars neither is currently available at local level nor the DAE has enough capacity to make the seed available to meet demand for local farmers in the near future. Thus, developing commercial seed producers through providing training and other supports to the selective progressive farmers for 3-4 years could be a highly effective model for rapid diffusion of the potential new cultivars at farm level.

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