Why are rice farmers in Bangladesh adopting Indian rice varieties?

by Md Abdur Rouf Sarkar, Mohammad Chhiddikur Rahman, Md Shajedur Rahaman, Mou Rani Sarker, Mohammad Ariful Islam, and Jean Balie

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Abstract

This study investigates the adoption status and reasons for adopting Indian rice varieties in two districts of Bangladesh. We employed purposive sampling to conduct 42 focus group discussions and a survey of 1260 farm households. Our findings shows, Indian varieties covered about 41.62% and 69.06% rice areas in wet and dry seasons, respectively. The higher yield, quality grain and better price lead to a significant increase in profitability in both seasons, explaining the high rate of adoption of Indian rice varieties relative to the domestic high-yielding varieties. Other factors include the fact that domestic varieties are relatively vulnerable to insects, diseases and in some cases lodging and characterized by lower market demand and higher price variability. The quasi-Maximum Likelihood Estimates (MLE) on socio-economic factors of adoption of Indian varieties confirm a positive correlation with low education level, multiple occupations, less family labor involvement, subsistence farming, information gap (about domestic varieties), weak extension connection, better market access, higher dependency on a single variety, higher historical yield and better price. These results suggest that more demand-driven research on product concepts is necessary. National breeding programs should focus on developing new varieties according to market demands and farmers' preferences.

Keywords: Farmers’ preferences, fractional logistic regression, profitability, variety adoption, varietal traits.

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1. Introduction

Rice (*Oryza sativa*) is the major food staple and source of calorie intake in Bangladesh. It has been cultivated for thousands of years in both the wet (August to November) and pre-monsoon (mid-April to July) seasons across the country. In the 1960s, the green revolution in Bangladesh promoted agricultural intensification largely relying on an agricultural inputs policy. Major chemical fertilizers were heavily subsidized. Public sector actors played an essential role in the distribution of inputs at the level of the small administrative unit. After the 2008 global food price crisis, the government decided to increase its policy support to the rice sector by subsidizing non-urea fertilizers and diesel for irrigation to reduce production costs. Modern seed production and distribution have strengthened public and private sectors partnership (Hossain et al., 2017). New policies also encouraged the adoption of High Yielding Variety (HYV) of rice and modern farming practices. To fully exploit these improved modern rice varieties' potential, policies further promoted chemical fertilizers and irrigation in the dry season (December to mid-April).

The coverage of specific rice varieties (rice cultivars) varies enormously across the country. Several categories of rice genotypes are adopted, including 1) traditional genotypes used for many decades; 2) high yielding rice varieties, developed and disseminated by public organizations such as the Bangladesh Rice Research Institute (BRRI), the Bangladesh Institute of Nuclear Agriculture (BINA) and universities; 3) exotic and native hybrid rice varieties introduced through government initiatives since 1997 (Husain et al., 2000); and 4) Indian varieties adopted by farmers since 1995 in areas close to the border (BRRI, 2016). The three rice growing seasons called pre-monsoon, wet and dry account for around 8%, 39% and 53% of the rice production. These harvests have nearly supplied the rice necessary to feed 167 million people (Agricultural Diary, 2020; BBS, 2020).

As is the case for other parts of the country, the India-Bangladesh border area is a favorable environment for rice cultivation. In this region, Indian rice varieties are among the most adopted. They are getting increasingly popular and are gradually replacing native rice cultivars. In the two border divisions of Rangpur and Rajshahi in Bangladesh, we observed the adoption of Indian rice varieties at an increasing rate. Besides, this region is known as a granary that regularly delivers a production surplus.

Decision-makers and researchers are concerned that Indian rice varieties are replacing native rice cultivars. The Department of Agricultural Extension (DAE) reported that Indian varieties covered about 11%, 19%, and 4% of the total pre-monsoon, wet, and dry season rice areas in 2011-12, respectively (BRRI, 2013). The area covered by Indian varieties had further increased in both wet (22%) and dry (10%) seasons by 2019-20 but had halved to 6% for the pre-monsoon season due to lower market price and lower yield potential in this season (BRRI, 2020). There is an ongoing debate in Bangladesh regarding the availability of some domestic cultivars that could be threatened by the growing prevalence of foreign (Indian) cultivars. More specifically, the topic of genetic erosion has become a matter of concern in both scientific and policy circles. The main issues relate to the concepts of national varietal security and varietal stability. It is argued that domestic varieties typically possess genes that are adapted to local conditions. Some of these traits may need to be harnessed in future rice national breeding programs. For example, Pathaichindachote et al. (2019) argued that the replacement of local cultivars by foreign varieties leads to a dramatic decrease in the genetic diversity of rice crops. Domestic cultivars are valuable genetic resources for future varietal improvement programs intended for the agro-climatic environment. This problem is compounded by the fact that Indian rice varieties have been imported informally and have spread rapidly. These varieties have not been subjected to plant quarantine carrying a risk of pests and disease transmission. Moreover, the informal trade of varieties does not ensure compliance with national seed standards such as quality, purity, and minimum germination rate.

Varieties name, adoption rate, agronomic management, and major varietal traits of Indian varieties remain unexplored. There has been no study on Indian varieties adoption in Bangladesh considering the aforementioned aspects to the best of our knowledge. Our research is the first of its kind. Therefore, this study proposes to uncover the adoption status of Indian varieties and to reveal the underlying causes of their adoption in the two districts of Rangpur and Bogura along the border with India.

The findings of this study help identify the positive and negative traits of domestic and Indian varieties. Focusing national breeding programs on those traits of improved HYV preferred by consumers and farmers may convince farmers to replace the Indian rice varieties, reducing the risks above.

Section 2 presents the data collection process and empirical methods. Section 3 describes the adoption status of Indian rice varieties and the reasons for adoption through tabular and empirical results. Section 4 concludes the study and provides policy recommendations.

2. Methodology

2.1 Study area and sampling

We employed a purposive sampling technique to select the study location in the Rangpur and Bogura districts of Bangladesh. The survey covered all the *Upazilas*[2] of the selected districts and chose two *unions*[3] from each *Upazila* (Appendix A.1), and we randomly selected 30 rice-growing farmers from each union (Table 1). To define the sampling process and ensure the sample was representative of the diversity of farmers in these two districts, we held consultations with local extension agents. While the sample from each *union* could be considered small, the overall sample for each of the two districts was big enough to

[2] An important unit in the administrative system of Bangladesh, which is formed with a few unions.
[3] The lowest administrative unit in the rural area.

adequately represent the heterogeneity of farmers. We interviewed a total of 1260 farmers face to face using a pre-structured questionnaire. Besides, we conducted 42 focus group discussions (FGDs) in 2017-18 to validate the survey findings in all *Upazilas* of those two districts. Ten stakeholders from each *union* were randomly chosen for the FGDs. These stakeholders included farmers, local representatives, school teachers, and Non-Government Organizations (NGOs) personnel. We also consulted two categories of experts, the *Upazila* Agriculture Officer and the Sub-assistance Agriculture Officer (SAAO), regarding varietal traits and present adoption status.

Table 1. Sampling distribution.

Districts	*Upazilas* (No.)	*Unions* (No.)	Farmers (No.)
Rangpur	09	09×2=18	18×30=540
Bogura	12	12×2=24	24×30=720
Total	21	42	1260

2.2 Season considered

In Bangladesh, there are three very diverse rice growing seasons per year. In this study, we considered the wet and dry seasons because the prevalence of Indian varieties cultivation is higher during these two seasons, while domestic and hybrid varieties are only cultivated during the pre-monsoon season.

2.3 Rice cultivars

This study investigated all the domestic and Indian rice cultivars that the surveyed farmers cultivated. In the Rangpur district, the wet season domestic rice cultivars were BR11, BR22, BR23, BRRI dhan33, BRRI dhan34, BRRI dhan39, BRRI dhan41, BRRI dhan44, BRRI dhan49, BRRI dhan51, BRRI dhan52, BRRI dhan56, BRRI dhan57, BRRI dhan62, BRRI dhan66, BRRI dhan72, ACI, Dhanigold and Hira-2, whereas the Indian cultivars were *Guti swarna*, *Mamun swarna*, *Ranjit swarna* and *Parija*. In the dry season, the domestic rice cultivars BRRI dhan28, BRRI dhan29, BRRI dhan36, BRRI dhan50, BRRI dhan55, BRRI dhan58, BRRI dhan59, BRRI dhan61, and BRRI dhan63, and the Indian cultivars *Zira*, *Khato-10*, *Moazzem zira*, *Parija*, and *Sampa katari* were found in Bogura district. More particularly, we considered the most popular and competitive domestic and Indian rice cultivars in the section on 'input use pattern', 'profitability' and 'varietal traits' for the reason of identification.

2.4 Data

The data for the study are drawn from the field survey 2017-18, carried out by the Agricultural Economics Division of the BRRI. The study intensively covered all the *Upazilas* of the two districts to make the data statistically representative. To fulfill the study's objectives, we collected household lists of the rice-growing farmers from *Upazila* Agriculture Office (UAO) and selected the respondents randomly. The survey questionnaire was structured in two modules: one deals with the farmers' socio-demographic profile, and the other one focuses on the input use pattern of rice growers. We also collected information about the area coverage and yield of different rice varieties at the *Upazila* level from UAO. Before we started the analysis, we cleaned and validated data using the random cross-checking method.

From the descriptive statistics, we found that, on average, the Indian rice varieties adoption was 52%. The age of farmers and their education levels were 43.65 and 7.38 on average, respectively. The source of earnings for 39% of the respondents were farming, and, on average, 2.18 persons per family were involved in that activity. The respondents' average family size (4.58 No.) was close to the national average of 4.5. Among the respondents, about 34% and 38% were marginal[4] and small[5] farmers, respectively.

[4] Marginal farmers are those who operated between 0.02 to 0.20 hectares of land.

[5] Small farmers are those who operated between 0.201 to 1.01 hectares of land.

Table 2. Descriptive statistics of a dataset for the econometric model.

Variable Name	Description	Mean	CV	Max	Min
Adoption intensity	Adoption percentage of Indian varieties	0.52	0.69	1	0
Farmers' age	Number of years of respondent age	43.65	0.21	57	22
Education	Years of schooling of the respondent	7.38	0.58	16	0
Occupation	Dummy: 1= only farming, 0=Otherwise	0.39	1.26	1	0
Household size	Number of household members	4.58	0.19	7	3
Members in farming	Number of family member engaged in farming	2.18	0.37	4	1
[1]Farm size	Dummy: 1=marginal farmers, 0=Otherwise	0.34	1.4	1	0
[2]Farm size	Dummy: 1= Small farmers, 0=Otherwise	0.38	1.28	1	0
Training	Dummy: 1=Farmers received rice production training, 0=Otherwise	0.32	1.47	1	0
Distance to UAO	Distance from farm household to *Upazila* Agriculture Office (km)	8.69	0.56	16	0.5
Distance to market	Distance from farm household to local market (km)	0.89	0.72	4	0.1
Domestic yield	Yield of domestic rice varieties (t/ha)	3.35	0.39	4.5	3
Indian yield	Yield of Indian rice varieties (t/ha)	3.80	0.54	5.91	4.01
Price differences	Price of Indian rice varieties over domestic varieties (US$/quintal)	0.12	105.76	25.61	-22.03
Cultivated varieties	Number of cultivated rice varieties per farm	1.65	0.44	4	1

Note: km=kilometer, t/ha=Ton per hectare, CV=Coefficient of Variation, Max=Maximum and Min=Minimum. Total number of observations = 1260. 1 US$=83.75 Bangladeshi currency (BDT).
Source: Analyzed and prepared by authors based on data from field survey 2017-18.

The remaining respondents were either medium or large farmers. About 32% of the respondents received rice production training. On average, they cultivated 1.65 varieties per farm. The average distances from farm households to UAO and nearby markets were 8.69 and 0.89 km, respectively. The average yield of domestic and Indian varieties was 3.35 and 3.80 t/ha, respectively, while the market price difference was 0.12 US$/quintal in favor of Indian varieties. Although the average price difference is low, the coefficient of variation explained higher price variability. That means that all the varieties cultivated by 1260 farmers drew lower mean with high variation (Table 2).

2.5 Econometric model

To analyze the socio-economic factors, we employed a fractional logistic regression model (Papke and Wooldridge, 1996; Wooldridge, 2010). It allows capturing nonlinear relationships, especially when the adoption intensity of Indian rice varieties is near 0 or 1. This regression model also allows overcoming several problems more convincingly than other methods using fractional response variables such as Ordinary Least Square (OLS) when estimates fall within the unit interval. Log-odds regression can be difficult to interpret, as it requires arbitrary adjustment for all observations ranging between 0 and 1, although many researchers used binary econometric models for analyzing the adoption of technologies (Chandio and Jiang, 2018; Mariano et al., 2012; Muzari et al., 2012; Noorhosseini et al., 2012). Maximum Likelihood Estimation (MLE), which estimates the parameters by maximizing a likelihood function, is known not to be robust to distributional failure and nonlinear least square. It requires $Var(Y|X) = \sigma^2$ for relative efficiency, which is unlikely for fractional Y (Gramig et al., 2008).

Fractional logistic regression is a quasi-MLE method with a conditional mean assumption. It allows for the direct estimation of the anticipated fractional response variable and the possibility that the normal probability model is misspecified (Greene, 2012). The model proposed by Papke and Wooldridge (1996) has the following structure:

$$E(Y|X) = \exp(X\beta)/[1 + \exp(X\beta)] = \Lambda(\mathrm{X}\beta) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2.1)$$

Where, $\beta's$ is the estimated coefficient of the explanatory variables X. The quasi-log likelihood for observation i is exactly the same as for the logit binary response model as:

$$l_i(\beta) = Y_i log\ [\Lambda(X_i\beta)] + (1 - Y_i)\ \log[1 - \Lambda(X_i\beta)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2.2)$$

Where, $\Lambda(.)$ is the logistic Cumulative Distribution Function (CDF) and $Y_i \in [0, 1]$ which differs from the binary logit that limits $0 \leq Y \leq 1$. The parameter estimates are identically dichotomous but need to be obtained with a fully robust variance estimator (Wooldridge, 2010). The variance assumption of a binomial generalized linear model requires a generally robust inference, which is expressed as:

$$Var(Y_i|X_i) = \sigma^2 p(X_i, \beta)[1 - p(X_i, \beta)] \quad \text{...(2.3)}$$

Where, $\sigma(X_i, \beta) = \Lambda\ (X_i\beta)$.

The generalized linear model's estimation requires binomial distributional and logit link function with a dichotomous dependent variable. But in this particular model, a program was developed using a statistical package that does not treat fractional dependent variables as binary (Gramig et al., 2008).

The marginal effects of the explanatory variables can be derived as follows,

Marginal Effect, $X_k = Pr\ (Y = 1|X, X_k = 1) - Pr\ (Y = 1|X, X_k = 0)$……….…… (2.4)

Model specification and variables

The vector of explanatory variables in the fractional logistic regression model is as follows:

$$X_i = (X_1, X_2, X_3, \dots, X_{14}) \quad \text{...(2.5)}$$

Where, X_1= farmer's age (years); X_2 = education (years of schooling); X_3 = occupation dummy (1=only farming, 0=otherwise); X_4 = household size (no.); X_5 = number of family members actively engaged in farming (no.); X_6= farm size dummy (1=marginal farmers, 0= otherwise); X_7= farm size dummy (1=small farmers, 0= otherwise); X_8= rice production training received (1=yes, 0=otherwise); X_9= distance to UAO (km); X_{10}= distance to local market (km); X_{11}= yield of domestic rice varieties (t/ha); X_{12}= yield of Indian rice varieties (t/ha); X_{13}= farm gate price difference between Indian and domestic rice varieties (US$/quintal); and X_{14}= no. of varieties cultivated per farm, denotes the socio-economic characteristics of the sampled rice farmers. Hence, the estimation model is specified as:

$$E(Y|X_i) = \Lambda(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_{14} X_{14}) \quad \text{.....................................} (2.6)$$

Here, Y is the fractional dependent variable that denotes the adoption intensity of Indian rice varieties in Bangladesh.

To test the normality of the distribution, we conducted a 'Skewness and Kurtosis' test as well as 'Kernel Density' test for normality. In both cases, we found that the distribution of the residuals was normal. We implemented the Breusch-Pagan/Cook-Weisberg test to verify whether the assumption of homoscedasticity is satisfied. The null hypothesis of constant variance was rejected with a 1% significance level, suggesting a heteroscedasticity problem. The results of the diagnostic tests are given in appendix B.1 and B.2. The frictional logistic regression automatically removed the heteroscedasticity problems in the model by giving robust standard errors. The mean variance inflation factor (VIF) was 3.17, which is less than 10, indicating that the dataset doesn't suffer from any multicollinearity problem. We used the STATA 14.0 software for the entire statistical analysis.

3. Results and Discussion

3.1 Adoption status

3.1.1 Brief history of the replacement of domestic varieties by Indian varieties

In the Rangpur district, the Indian rice variety that was first introduced in 2003 for the wet season was called 'Indian (*Varotio) swarna'* (Table 3). Today, different *Upazilas* of the district introduced various types of *Swarna* rice varieties (e.g., *Lal swarna*, *Guti swarna, Ranjit swarna, Swarna-5, Nepali swarna, and Mamun swarna*). Before introducing *Swarna* rice varieties, *Sapahar* (a local variety), *Pajam* (an improved local variety), and BR11 were the dominant rice varieties. According to the farmers and extension experts met, BR11 was replaced by *Guti swarna* because it is highly susceptible to sheath blight disease, high Brown Plant Hopper (BPH) and leaf folder infestation, and exhibits lower yield.

About 18 years ago, 'Indian (*Varotio) Zira'* which belongs to the family of the Indian Zira rice varieties was introduced in the Bogura district for the dry season. Besides, farmers adopted other Indian varieties in this region such as *Parija*, *Miniket*, *Super miniket*, and *Sampa katari*. In different *Upazilas* of the district, various types of *Zira* rice varieties like *Zira*, *Moazzem zira*, *Hajari zira*, etc have been cultivated (Table 3), one superior variety replacing a less preferred variety over time. For example, *Zira* rice varieties have replaced varieties bred by the BRRI in particular BRRI dhan28 in the Bogura district. The main factors explaining the adoption of *Zira* rice varieties in the dry season were: long slender type grain, higher market demand at miller level, increased yield, and better market price.

Table 3. First introduction of Indian varieties and replacement of domestic HYVs.

District	Introduction Year	First Introduced Indian HYV	Step-wise Introduction of Indian HYV	Step-wise replacement of Domestic HYV
Rangpur	2003	Indian *(Varotio) swarna*	Lal swarna→Guti swarna→Ranjit swarna→ Swarna-5→ Nepali swarna→Mamun swarna	Sapahar→Pajam→BR11
Bogura	2000	Indian *(Varotio) Zira*	Parija→Miniket→Super Miniket→Zira→Moazzem Zira→Hajari Zira→Sampa katari	IR8→BR3→BR14→BRRI dhan28

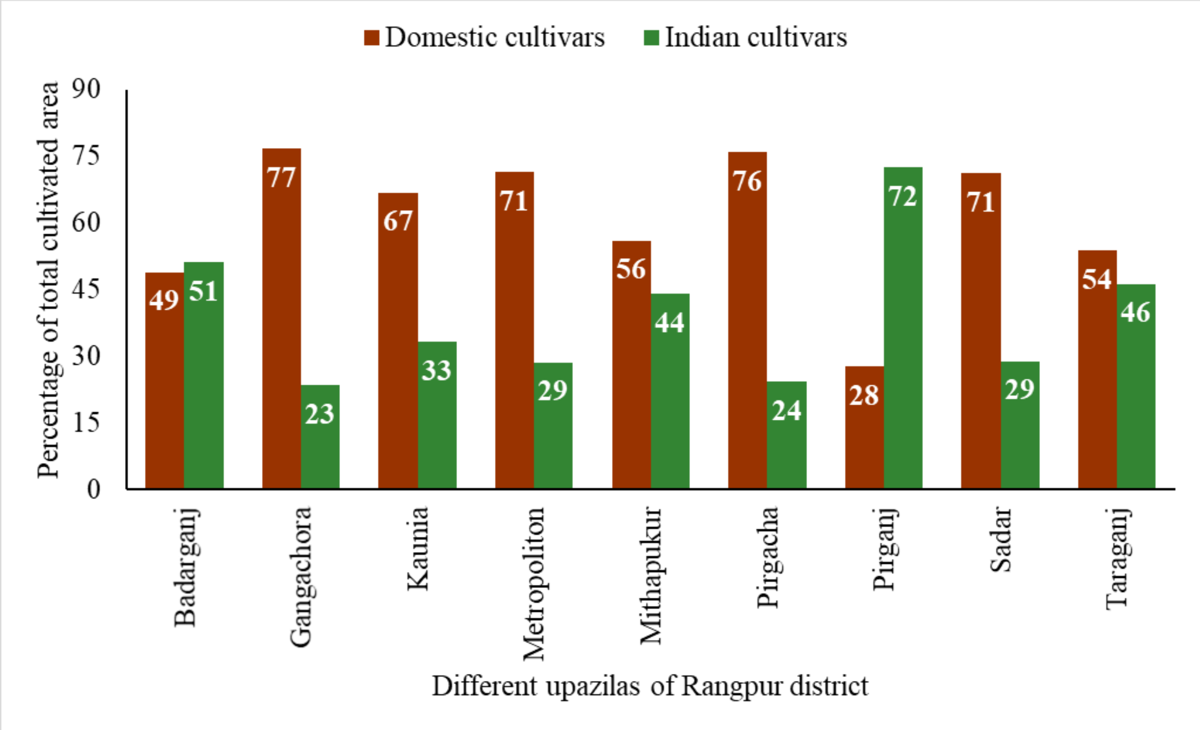
Source: Analyzed and prepared by authors based on data from field survey 2017-18.

3.1.2 Area coverage of domestic and Indian rice varieties in the wet season

Overall, the rate of adoption of domestic and Indian rice varieties was 58.38% and 41.62% of total wet season areas in the Rangpur district, respectively. Among different *Upazilas*, the rates of adoption of Indian varieties were the highest in Pirganj (72%) and Badarganj (51%). The rest of the *Upazilas* still exhibited preferences for domestic varieties in the wet season (Figure 1).

According to the FGD findings, the popularity of Indian varieties has increased over time in all *Upazilas.* The respondents opined that the major drivers for adopting Indian varieties were high yield potential, a stable market price, and their aptitude to fit in the cropping patterns. In contrast, the domestic varieties lost popularity due to their comparatively higher susceptibility to pest infestation and weaker market price stability.

Figure 1. ***Upazila*****-wise adoption status of wet season rice varieties in Rangpur district, Bangladesh.**



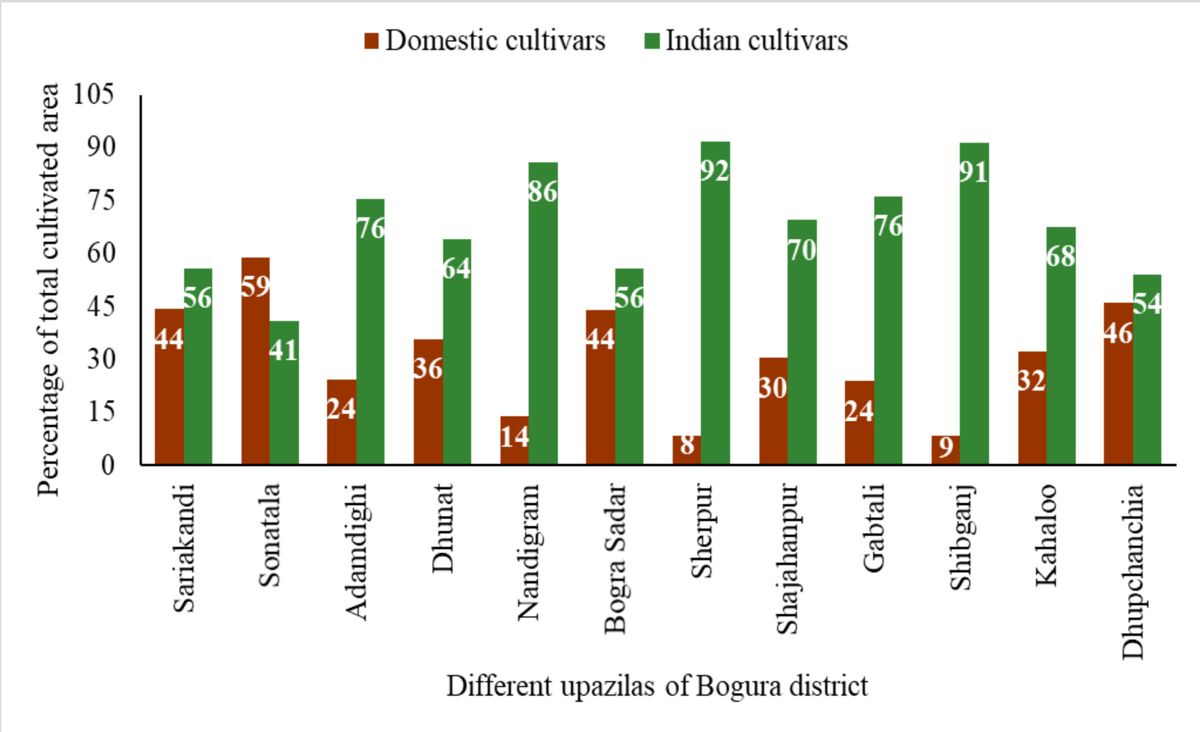
Source: Prepared by authors using data from local *Upazila* office of DAE, 2017-18. Department of Agricultural Extension, Rangpur, Bangladesh.

3.1.3 Area coverage of domestic and Indian rice varieties in the dry season

In the Bogura district, Indian varieties were found to dominate with 69.06% of total dry season area coverage, whereas domestic varieties covered the rest (30.94%). Among different *Upazilas*, the adoption rates of Indian varieties were significantly higher than that of domestic varieties. The only exception was the Sonatala *Upazila* where the domestic varieties were popular, representing 59% of the total cultivated rice area (Figure 2).

From FGD results, the replacement rates of domestic varieties by Indian cultivars were much higher in the dry season with limited varietal diversification. Interestingly, most farmers produced domestic varieties for their consumption while cultivated Indian varieties mostly for commercial purposes.

Figure 2. ***Upazila*-wise adoption status of dry season rice varieties in Bogura district, Bangladesh.**



Source: Prepared by authors using data from local *Upazila* office of DAE, 2017-18. Department of Agricultural Extension, Bogura, Bangladesh.

3.2 Reasons for adopting Indian varieties

We identified the main factors driving the adoption of Indian rice varieties in the Rangpur and Bogura districts: yield advantage, price variation, input use patterns, profitability, farmers' preferences, varietal traits, slow adoption of newly released domestic varieties, and socio-economic variables.

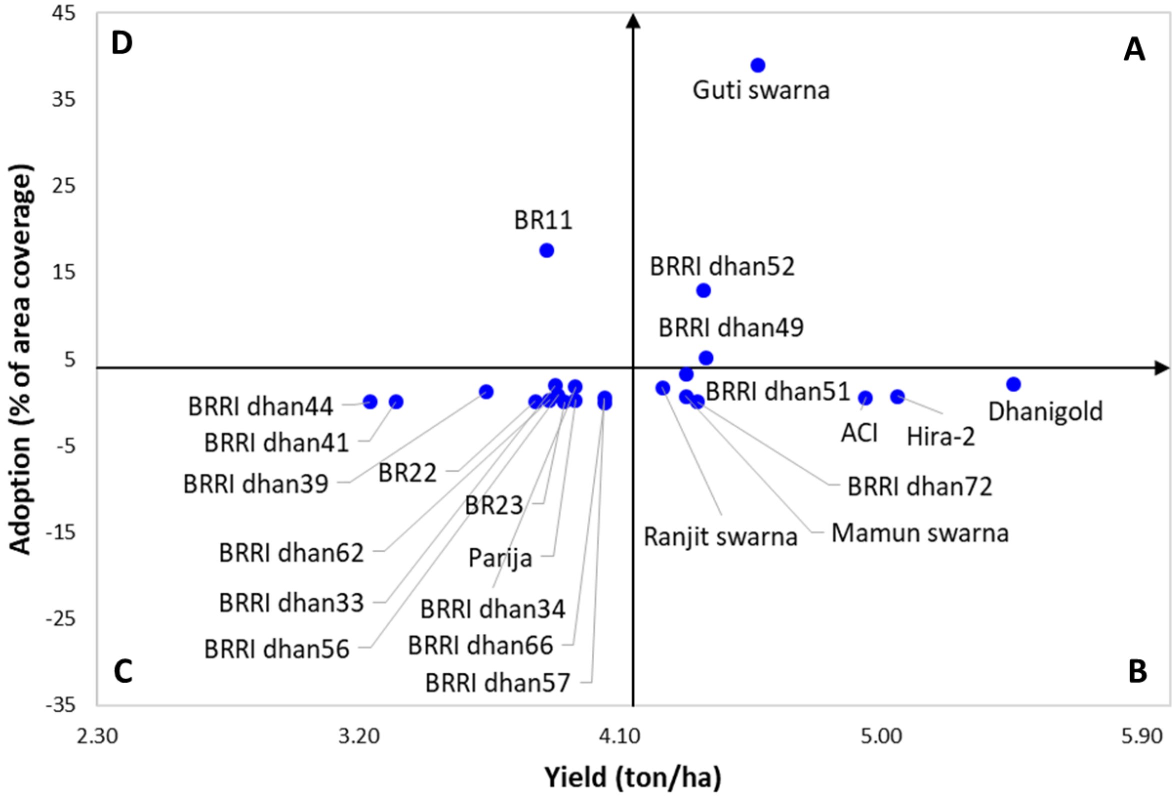
3.2.1 Yield advantage

Yield is the main driving force of adopting a new variety, as was emphasized by the respondents during FGDs. Therefore, we explored the yield performance of modern rice varieties in both the wet and dry seasons.

Wet season: We present the interaction effects of yield and adoption rate of different rice varieties in the scatter diagram (Figure 3). This diagram shows that the adoption rate was highest for *Guti swarna* (38.92%) followed by BR11 (17.61%), BRRI dhan52 (12.91%), BRRI dhan49 (5.18%), and so on. Looking at yield, Dhanigold (5.46 t/ha) gave the highest yield followed by Hira-2 (5.06 t/ha), ACI (4.95 t/ha), *Guti swarna* (4.58 t/ha), BRRI dhan49 (4.40 t/ha) and so on. The graph depicts the combined effect of yield and adoption rate. The adoption rate of *Guti swarna*, BRRI dhan49, and BRRI dhan52 were higher when the yield of these varieties was comparatively higher due to their ability to escape and recover from stresses quickly, seed availability, good taste, and overall farmers' acceptability. Conversely, the adoption of BR11 was higher than that of BRRI dhan49 and BRRI dhan52 (owing to good eating quality) despite the yield was significantly lower at only 3.85 t/ha. This is due to a genetic potential that decreased after being cultivated for a long time, a factor that is compounded by its susceptibility to sheath blight disease and BPH infestation. Previously, BR11 was the top-yielding 'Mega Rice Variety[6]' in the study areas, as was mentioned during FGDs. Some other varieties had good yield potential (Zone B in Figure 3) several factors including inferior grain quality, inability for farmers to preserve seeds for the next planting season, and scarcity of good quality seed hindered higher adoption rates. We also found that the reasons behind the low adoption and low yielding varieties (Zone C in Figure 3) were long growth duration (that hinders early Rabi[7] crops), severe pest and disease infestation, and unavailability of quality seed.

[6] The variety that covered at least 1 million hectare of land and sustain for a longer period of time in Bangladesh.
[7] Rabi season starts from November and continues up to April.

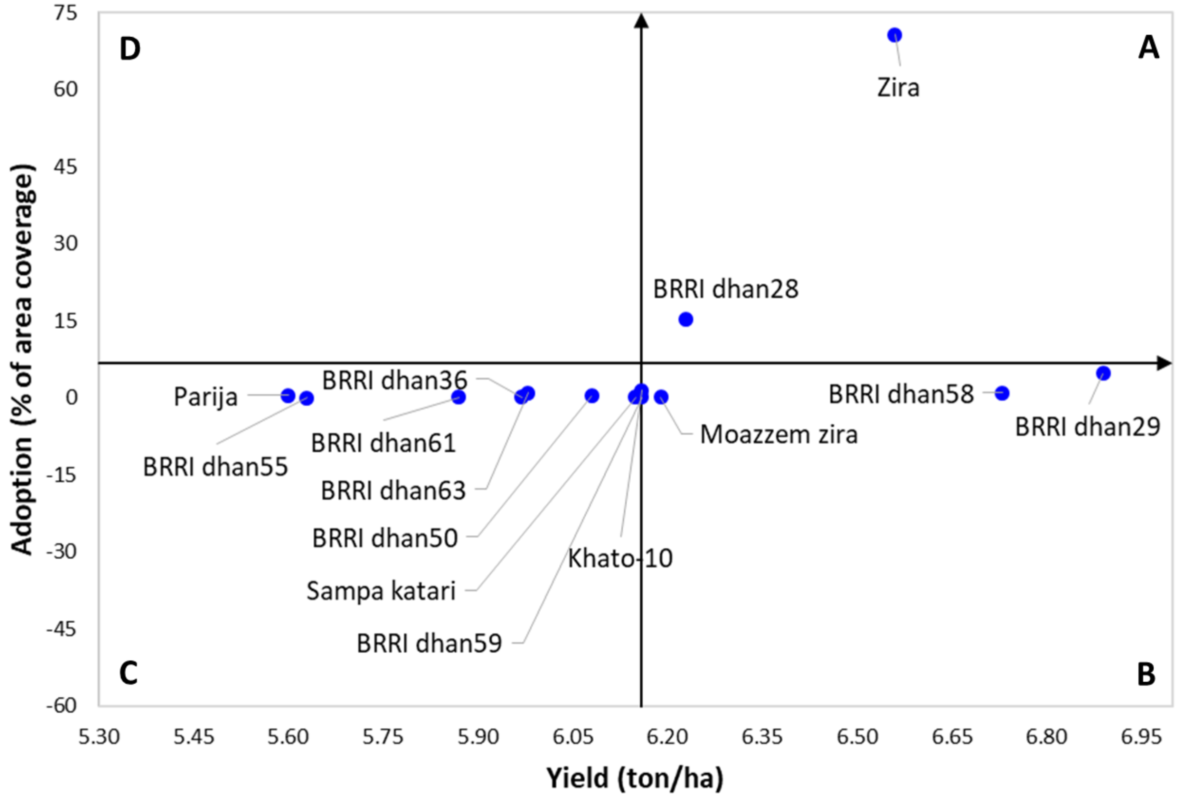
Figure 3. Interaction effects of adoption rate and yield of wet season rice varieties in Rangpur district, Bangladesh.



Note: The locus (4.15, 3.95) of the two arrow bars has been drawn using the average of yield and adoption rate. The English alphabet presenting "A= Higher Yield vs Higher Adoption zone; B=Higher Yield vs Lower Adoption zone; C=Lower Yield vs Lower Adoption zone; and, D= Lower Yield vs Higher Adoption zone. Source: Analyzed and prepared by authors based on data from local *Upazila* office of DAE, 2017-18. Department of Agricultural Extension, Rangpur, Bangladesh.

Dry season: Figure 4 shows the interaction effects of yield and adoption rate of different rice varieties in the dry season. The adoption rate was highest for *Zira* (70.71%) followed by BRRI dhan28 (15.17%), BRRI dhan29 (4.76%), *Khato-10* (1.36%), BRRI dhan58 (0.96%) and so on. BRRI dhan29 (6.89 t/ha) gave the highest yield followed by BRRI dhan58 (6.73 t/ha), *Zira* (6.56 t/ha), BRRI dhan28 (6.23 t/ha) and so on. *Zira* is rapidly gaining popularity for its higher average yield (0.33 t/ha) than BRRI dhan28, along with better grain quality and a much higher likelihood for farmers to transact the product at farm-gate. The nationally bred BRRI dhan28 variety used to be the mega rice variety in the study areas. However, its productivity has been declining over time due to its higher susceptibility to blast disease and severe lodging problems. Although BRRI dhan29 and BRRI dhan58 gave higher yield than other varieties, their adoption rate was lower (Zone B in Figure 4). This is explained by a longer growth period, bold grain, and the unavailability of quality seed. Importantly, *Moazzem zira* and *Khato-10* had yield potentiality in the study areas, but an inadequate supply of seed explained their low adoption rate. Other varieties (shown in Zone C of Figure 4) had lower yields with low adoption rates because of their high susceptibility to blast disease, bold grain, and scarcity of quality seed.

Figure 4. Interaction effects of adoption rate and yield of dry season rice varieties in Bogura district, Bangladesh.



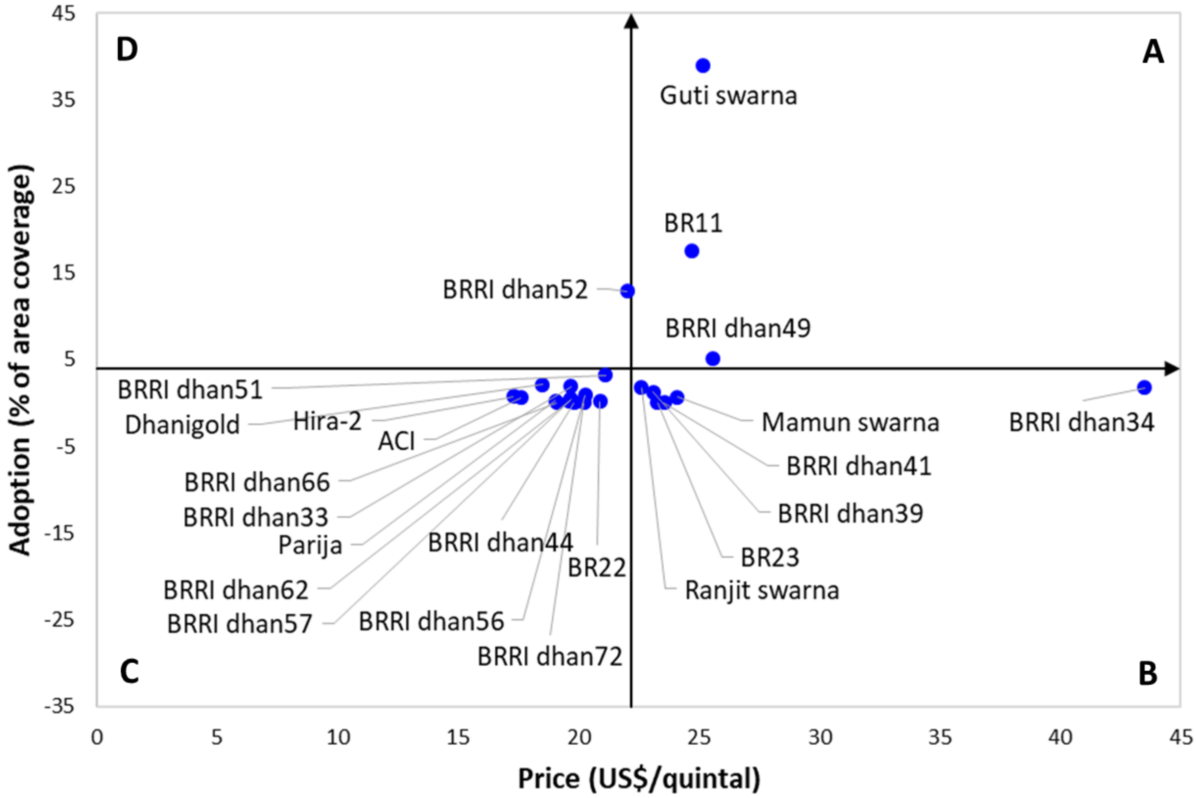
Note: The locus (6.16, 6.79) of the two arrow bars has been drawn using the average of yield and adoption rate. The English alphabet presenting "A= Higher Yield vs Higher Adoption zone; B=Higher Yield vs Lower Adoption zone; C=Lower Yield vs Lower Adoption zone; and, D= Lower Yield vs Higher Adoption zone. Source: Analyzed and prepared by authors based on data from local *Upazila* office of DAE, 2017-18. Department of Agricultural Extension, Bogura, Bangladesh.

3.2.2 Price variation

The acceptance of a variety depends largely on market preferences. Price is important and often the main factor of market preferences. Therefore, we explored the farm-gate price of different rice varieties in both wet and dry seasons.

Wet season: The average farm-gate price for BRRI dhan34 was found to be the highest (43.52 US$/quintal) followed by BRRI dhan49 (25.61 US$/quintal), *Guti swarna* (25.16 US$/quintal), BR11 (24.72 US$/quintal), *Mamun swarna* (24.12 US$/quintal) and so on (Figure 5). BRRI dhan34 gets a higher price for its aroma and grain quality, but exhibits a lower adoption rate as the average consumer generally prefers the parboiled rice with non-aromatic type. *Guti swarna*, BR11, and BRRI dhan52 presented higher market acceptance rates at the millers' level for their medium bold type grain. Another reason is that they are highly demanded varieties by the consumers in the southern part of Bangladesh (Barisal, Patuakhali, Satkhira, Bhola, etc.). Besides, head rice and filled grain percentages for *Guti swarna* and BR11 are much higher than what is commonly found in other wet season varieties. By contrast, BRRI dhan49 was found to have a relatively higher market price for its "*Naizershail*" (a popular brand to the consumer with colossal market demand) type grain and increased demand at millers' level. Also, processors were keen to supply milled BRRI dhan49 by the brand name of *BR49, Pajam,* and *Nazir* after grading that would allow them to derive a price advantage of up to 5.97 US$/quintal. However, the adoption rate of BRRI dhan49 was comparatively lower than that of *Guti swarna* (Zone A in Figure 5) mainly because it is highly susceptible to false smut disease which deteriorates grain quality. Although they are currently less adopted, *Mamun swarna* and *Ranjit swarna* varieties (Zone B in Figure 5) have the scope to expand their coverage area due to their comparatively better grain quality and higher market price. Varieties in Zone C are characterized by low adoption and low market price, which is primarily explained by their inferior grain quality (stickiness).

Figure 5. Interaction effects of adoption rate and market price of wet season rice varieties in Rangpur district, Bangladesh.

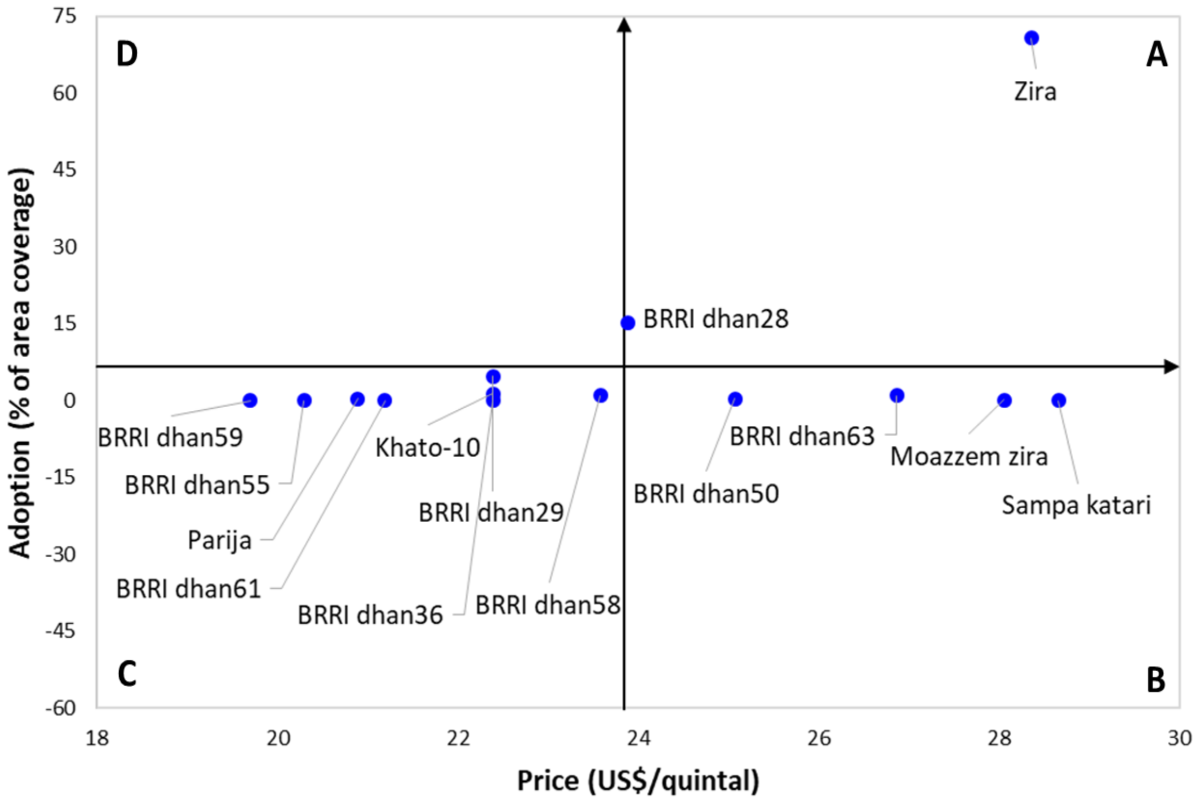


Note: The locus (22.21, 3.95) of the two arrow bars has been drawn using the average of market price and adoption rate. The English alphabet presenting "A= Higher Price vs Higher Adoption zone; B=Higher Price vs Lower Adoption zone; C=Lower Price vs Lower Adoption zone; and, D= Lower Price vs Higher Adoption zone. Source: Analyzed and prepared by authors based on data from farmers' interviews and local *Upazila* office of DAE, 2017-18. Department of Agricultural Extension, Rangpur, Bangladesh.

Dry season: The *Sampa katari* variety obtained the highest price (28.66 US$/quintal) followed by *Zira* (28.36 US$/quintal), *Moazzem zira* (28.06 US$/quintal), BRRI dhan63 (26.87 US$/quintal), BRRI dhan50 (25.07 US$/quintal), BRRI dhan28 (23.88 US$/quintal) and so on. Figure 6 shows that the farm-gate price of Indian varieties was found to be significantly higher than that of domestic rice varieties. According to the FGD findings, rice growers did not adopt *Sampa katari* and *Moazzem zira* widely due to their long growth duration, high production cost and the delays they generate in cultivating pre-monsoon season crops. The interaction effects of adoption rate and the market price of *Zira* and BRRI dhan28 were higher, but there was a vast dispersion between these varieties (Zone A in

Figure 6). This dispersion causes higher milling outturn, long slender type grain, and good taste to eat. Long slender type grain varieties, such as BRRI dhan50 and BRRI dhan63, can fetch a higher market price, but they are highly susceptible to neck blast disease, leading to a lower adoption rate. The rice varieties' market price and adoption rate in Zone C was lower due to the relatively bold type of grain a trait that does not sell well in Bangladesh.

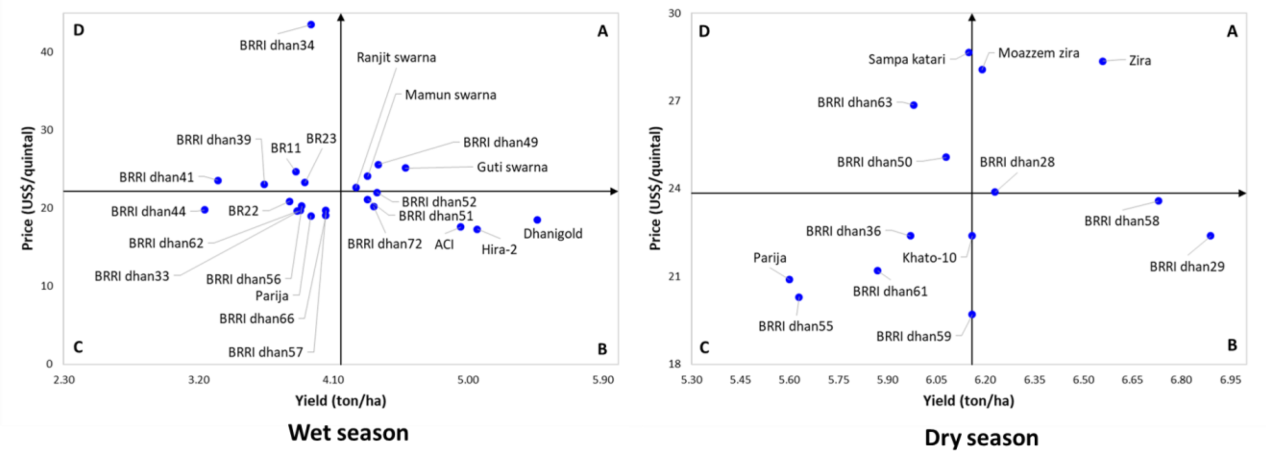
Figure 6. Interaction effects of adoption rate and market price of dry season rice varieties in Bogura district, Bangladesh.



Note: The locus (23.84, 6.79) of the two arrow bars has been drawn using the average of market price and adoption rate. The English alphabet presenting "A= Higher Price vs Higher Adoption zone; B=Higher Price vs Lower Adoption zone; C=Lower Price vs Lower Adoption zone; and, D= Lower Price vs Higher Adoption zone. Source: Analyzed and prepared by authors based on data from farmers' interviews and local *Upazila* office of DAE, 2017-18. Department of Agricultural Extension, Bogura, Bangladesh.

The yield and market price emerge as the two main drivers of adoption of Indian rice varieties, as shown in Figure 7 for both the wet and dry seasons. Moreover, Figure 7 (left-hand panel) shows that the yield dispersion was much higher than the wet season's price dispersion. The variety BRRI dhan34 appears as an outlier. However, in the dry season (right-hand panel), this characteristic was not visible in the study areas as both the price and yield dispersions were important. Indian varieties are found predominantly in the A corner of the scattered plots for both seasons, suggesting a clear association between the level of adoption of Indian varieties and the higher than average market price and yield. By contrast, most of the traditional domestic varieties exhibit low adoption rates because they embody lower yield and a lower market price (see in the C corner).

Figure 7. Interaction effects of yield and market price of wet and dry seasons rice varieties in Rangpur and Bogura district, Bangladesh.



Note: The English alphabet presenting "A= Higher Yield vs Higher Price zone; B=Higher Yield vs Lower Price zone; C=Lower Yield vs Lower Price zone; and, D= Lower Yield vs Higher Price zone. Source: Analyzed and prepared by authors based on data from farmers' interviews and local *Upazila* office of DAE, 2017-18. Department of Agricultural Extension, Rangpur and Bogura districts, Bangladesh.

3.2.3 Input use patterns

To compare the domestic and Indian rice varieties' input use pattern, the study considered the highest area covered with varieties of each category. For the wet season, we compared BR11 as domestic and *Guti swarna* as Indian varieties. For the dry season, we compared the Indian variety *Zira* with the domestic variety BRRI dhan28 and BRRI dhan58.

Wet season: Table 4 shows the per hectare input use pattern of wet season rice varieties. BR11 was found to be more labor intensive than *Guti swarna*. Farmers usually used fewer working days in intercultural operations such as transplanting, harvesting while contracting labor for carrying/transport. Most farmers also rented power threshers. About 72% of farmers used BR11 seeds from the Bangladesh Agricultural Development Corporation (BADC) and other companies. Roughly 87% of farmers used their seeds to grow *Guti swarna*. Farmers generally opined that their home-supplied seed quality and germination capacity were comparatively lower than those they could obtain from other trusted sources. That's why the seed rate for *Guti swarna* (37 kg/ha) was a bit higher than for BR11 (34 kg/ha). Farmers usually applied lower quantities of fertilizer and also spent less time to grow *Guti swarna* than BR11. This explains the higher adoption rate of *Guti swarna* in the Rangpur district.

Table 4. Per hectare input use pattern of BR11 and *Guti swarna* rice varieties cultivation in Rangpur district, Bangladesh.

Input item	BR11	*Guti swarna*
Human labour (man-day/ha):	65	58
Hired	51	48
Family	14	10
Seed (kg/ha)	34	37
Fertilizer (kg/ha):		
Urea	182	173
TSP	87	74
MoP	99	78
DAP	30	24
Gypsum	45	56
$ZnSO_4$	2	3
Theovit	-	6

Note: TSP= Triple superphosphate, MoP= Muriate of potash, DAP= Diammonium phosphate, $ZnSO_4$= Zinc sulfate. Source: Analyzed and prepared by authors based on data from field survey 2017-18.

Dry season: The most labor intense variety (77 man-days/ha) was BRRI dhan58 followed by *Zira* (73 man-days/ha) and BRRI dhan28 (68 man-days/ha). The seed rates for BRRI dhan28, BRRI dhan58 and *Zira* rice varieties were 37, 36 and 32 kg/ha, respectively. This indicates that farmers used a substantially higher amount of seed than the BRRI recommended rate (25 to 30 kg/ha) (BRRI, 2018). Generally, farmers applied almost similar fertilizers for BRRI dhan58 and Zira, while they applied a lower fertilizer level for BRRI dhan28 (Table 5). Farmers tended to use fewer inputs altogether for BRRI dhan28 as they were losing interest in its cultivation mostly due to its lower yield and higher susceptibility to the blast disease.

We observed no significant difference in inputs use between Indian and domestic rice varieties. During FGDs, respondents also opined that input use did not influence the adoption of Indian varieties in the Bogura district.

Table 5. Per hectare input use pattern of *Zira*, BRRI dhan28 and BRRI dhan58 rice varieties in Bogura district, Bangladesh.

Input item	*Zira*	BRRI dhan28	BRRI dhan58
Human labour (man-day/ha):	73	68	77
Hired	58	55	61
Family	15	13	16
Seed (kg/ha)	32	37	36
Fertilizer (kg/ha):			
Urea	185	173	189
MoP	142	110	138
DAP	145	120	148
Gypsum	75	70	74
ZnSO4	7	5	8
Boron	4	4	3

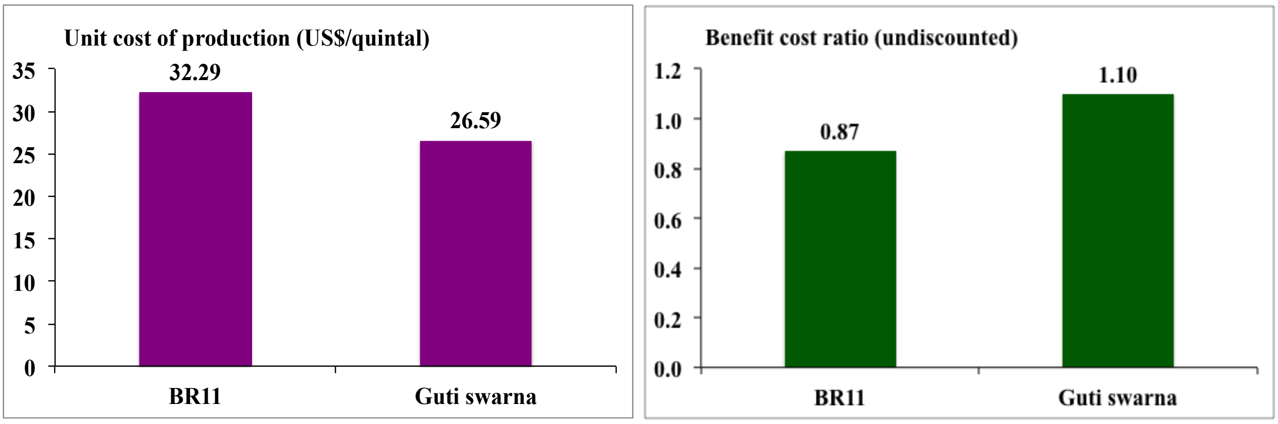
Note: MoP= Muriate of potash, DAP= Diammonium phosphate, $ZnSO_4$= Zinc sulfate. Source: Analyzed and prepared by authors based on data from field survey 2017-18.

3.2.4 Profitability

Like the input use pattern, the study compared the profitability between rice varieties in each season.

Wet season: The cost of producing one quintal of BR11 paddy was 32.29 US$, which was 21.44 percent higher than the production costs of *Guti swarna* (26.59 US$/quintal) in the Rangpur district (Figure 8). The undiscounted Benefit-Cost Ratio (BCR) indicated that, BR11 was not an economically attractive option for farmers. However, many farmers still decided to grow it due to its immense significance for family consumption. Overall, *Guti swarna* was found to be a more profitable variety for farmers because it would require less cash advances and attract a higher farm-gate price.

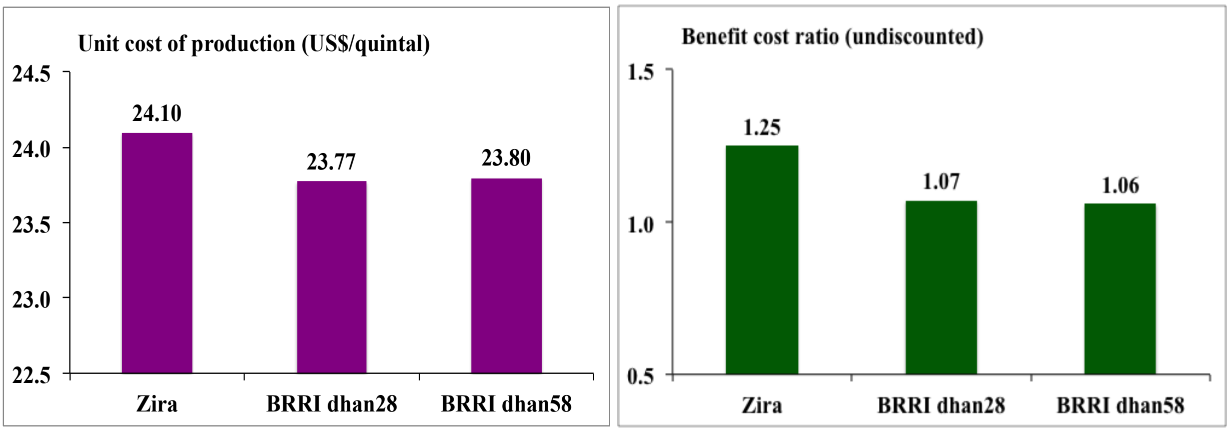
Figure 8. Comparative profitability of BR11 and *Guti swarna* rice varieties cultivation in Rangpur district, Bangladesh.



Source: Analyzed and prepared by authors based on data from field survey 2017-18.

Dry season: *Zira* exhibited a higher unit cost of production (24.10 US$/quintal) followed by BRRI dhan58 (23.80 US$/quintal) and BRRI dhan28 (23.77 US$/quintal). *Zira* and BRRI dhan58 revealed similar total production costs but comparatively lower productivity for the former than the latter. Moreover, the undiscounted BCR showed that *Zira* was roughly 20% more profitable than BRRI dhan28 and BRRI dhan58 in the Bogura district (Figure 9). This is explained mainly by the higher market price that *Zira* can offer. Although the yield of BRRI dhan58 was found to be higher, its market price was comparatively lower because it is less demanded by millers and unfamiliar to other value chain actors. These factors explain the lower BCR of BRRI dhan58 if compared to *Zira*. Overall, farmers who typically aim to maximize their profits appear to be better off when adopting Indian varieties.

Figure 9. Relative profitability of *Zira*, BRRI dhan28 and BRRI dhan58 in Bogura district, Bangladesh.



Source: Analyzed and prepared by authors based on data from field survey 2017-18.

3.2.5 Ranking of farmers' preferences about Indian rice varieties

Table 6 depicts the sequence that an average farmer would follow in each district in replacing rice varieties based on its priorities. The trend is clearly in favor of Indian rice varieties. Generally, preferences have been changing over time depending on gender, income levels, culture, agro-climatic factors, introduction of new genotypes, and so on. In the Rangpur district, most of the farmers ended up adopting *Guti swarna* as their favored variety for the wet season. Whereas in the Bogura district, farmers tended to cultivate the *Zira* variety the most in the dry season.

Table 6. Ranking of farmers' preferences about Indian HYV over time.

District	Ranking of farmers' preference over time
Rangpur	*Lal swarna* → *Nepali swarna* → *Mamun swarna* → *Ranjit swarna* → *Swarna-5* → *Guti swarna*
Bogura	*Parija* → *Miniket* → *Super Miniket* → *Sampa katari* → *Hajari Zira* → *Moazzem Zira* → *Zira*

Source: Analyzed and prepared by authors based on data from field survey 2017-18.

3.2.6 Varietal traits

Farmers of the Rangpur and Bogura districts were asked about different traits of cultivated rice varieties in the wet and dry seasons. Their opinions and explanations for replacing domestic rice varieties with Indian varieties are provided in Tables 7 and 8.

In the Rangpur district as was anticipated before, the popularity of BR11 has decreased for its susceptibility to sheath blight and bacterial blight diseases; its comparatively longer growth duration, higher production cost; higher susceptibility to BPH and leaf folder; lower market price due to bold grain; severe lodging problem, and uneven panicle exertion due to cold and drought. Although BR11 exhibited many negative traits, farmers cultivated it mostly because quality seeds were easily available from trusted dealers whereas very limited amount of newly released rice varieties seed was available in the market. Moreover, farmers tended to cultivate multiple varieties rather than a single variety to mitigate the risk of production losses in the wet season. BRRI dhan49 was found to be a good variety in terms of grain quality and market price. By contrast, it was less attractive to farmers for its high susceptibility to false smut disease, which deteriorates grain quality, and yield. It was also more prone to attacks by rats that could cause severe crop damages. BRRI dhan52 was gaining popularity in the very low laying areas of the Rangpur district due to its adaptation to submergence conditions (for up to 10-14 days) and its relatively good yield.

Indian varieties have become popular in the wet season due to their moderate growth duration, allowing them to intercrop them with potatoes easily. Besides, they exhibit comparatively higher yields than other modern varieties, are less prone to infestation by pests and other diseases, offer quick recovery capacity from any stress, particularly drought. They also obtain higher market demand by millers because of medium bold grain, offer a higher milling outturn resulting in higher market price at the farm gate. On top, the quality of the straw at harvest is good and straws can be sold for cattle feeding providing extra income to farmers. Among the main constraints, farmers noted a higher tendency of lodging at very low-lying areas and vulnerability to sheath blight diseases, to some extent.

In the Bogura district, farmers stopped cultivating BRRI dhan28 due to its higher susceptibility to blast, infestation of BPH, and severe lodging problem, which in some cases accounted for up to 100% crop damage. Nevertheless, BRRI dhan28 was credited with some positive traits i.e., good taste, reasonable market price, fair demand by millers, and moderate growth duration that made it well fitted for intercropping with mustard and/or potato in some growing areas. BRRI dhan63 was considered a premium quality rice, but it was seen as prone to severe infections by blast disease and shattering that could cause significant yield reduction. The major barriers towards the adoption of BRRI dhan50 were a higher than usual susceptibility to neck blast, higher percentage of broken grain, and shattering.

In contrast, Indian rice varieties dominated in the dry season due to their higher yield than other MVs, their lucrative farm-gate price, long slender type grain, higher milling outturn, and consistently strong demand millers and final consumers. The few negative traits mentioned included sensitivity to blast disease in some areas, and a heavy panicle weight combine with a weak stem that could cause lodging. Overall, farmers were almost systematically shifting their preferences to Indian rice varieties to the detriment of domestic varieties.

Table 7. Comparative varietal traits of major wet season rice varieties in Rangpur district, Bangladesh.

Traits	Domestic Varieties			Indian Varieties		
	BR11	BRRI dhan49	BRRI dhan52	*Guti swarna*	*Ronjit swarna*	*Mamun swarna*
Yield (t/ha)	3.85	4.40	4.39	4.58	4.25	4.33
Plant height (cm)	115	100	116	95	98	92
Growth duration (days)	150-155	135-140	145-150	140-145	140-145	135-140
Lodging	Lodging problem	No lodging	Lodging problem	Lodging problem in the low land	No lodging	Lodging problem
Shattering	No shattering	No shattering	No shattering	No shattering	No shattering	No shattering
Diseases	Highly susceptible to sheath blight and bacterial blight	Highly susceptible to false smut	Susceptible to sheath blight	✓ Susceptible to sheath blight ✓ Lower infestation of sheath rot	Less infestation of sheath blight	Less infestation
Insect*	Susceptible to BPH and leaf folder	✓ Susceptible to BPH ✓ Rat attack due to early ripening	Susceptible to BPH	Less infestation of ear cutting caterpillar	Less infestation	Less infestation
Resistance	✓ Panicle cannot exert properly due to cold and drought. ✓ Plant cannot survived up to 10 days under stagnant water at low land	---	Submerged up to 2 weeks	✓ Quick recovery capacity from any stress ✓ Drought escaping	---	More rainfall during flowering stage caused grain sterility
Grain size and shape	Bold	Medium slender	Medium bold	Medium bold	Medium slender	Medium slender
Milling outturn (%)	65.00	61.25	65.00	70.00	62.50	62.50
Straw quality	Good	Good	Very good	Good	Very good	Good
Price (US$/quintal)	24.72	25.61	22.03	25.16	22.63	24.12
Others	Used to make puffed rice	Good taste to eat for its *Nazirshail* type grain	High tillering ability alongside the number of grain sterility is also high	Erect flag leaf	---	---

*Yellow Stem Borer was a common insect for all varieties in wet season. cm= Centimeter. Source: Analyzed and prepared by authors based on data from field survey 2017-18.

Table 8. Comparative varietal traits of major dry season rice varieties in Bogura district, Bangladesh.

Traits	Domestic Varieties			Indian Varieties		
	BRRI dhan28	BRRI dhan50	BRRI dhan63	*Zira*	*Moazzem Zira*	*Sampa Katari*
Yield (t/ha)	6.23	6.08	5.98	6.56	6.19	6.15
Plant height (cm)	90	82	86	77	80	75
Growth duration (days)	140-145	155-160	150-155	150-155	150-155	155-160
Lodging	Lodging problem	No lodging	No lodging	Lodging problem due to panicle weight and weak stem	No lodging due to strong stem	Lodging problem
Shattering	No shattering	Shattering problem	Shattering problem	No shattering	No shattering	No shattering
Diseases	Highly susceptible to blast	Highly susceptible to Neck blast	Highly susceptible to blast	Susceptible to blast	Susceptible to blast	Susceptible to blast and bacterial blight
Insect*	Susceptible to BPH	Susceptible to BPH	Less infestation	Susceptible to BPH	Less infestation	Susceptible to BPH and leaf folder
Grain size and shape	Medium slender	Long slender	Long slender	Long slender	Long slender	Short slender
Milling outturn (%)	62.50	52.50	61.00	70.00	65.00	63.00
Straw quality	Good	Very good	Very good	Good	Good	Good
Price (US$/quintal)	23.88	25.07	26.87	28.36	28.06	28.66
Others	Good taste to eat and non-sticky	Aroma, lower head rice percentage	---	Taste reduces if rice become cold	Input intensive (fertilizer and irrigation)	Non-sticky rice

*Yellow Stem Borer was a common insect for all varieties in dry season. cm= Centimeter. Source: Analyzed and prepared by authors based on data from field survey 2017-18.

3.2.7 Slow adoption of newly released domestic rice varieties

We also observed that newly released domestic rice varieties were slowly adopted if at all. The main causes behind this were as follows: (i) unavailability and untimely supply of seed to the farmers; (ii) lack of information directed to the farmers on the new varieties; (iii) less confidence on the performance of new varieties due to risk aversion behavior of the farmers in terms of yield, pest infestation, and market demand; (iv) inadequate in-situ demonstration of the qualities of new varieties; (v) substantial delay in sharing the feedback of demonstrated varieties with farmers; and, (vi) weak linkages among researchers, extension agents and farmers (Table 9). This relatively ineffective seed system was an important reason why Indian rice varieties dominated in the study areas.

Table 9. Major drivers for slow adoption of newly released rice varieties.

Reasons for slow adoption	Responses (%)	Rank
Unavailability and untimely seed supply	58.00	1
Lack of information of new varieties	56.25	2
Less confidence on yield, pest infestation and market demand of new varieties	43.08	3
Poor connection among research, extension and farmers	40.17	4
Inadequate demonstration	31.58	5
Delay sharing the feedback of demonstrated varieties	15.50	6

Note: The summation of percentages is not equal to 100 because of the same respondent's multiple answers. Source: Analyzed and prepared by authors based on data from field survey 2017-18.

3.2.8 Socio-economic factors

Socio-economic factors significantly influenced the adoption of Indian rice varieties among the sampled farm households in the study areas. The results of our quasi-MLE showed that, level of education, occupation (only farming), number of active family members in farming, rice production training received, distance to local market, and yield of domestic varieties were all negatively associated with the adoption of Indian rice varieties (Table 10). Educated farmers tended to adopt more domestic varieties because they could easily access information about domestic varieties' advantages through their good relations with seed dealers and extension agents. Farmers who engaged in multiple occupations were less likely to dedicate more time to farming. Therefore, they preferred varieties that required less intensive care, hence tended to cultivate Indian varieties. Domestic varieties adoption increased with the increase in engagement of family members in farming. Because Indian varieties need less intensive care, they require minimum family labor involvement. The farmers who received rice production training from DAE were keen to cultivate domestic rice varieties due to varietal information availability. Farmers usually purchase Indian rice varieties seed from the local market and sell the paddy in the same place. Therefore, the closer distance between the local market and the farm, the higher the adoption of Indian varieties. In most cases, the yield advantage had a significant influence on the varietal choice. Therefore, we hypothesize that increasing yield of domestic rice varieties could hinder the adoption of Indian varieties.

Table 10. Quasi-MLE of fractional logistic regression for adoption of Indian rice varieties.

Socio-economic factors	Coefficients	Marginal effects
Intercept	-0.673** (0.344)	-
Farmers age (years)	0.004 (0.003)	0.022
Years of schooling	-0.016** (0.006)	-0.017
Occupation dummy (1= farming only, 0=Engaged in multiple occupations)	-0.184*** (0.058)	-0.009
Household size (no.)	0.002 (0.032)	0.001
Members active participation in farming (no.)	-0.068** (0.032)	-0.020
[1]Farm size (1=marginal farmers, 0=otherwise)	1.138*** (0.101)	0.037
[1]Farm size (1=small farmers, 0=otherwise)	0.038 (0.092)	0.003
Training received (1=yes, 0=otherwise)	-0.254*** (0.071)	-0.009
Distance to *Upazila* agriculture office (km)	0.017** (0.007)	0.021
Distance to local market (km)	-0.092** (0.045)	-0.011
Yield of domestic varieties (t/ha)	-0.660*** (0.060)	-0.334
Yield of Indian varieties (t/ha)	0.677*** (0.046)	0.434
Price difference (US$/quintal)	0.070*** (0.011)	0.021
Cultivated varieties (no./farm)	-0.028 (0.037)	-0.006
Wald χ^2	3226.76***	

Pseudo R^2	0.42
Total no. of observations	1260

Note: Dependent variable: Adoption intensity of Indian rice varieties. Asterisks denote level of significance as *P<0.10, **P <0.05 and ***P<0.01. Value of the parentheses represents the robust standard errors. [1]Dummy variable for farm size: Base variable is medium and large farmers having greater than 1.01 hectares of operated land. Source: Analyzed and prepared by authors based on data from field survey 2017-18.

We also found that for the marginal farm size, the longer the distance to *Upazila* agriculture office, the higher the yield of Indian varieties, and the bigger the price difference between India and domestic varieties, the more the adoption of Indian rice varieties (Table 10). Overall, it appears that marginal farms had a higher tendency to grow Indian rice varieties for its yield advantage. The small to large farmers were cultivating Indian rice varieties commercially. Higher yield potential and better farm-gate price of Indian rice varieties were the essential factors of adoption. By contrast, the farmers who stayed near to the *Upazila* agriculture office were well connected with extension personnel (gets information and input support) and tended to adopt domestic rice varieties more.

Other factors such as farmers' age, household size, small farm size, and farm-wise cultivated varieties were not significantly correlated with the adoption of Indian rice varieties.

More specifically, young farmers are more cosmopolite and quicker to adopt new technology (information about crop management) and, as a result, keen to allocate more land to domestic varieties. As farmers of the study areas were generally risk-averse, they cultivated multiple varieties (on an average 1.65 no./farm, see Table 2) instead of a single variety. Only those farmers who adopted a single variety preferred to cultivate Indian varieties. Last but not least, educated and experienced farmers who had benefitted from at least one rice production training and were well connected with extension personnel were found to be likely to grow high yielding domestic rice varieties.

4. Conclusions and Recommendations

Adoption of Indian rice varieties has been increasing rapidly in the border region of Bangladesh. This study evaluates the main reasons that could explain this trend in selected areas to draw strategies for developing and expanding domestic rice varieties. The findings revealed that the adoption of Indian rice varieties was explained by their yield advantage, higher market price, less inputs requirement, higher profitability, better agronomic qualities such as lower risks of infestation by pests and diseases, a better aptitude to fit in various cropping pattern, quick recovery capacity from stresses especially drought, lower labor requirements, and other socio-economic factors such as age, farm size, education. The fact that the dissemination strategy of competing for new domestic had been cumbersome also played a role in favor of Indian varieties. Indian varieties contribute significantly to the food security of the population in the border regions of Bangladesh. Accordingly, the demand for seeds of Indian varieties has been increasing.

One of the problems with the current situation lies with the fact that there is no legal authority in charge of multiplying and supplying seeds to the farmers. Hence, farmers are bound to take the responsibility to multiply and preserve seeds from one season to the next. As a result, the quality of the seeds may deteriorate over time. Moreover, too high degree of dependency on Indian rice varieties may lead to genetic erosion of domestic varieties. This is potentially problematic because many domestic varieties embody valuable traits with quite diverse genetic backgrounds. They are generally well adapted to local biophysical conditions (Frankel, 1973; Brush, 1999). However, Indian varieties are currently preferred in the areas studied for their market (price), agronomic (yield), and socio-economic (labor) advantages. Domestic rice varieties to convince farmers to adopt them would need to be viable, competitive, and suitable to specific cropping regions. Unless new, improved domestic varieties can compete on these particular factors, Indian varieties will most likely continue to dominate. Researchers, policymaker, extension personnel and farmers need to work together to identify the most viable alternative options in terms of market-driven breeding, market a policy if they the goal is to minimize the possible adverse effects of an overreliance on Indian varieties. Our findings outline recommendations under four pillars: research, technology, extension, and market.

Improving market-driven breeding research

- In varietal development, rice scientists and rice breeders must identify and prioritize the most relevant product concepts and develop product profiles accordingly. This requires adopting a market-based approach placing rice growers, rice millers, and rice consumers in the center to identify and meet their preferences with new product concepts. In this regard, moderate yield potential, market price, growth duration, disease, and insect resistance should be duly considered. Ghimire et al. (2015) drew a very similar recommendation.
- Breeders may purify and select pure lines of the existing popular Indian varieties and release them for the concerned areas through the certification of the national seed board of the Ministry of Agriculture.

Improving varietal technology

- The popular varieties can be traded between two countries through a seed exchange agreement. The "seed-without-border" initiative sponsored by the International Rice Research Institute and Bangladesh is a party provides a useful and ready-to-use framework in this regard.
- 'Seed Village' at farmers' level should be established to accelerate quality seed production and multiplication.

- Bangladesh Agricultural Development Corporation (the largest government seed multiplication agency) should enlarge the seed multiplication program of newly released rice varieties.
- To reduce adoption lag, farmers can be engaged in the seed production process of newly released rice varieties at the very early stage of dissemination with the Department of Agricultural Extension's supervision.
- Public-private partnerships should be strengthened for seed multiplication of new varieties.

Improving client-focused extension services

- As seed production and quality are the major issues for Indian seeds, a sustainable seed system should build on robust legal frameworks, sound scientific and reliable and qualified extension services. Encouraging farmers for quality seed production, a step should be taken to recognize their seed as 'Truthfully Labeled Seed' through intensive monitoring of government authorized agencies. It is also necessary to take seed purification training at the farmers' level and strengthening quarantine wing to prevent seed-borne diseases, which will enhance productivity at 5-20% (http://www.knowledgebank.irri.org/step-by-step-production/pre-planting/seed-quality).
- Training on seed technology, pest, and nutrient management should be provided to the farmers and extension personnel at the beginning of each season.
- The information about newly released rice varieties should be disseminated through leaflets, booklets, mobile apps, Short Messaging Service (SMS) and mass media.
- The demonstration program for popularizing newly released rice varieties should be reinforced covering multiple locations.
- Site selection for the demonstration should be made where farmers can have easy access.
- Location-specific varieties should be exhibited accordingly.

- Feedback of demonstrated varieties should be shared in a timely fashion to the concerned research institutes and farmers' associations.

Enabling market drivers for the adoption of domestic rice varieties

- A fair farm-gate price should be offered to farmers for domestic rice varieties similar to what is done for Indian varieties.

Declaration of Interests

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

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CRediT Authorship Contribution Statement

Md Abdur Rouf Sarkar: Conceptualization, Investigation, Methodology, Data curation, Writing – original draft. **Mohammad Chhiddikur Rahman:** Investigation, Formal analysis, Data curation, Writing – original draft. **Md Shajedur Rahaman:** Investigation, Data curation, Writing - original draft. **Mou Rani Sarker:** Data curation, Writing- original draft. **Mohammad Ariful Islam:** Formal analysis. **Jean Balie:** Supervision, Methodology, Writing - review & editing.

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Appendix A

Table 1: Description of the study locations

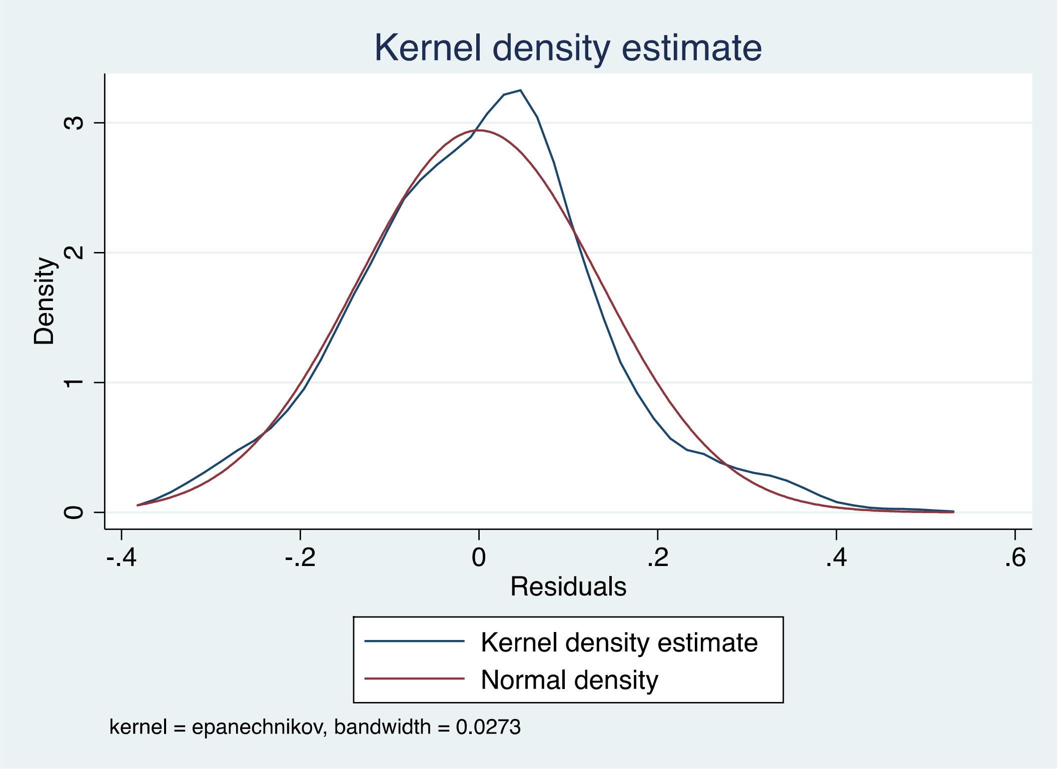
District name	*Upazila* name	Union name
	Badarganj	Ramnathpur, Madhupur
	Gangachora	Gangachara, Alambiditor
	Kaunia	Tepamadhupur, Kursha
	Metropoliton	Metropoliton, Darshana
Rangpur	Mithapukur	Ranipukur, Balarhat
	Pirgacha	Annadannagar, Pirgachha
	Pirganj	Bhendabari, Mithipur
	Sadar	Mominpur, Haridebpur
	Taraganj	Alampur, Kursha
	Sariakandi	Kazla, Kamalpur
	Sonatala	Sonatala, Balua
	Adamdighi	Adamdighi, Nasaratpur
	Dhunat	Nimgachi, Kalerpara
	Nandigram	Nandigram, Bhatgram
Bogura	Bogra Sadar	Rajapur, Gokul
	Sherpur	Khanpur, Mirzapur
	Shajahanpur	Amrul, Arai
	Gabtali	Gabtali, Nasipur
	Shibganj	Raynagar, Shibganj
	Kahaloo	Paikar, Kahaloo
	Dhupchanchia	Dhupchanchia, Talora

Appendix B

1. Test for Normality

```
. sktest res

                    Skewness/Kurtosis tests for Normality
                                                      ——— joint ———
    Variable         Obs  Pr(Skewness)  Pr(Kurtosis) adj chi2(2)   Prob>chi2
─────────────┼──────────────────────────────────────────────────────────────
         res       1,200     0.0151        0.0148       11.19         0.0037
```



2. Test for Constant Variance

```
. estat hettest

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of Adop_india

         chi2(1)      =     6.88
         Prob > chi2  =   0.0087
```