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Research Article

Adoption Analysis of BADC Produced *Boro* Rice Seed and Its Impact on Farm Household Food Security in Bangladesh

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Abstract

The purpose of this study is to look into the factors that influence adoption of BADC produce *Boro* rice seed and its impact on farm household food security in Bangladesh. The endogenous switching regression model (ESRM) and the propensity score matching (PSM) method were employed to identify the factors that influence adoption of BADC *Boro* rice seed and assessed its adoption impact on farm household food security. The analysis revealed that age, farm size, rice area, farm income, extension service, livestock ownership and government assistance had significant influence on adoption of BADC *Boro* rice seed. The estimated results show that education, farm size, earning members, farm income had positive and significant influence in attaining food security status of both adopters and non-adopters farm household. The estimated coefficient of correlation between the adoption equation and the food security equation of adopters was positive and significant. The study confirms that BADC produce *Boro* rice seed adoption had positive and significant impact on farm household food security of Bangladesh. The study recommended that BADC should implement appropriate policies to increase *Boro* rice seed production and enhance its adoption level through extension service so that food security situation improve in Bangladesh.

Keywords

Adoption, BADC, *Boro* Seed, Bangladesh, Food Security

1. Introduction

Quality seed is one of the essential component for enhancing crops production and productivity [8, 17]. Adopting high quality seed is a crucial step towards eradicating hunger, poverty and food insecurity in emerging countries [30]. Quality seed provides a significant higher yield and better quality of crops product compare to locally produced crops of seed [29]. Ensuring the availability of high-quality seed and plant materials for most important crops is the greatest strategy to sustain food security [15]. Seed security is one of the economic and biological challenges in Bangladesh. The government of Bangladesh is actively involved in the innovation of new crop varieties as well as the propagation and distribu-

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tion of diverse crops seed. Bangladesh is now dealing with a number of significant issues including an expanding population and shrinking agricultural land. The amount of agricultural land is declining more than 1% every year in Bangladesh due to various reason such as housing, industries, roads and highways, river erosion, civic infrastructure and urbanization etc. [27]. To consider aforementioned circumstances, adopting high quality crops seed is an important way in increasing food production on relatively less land. *Boro* rice is the most important food crop in Bangladesh in terms of output and meeting the country's food requirement. With the development of *Boro* rice varieties both acreage and production of *Boro* rice are increasing over time in Bangladesh [7]. So, food security of Bangladesh depends on better *Boro* rice production. Quality *Boro* rice seed is essential to boost output and productivity of *Boro* rice. Both public and private sector entities in Bangladesh produce quality seed and distribute to farmers. BADC is the largest public sector institution under the Ministry of Agriculture provide quality seed to farmers at reasonable price. BADC supplied 0.66 lakh MT *Boro* rice seed in the last financial year 2022-23 which met 48.91% of the national demand [21]. Consequently, *Boro* rice production in Bangladesh is greatly impacted by BADC *Boro* rice seed. As a result, research on adoption of BADC *Boro* rice seed has been taken in order to increase *Boro* rice productivity and improve food security situation of Bangladesh. This study's aims to explore the factors that influence adoption of BADC *Boro* rice seed and its impact on farm households' food security. The usage of BADC *Boro* rice seed is expected to boost better yields and enhance the amount of food available to the farm household. The application of BADC *Boro* rice seed produces more food, which is projected to contribute to the farmers' food consumption and leading to family food security. On the other hand, the use of BADC *Boro* rice seed will undoubtedly increase farm households' revenue from the sale of surplus output. It eventually improves the food security situation for farm household through higher consumption and spending on other foods that are necessary for diet. A great number of research on adoption and food security were conducted in the past. Paltasingh [23] examined land tenure security and adoption of modern rice technology in Odisha and found that farmers' education, farm size, secured tenural status and long-term tenancy contract had enhanced adoption of modern rice technology. Miah *et al*. [18] assessed factors affecting adoption of improved sesame technologies in some selected areas in Bangladesh and concluded that family labour, availability of improved seed, farmers' cosmopolitness and extension contract had significant influence on adoption improved sesame variety. Shiferaw *et al*. [28] analyzed the effects of modern wheat technology adoption on food security among smallholder farmers in Ethiopia and found that prices of wheat, the prices of competing crops, sources of variety information, input costs, agro-ecology and geographical location had significant influence on adoption of improved wheat varieties. Mariano *et al.* [14] examined factors influencing farmers' adoption of modern rice technologies and good management practices in the Philippines and identified that farmers' education, machinery ownership, irrigation water supply, capacity-enhancement activities and profit-oriented behavior had positive impact on adoption of modern rice technology. Arouna *et al.* [4] studied on contribution of improved rice varieties to poverty reduction and food security in Sub-Saharan Africa and explored that the adoption of improved rice varieties had a beneficial impact on household food security. The aforesaid discussion clear that a lot of studies were done on adoption and food security but no such type of study was done so far on BADC *Boro* seed adoption and farm household food security. The findings of the study are expected to provide valuable information and may be helpful for researchers, planners and policymakers in formulating suitable policy for sufficient *Boro* seed production in Bangladesh. However, the specific objectives of this study were (i) to explore the factors influencing adoption of BADC *Boro* rice seed; and (ii) to assess the adoption impact of BADC *Boro* rice seed on farm households' food security.

2. Materials and Methods

2.1. Data Source

Both primary and secondary data were used to perform the study. A farm survey was conducted from November 2021 to July 2022 in order to gather primary data. The database initially were comprised 480 farms located in all over Bangladesh. These farms were classified as adopters and non-adopters of BADC *Boro* rice seed. Farmers who exclusively utilized BADC *Boro* rice seed were classified as adopting farmers. Non-adopting farmers were included who utilized their own saved *Boro* rice seed, private companies, NGO_S and purchased seed or seedlings from local market or neighboring farmers. Secondary data (food composition table) were gathered from institute of nutrition and food science, center for advance research science of Bangladesh. Secondary data (food composition table) were used to estimate calorie intake of farm household.

2.2. Sampling Design

The study was covered in all over Bangladesh. Multistage sampling technique were used in this study. At first, eight districts were chosen from eight divisions of Bangladesh where BADC authority allocated highest amount of *Boro* rice seed in 2020-21 *Boro* season. Mymensingh, Kishoreganj, Cumilla, Sylhet, Barishal, Khulna, Pabna and Dinajpur district were finally selected for the study. One *upazila* (sub-district) was chosen from each selected district where the maximum amount of *Boro* rice seed was allocated. One union was picked from each selected *upazila* in cooperation with

BADC and DAE personnel where BADC *Boro* rice seed was extensively used. Two agricultural blocks from each selected union were purposely selected. With the assistance of DAE personnel and BADC register seed dealers separate lists of adopters and non-adopters were created in each block. From separate lists of farmers in each block, 15 adopters and 15 non-adopters were chosen randomly. From each union 30 adopters and 30 non-adopters total of 60 farmers were selected. Finally, 240 adopters and 240 non-adopters total of 480 farmers were picked for the study.

2.3. Data Collection Procedure and Analysis

A preliminary interview schedule was prepared to gather primary data. Preliminary interview schedule was pre-tested in the closest study areas. The interview schedule was reviewed and finalized following pre-test. Primary data were gathered using pre-tested and semi-structured interview schedule. Primary data were collected from the selected respondents using face-to-face interview approach. The collected data were analyzed and interpreted based on STATA version 14 software.

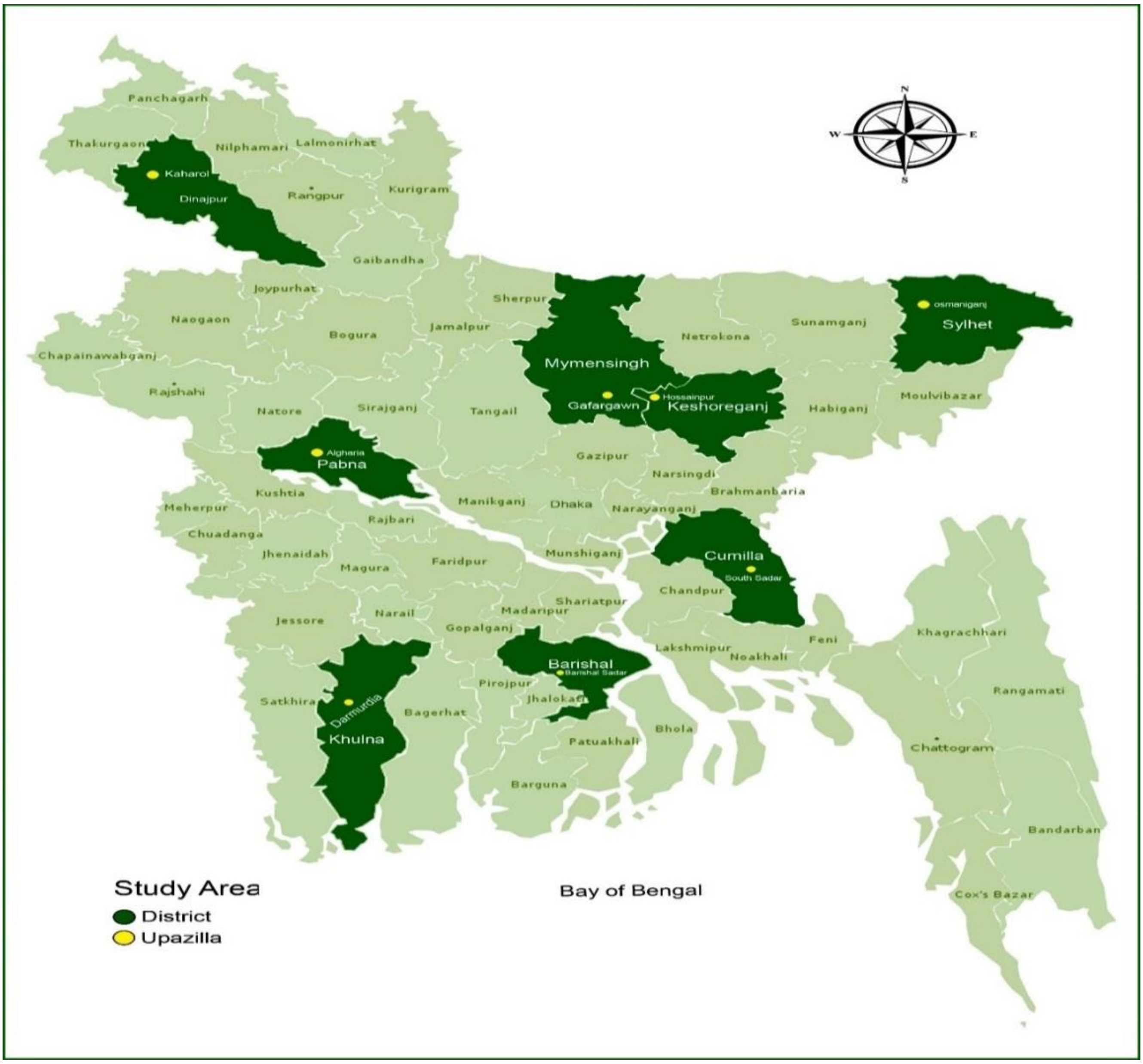

Figure 1. *Showing study areas on a map of Bangladesh.*

Table 1. *Sample size determination in the study areas.*

District	*Upazilla*	Union	Adopters	Non-adopters	Total
Mymensingh	Gafargaon	Barobaria	30	30	60
Kishoreganj	Hossainpur	Sidla	30	30	60
Cumilla	Sadar south	Goliara	30	30	60
Sylhet	Osmaninagar	Sadipur	30	30	60
Barishal	Sadar	Jagua	30	30	60
Khulna	Dumuria	Dumuria	30	30	60
Pabna	Atgharia	Ekdanto	30	30	60
Dinajpur	Kaharole	Sundarpur	30	30	60
Total			240	240	480

Table 2. *Description of variables included in the model.*

Variable	Definition
Dependent	-
Adoption	1 if farmers adopt BADC *Boro* rice seed, 0 otherwise
Food security	1 if farmers food secure, 0 otherwise
Independent	-
Age	Age of the household head in year
Education	Total years of formal schooling of household head
Family size	Total family members of household
Earning member	Total earning member of household
Member in farming	Total family member involve in farming
Farming experience	Total years of farming activities engaged household head
Farm size	Total crop area planted in hectare
Rice area	Total rice area planted in hectare
Farm income	Total income comes from farm activities (Tk)
Non-farm income	Total income comes from non-farm activities (Tk)
Amount of credit	Total amount of credit receive by household head in previous year (Tk)
Extension service	1 if farmers receive extension service, 0 otherwise
Livestock ownership	Total number of livestock exist in household
Farm machinery	Total number of farm machinery exist in household
Government assistance	1 if the farmers receive government assistance, 0 otherwise
Market distance	Distance from farmers home to market (Km)

* Tk.: Bangladeshi currency

2.4. Analytical Techniques

The endogenous switching regression model (ESRM) and propensity score matching (PSM) method were employed in this study to obtain unbiased and consistent results considering endogeneity, heterogeneity and self-selection bias. An econometric issue involving sample selection bias and heterogeneity is the driving force behind the use of endogenous switching regression model. [12]. The adoption of BADC Boro rice seed and its impact on farm household food security were evaluated in this study using the endogenous switching regression model (ESRM) and the propensity score matching (PSM) method. These two methods are described in brief below:

2.4.1. Endogenous Switching Regression Model (ESRM)

Two estimating models and a criterion function y_i, which indicates the condition the farmer faces, were used in this study to depict the food security status of farmers.

$$y_i^* = \beta X_i + \mu_i \quad (1)$$

$$\text{Condition 1: } A_{1i} = \alpha_1 j_{1i} + \varepsilon_{1i} \text{ if } y_i = 1 \quad (2)$$

$$\text{Condition 2: } A_{2i} = \alpha_2 j_{2i} + \varepsilon_{2i} \text{ if } y_i = 0 \quad (3)$$

Where,

y_i^* = The unobservable or latent variable for BADC *Boro* rice seed adoption

X_i = The nonstochastic vector of observed farmers' socio-economic factors of adoption

A_i = The farmer food security outcome in conditions 1 (adopters) and 2 (non-adopters)

j_i = The vector of exogenous variables assumed to influence food security

μ_i, ε_i = The respective random disturbance terms associated with the adoption of BADC *Boro* rice seed and food security outcome variable.

It must be stressed that variables in non-stochastic vectors j_i in equations (1) to (3) may overlap and that appropriate identification implies that at least one variable in X is not in j. Under these conditions, a non-zero covariance between the error terms of the adoption decision equation and the food security outcome equation may result from farmers' decisions to adopt or not adopt BADC *Boro* rice seed. Consequently, it was presumed that the error components in μ_i, ε_{1i} and ε_{2i}, would follow a trivariate normal distribution with zero mean and the subsequent nonsingular covariance matrix, expressed as follows:

$$\begin{pmatrix} \sigma^2_{\varepsilon_{1i}} & \sigma_{\varepsilon_{1i}\varepsilon_{2i}} & \sigma_{\varepsilon_{1i}\varepsilon_{2i}} \\ \sigma_{\varepsilon_{1i}\varepsilon_{2i}} & \sigma^2_{\varepsilon_{2i}} & \sigma_{\varepsilon_{2i}\mu_i} \\ \sigma_{\varepsilon_{1i}\mu_i} & \sigma_{\varepsilon_{2i}\mu_i} & \sigma^2_{\mu_i} \end{pmatrix} \quad (4)$$

Where, $var(\varepsilon_{1i}) = \sigma^2_{\varepsilon_{1i}}$, $var(\varepsilon_{2i}) = \sigma^2_{\varepsilon_{2i}}$ $var(\mu_i) = \sigma^2_{\mu_i}$ $cov(\varepsilon_{1i}\varepsilon_{2i}) = \sigma_{\varepsilon_{1i}\varepsilon_{2i}}$

$cov(\varepsilon_{1i}\mu_i) = \sigma_{\varepsilon_{1i}\mu_i}$ and $cov(\varepsilon_{2i}\mu_i) = \sigma_{\varepsilon_{2i}\mu_i}$. The covariance between ε_{1i} and ε_{2i} is not determined since A_{1i} and A_{2i} are not concurrently observed [12]. That suggests that the error component of the adoption equation (1) μ_i is correlated with the error components of the food security outcome function (equation 2 and 3), the expected values of ε_{1i} and ε_{2i} contingent on the sample selection are nonzero.

$$E(\varepsilon_{2i}/A = 0) = E(\varepsilon_{2i}/\mu_i \leq -j'\lambda) = \sigma_{\varepsilon_{2i}\mu_i} \frac{-\phi(j'\lambda/\theta)}{1-\vartheta(j'\lambda/\theta)} = \sigma_{\varepsilon_{2i}\mu_i}\gamma_{2i} \quad (5)$$

$$E(\varepsilon_{1i}/A = 0) = E(\varepsilon_{1i}/\mu_i > -j'\lambda) = \sigma_{\varepsilon_{1i}\mu_i} \frac{-\phi(j'\lambda/\theta)}{1-\vartheta(j'\lambda/\theta)} = \sigma_{\varepsilon_{1i}\mu_i}\gamma_{1i} \quad (6)$$

Where, Φ and ϑ, respectively represent the probability density and cumulative distribution functions. A_{1i} and A_{2i} are inverse mills ratios of Φ and ϑ assessed at $j'\lambda$. To take into account for selection bias inverse mills ratios were added to equation (1). The endogenous switching models are regressed using full information maximum likelihood estimation [5, 30]. To generate consistent standard errors, the full information maximum likelihood technique is used to estimate the probit model or selection equation and the regression equations concurrently. Considering the trivariate normal distribution assumption for the error components, the log likelihood function for the system of equation (1) to (2) can be stated as follows:

$$LnL_i = \sum_{i=1}^{N} y_i \left[ln\emptyset \langle \frac{e_{1i}}{\sigma_{e1}} \rangle - ln\sigma_{e1} + ln\emptyset(\varphi_{1i}) \right] + (1 - y_i) \left[ln\emptyset \langle \frac{e_{2i}}{\sigma_{e2}} \rangle - ln\sigma_{e2} + ln\emptyset(\varphi_{2i}) \right] \quad (7)$$

Where, $\varphi_{ji} = \frac{\beta X_i + \gamma_j e_{ji}/\sigma_j}{\sqrt{1-\gamma_j^2}}, j = 1, 2$, with γ_j representing the coefficient between the error component μ_i of the selection equation (1) and the error component ε_{ij} of equations (2) and (3), respectively. The importance and signs of the correlation coefficients (ρ) derived from the simultaneous estimations are very relevant. If the estimated covariance $\sigma_{\varepsilon_{1i}\mu_i}$ and $\sigma_{\varepsilon_{2i}\mu_i}$ are statistically significant, then BADC *Boro* rice seed adoption decision and the food security outcome variable are correlated. That means it can detect evidence of endogenous switching and reject the null hypothesis that sample selectivity bias does not exist. [12]. Negative selection bias ($\rho < 0$) suggests that farmers with below-average food security level are more likely to adopt BADC *Boro* rice seed. Farmers with higher levels of food security are more likely to use BADC *Boro* rice seed if there is positive selection bias ($\rho > 0$). By applying endogenous switching regression, it provides a comparative analysis of the expected food security status of adopters and non-adopters of BADC *Boro* rice seed, examines food security in the counterfactual assumptions that adopters of BADC *Boro* rice seed did not adopt and that non-adopters did adopt as follows:

$$E(A_{1i}/y_i = 1) = \alpha_1 j_{1i} + \sigma_{\varepsilon_{1i}\mu_i}\gamma_{1i} \quad (8)$$

$$E(A_{2i}/y_i = 0) = \alpha_2 j_{2i} + \sigma_{\varepsilon_{2i}\mu_i}\gamma_{2i} \quad (9)$$

$$E(A_{1i}/y_i = 1) = \alpha_2 j_{2i} + \sigma_{\varepsilon_{2i}\mu_i}\gamma_{2i} \quad (10)$$

$$E(A_{2i}/y_i = 0) = \alpha_1 j_{1i} + \sigma_{\varepsilon_{1i}\mu_i}\gamma_{1i} \quad (11)$$

2.4.2. Propensity Score Matching (PSM)

Propensity score was defined by Rosenbaum and Rubin [25] as the conditional probability of receiving treatment given a vector of observable factors. The propensity score represents the probability of selecting a treatment based on observed variables. The PSM method was used to supplement the endogenous switching regression in comparing the food security outcome of adopters of BADC *Boro* rice seed and their counterparts. The probit model was used to create the propensity score for those who initially adopted BADC Boro rice seed. The propensity score is expressed as in equation 12:

$$p(x) = \Pr\{Z = 1|X\} = E\{Z|X\} \quad (12)$$

Where, p(x) is the propensity score, Z= {1, 0} is the treatment variable or the dummy adoption variable and X is a vector of farmers characteristics. The average treatment effect on the treated (ATT) is then computed using the estimated propensity scores. An indicator of how adoption affects adopters is provided by the ATT. Farmers face two potential outcomes (Y) given their adoption status (Z) such that Y = Y_0 if Z = 0 and Y = Y_1 if Z = 1. $E(Y_1 – Y_0)$ indicates the average treatment effect on the treated (ATT). The ATT may alternatively be written as $E(Y_1|Z = 1) – E(Y_0|Z = 1)$. A probit (or logit) model is typically used to specify the selection equation in propensity score matching [3]. The probit adoption model used in this study was defined as an index function using Y_i, an unobserved continuous variable, as shown in equation 13:

$$Y_i = X_i\beta_i + \varepsilon_i$$

$$Y_i = \begin{cases} 1\ if\ Y_i > 0 \\ 0\ otherwise \end{cases} \quad (13)$$

Where,

Y_i = Food security outcome (1for food secure and 0 for food insecure)

X_i = Vector of farm and household characteristics

β_i = Vector of parameters to be estimated and

ε_i = Random error.

This study followed recent studies to estimate the ATT using the nearest neighbour matching (NNM), kernel-based matching (KBM) and radius matching (RM) of the PSM [20, 26, 33].

2.4.3. Estimation of Calorie Intake

For the measuring the per capita daily calorie intake of farm household, the crops, animal products, and other food items consumed from own production as well as those acquired from the market were taken into consideration. For this purpose, households' all consumption data for the previous day were collected through interviewing household head. Calorie intake was computed by recording and calculating the kilogram quantities of crops, animal products, and other food items that were produced and purchased. To find out a household member's daily calorie intake per capita, divide total calorie intake by the adjusted size of the household. Two children under the age of six were counted as one adult member regardless of gender [22]. Food composition table for Bangladesh were used to calculate the nutrient values of the foods.

3. Results and Discussion

3.1. Descriptive Statistics of Variables Included in the Model

Table 3 displays the socioeconomic factors of the sample farmers according to their adoption status of BADC *Boro* rice seed. The t-value and p-value demonstrate that several factors included in the empirical study significantly differ between adopters and non-adopters. Adopters and non-adopters were divided into two categories: food secure household and food insecure household based on their daily per capita kilo calorie intake. A household which daily per capita calorie intake over 2122 kcal was regarded as food secure and those below 2122 kcal regarded as food insecure household [1, 32]. Food security variable was regarded as dummy or categorical variable. Food security variable indicates 1 whether farm household were food secure and 0 otherwise. Table 3 demonstrates that adopters were more food secure than non-adopters. This results is consistent with Mansaray and Jin [13] who found that farmers who adopted improved rice variety were better food secure than non-adopters. Table 3 also shows that there were significant difference between adopters and non-adopters in terms of farm size, rice area, farm income, livestock ownership and extension service. Table 3 revealed that there was no significant difference in terms of age, education, farming experience, family size, earning member, member in farming, non-farm income, amount of credit, farm machinery, government assistance and market distance between adopters and non-adopters.

Table 3. *Summary statistics of variables included in the model.*

Variables	Adopters (N=240) Mean (SD)	Non-adopters (N=240) Mean (SD)	t-value	p-value
Food security outcome	0.702 (0.45)	0.620 (0.48)	1.93	0.049*
Age	48.42 (13.37)	49.05 (13.28)	-0.51	0.61
Education	5.97 (4.39)	5.55 (4.26)	1.05	0.292
Farming experience	30.179 (13.278)	31.462 (13.746)	-1.04	0.298
Family size	5.370 (2.057)	5.45 (2.277)	- 0.39	0.689
Farm size	0.903 (0.742)	0.780 (0.589)	2.01	0.044**
Rice farm size	0.761 (0.765)	0.644 (0.486)	1.99	0.046**
Earning member	1.600 (0.785)	1.508 (0.818)	1.36	0.174
Member in farming	1.375 (0.709)	1.479 (0.702)	-1.55	0.121
Farm income	148033 (139026)	121871 (101200)	2.35	0.019**
Non-farm income	51140 (87142)	46262 (88068)	0.60	0.542
Amount of credit	13095 (40069)	14841 (34447)	-0.511	0.608
Livestock ownership	3.362 (2.896)	2.81 (3.155)	1.97	0.048**
Government assistance	0.275 (0.447)	0.325 (0.469)	-1.19	0.232
Extension service	0.550 (0.498)	0.425 (0.495)	2.75	0.006**
Farm machinery	0.325 (0.573)	0.300 (0.494)	0.511	0.609
Market distance	3.036 (2.481)	2.864 (1.647)	0.884	0.377

Note: ***, ** and * represent significant at 1%, 5% and 10% level, respectively.
Source: Authors' estimation, 2023.

3.2. Factors Influencing Adoption of BADC *Boro* Rice Seed

Table 4 presents the findings from the two-stage endogenous switching regression model that was estimated for the adoption of BADC Boro rice seed and its effect on farm household food security. The selection equation's results (column 1) shows the initial step of farmers' decision to use BADC *Boro* rice seed. The selection equation's results indicate normal probit coefficients. The endogenous switching regression model's findings demonstrate that adoption of BADC *Boro* rice seed was strongly impacted by age, education, farm size, rice area, farm income, livestock ownership, government assistance and extension service. The age variable's coefficient was significant but negative, it means that the probability of adoption of BADC *Boro* rice seed decreases with the increases of farmers' age. It indicates that the young farmers were more adopters of BADC *Boro* rice seed. This results is consistent with Kalinda *et al.* [11] who found that farmers' age was negatively associate with adoption of improved maize seed. The study found a favorable significant relationship between farm size, rice area and adoption of BADC *Boro* rice seed. It means that large farmers were more adopters than small farmers. The positive coefficient of farm size and rice area implies that if farm size and rice area increase then adoption of BADC *Boro* rice seed will increase. This results is consistent with Mariano *et al*. [14] who identified that farm size was positively related with adoption of modern rice technologies and good management practices. The coefficient of farm income was positive and significant implies that if farm income increases then adoption of BADC *Boro* rice seed will increase.

Table 4. *Factors influencing BADC Boro rice seed adoption and food security.*

Variables	**Selection (Column 1)**		**Food security status**			
			Adoption (Column 2)		**Non-adoption (Column 2)**	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Constant	0.989	0.412	0.636	0.186	0.589	0.188
Age	- 0.015**	0.007	0.0005	0.0024	0.0003	0.0026
Education	0.021**	0.010	0.012**	0.0056	0.016**	0.0071
Family size	0.009	0.032	- 0.008	0.017	-0.018	0.016
Farm size	0.981***	0.165	0.013**	0.006	0.010**	0.004
Rice area	0.694***	0.134	0.246**	0.106	0.113	0.108
Earning members	- 0.009	0.103	0.012**	0.0048	0.023***	0.0055
Members in farming	0.141	0.109	0.060	0.095	0.080	0.059
Farm income	0.0079*	0.004	0.0031**	0.0015	0.0028**	0.0013
Non-farm income	0.0038	0.0068	0.0035	0.0042	0.0021	0.0036
Amount of credit	0.0004	0.0015	0.0013	0.0024	0.0063	0.0092
Livestock ownership	0.039*	0.019	0.0048**	0.0017	0.0033	0.0115
Government assistance	0.435**	0.215	0.060	0.053	0.013**	0.0063
Extension service	0.307**	0.123				
Farm machinery	0.002	0.121				
Market distance	0.004	0.031				
Wald chi^2	11.68					
Log likelihood	- 610.11					
LR test of indep.eqns	20.00**					
σ_1			0.449	0.021		
σ_2					0.482	0.022
/lns1			0.798	0.048		
/lns2					0.729	0.045
ρ_1			0.171**	0.069		
ρ_2					- 0.028	0.330

Note: ***,** and * represent significant level at 1%, 5% and 10%, respectively.
Source: Authors' estimation, 2023.

This results is consistent with Rahman and Khatun [24] who investigated that farm income had positive influence on adoption of BARI AAM-3 in Bangladesh. The coefficient of livestock ownership was positive and significant indicates that if livestock ownership increases, then probability of adoption of BADC *Boro* rice seed will increase. This results is consistent with Tesfaye *et al.* [31] who identified that cattle ownership had positive and significant impact on adoption of improved wheat technology. The coefficient of extension service was significant and positively influenced adoption of BADC *Boro* rice seed. It implies that if the extension service enhances the probability of adoption of BADC *Boro* rice seed will increase. This results is consistent with Idrisa *et al.* [9] who found that extension contact had positive influence on adoption of improved soybean seed. The variable of government assistance was significant and positively influenced adoption of BADC *Boro* rice seed. It suggests that if farmers get more government assistance the probability of adoption of

BADC *Boro* rice seed will increase. The coefficients of variable such as education, family size, members involve in farming, non-farm income, farm machinery and market distance had positive but insignificant influence on adoption of BADC *Boro* rice seed. The coefficients of variable earning member and amount of credit had negative but insignificant influence on adoption of BADC *Boro* rice seed.

3.3. Factors Influencing Food Security of BADC *Boro* Rice Seed Adopters and Non-adopters

Table 4 displays the maximum likelihood estimates of the endogenous switching regression model for the adoption of BADC *Boro* rice seed. The estimated results including education, farm size, rice area, earning member, farm income, livestock ownership and government assistance had positive and significant influence on food security outcome of adopters and non-adopters household. The variables such as age, members involve in farming, non-farm income and amount of credit had positive but insignificant influence on food security outcome of adopters and non-adopters household. The variable education was positively and significantly influenced food security status of both adopters and non-adopters household. It implies that the level of education of household head increases then food security status of both adopters and non-adopters will increase. This results is consistent with Aidoo *et al*. [2] who found that education level of household head had positive influence on food security status of household. Farm size was positively and significantly influenced food security status of both adopters and non-adopters household. It means that if farm size increases the probability of households' food security status both adopters and non-adopters will increase. This results is consistent with Miah *et al*. [19] who revealed that farm size had positive and significant influence on farm household food security in hilly people of Bangladesh. Earning members of household was positively and significantly influenced food security status of both adopters and non-adopters household. It means that if earning members of household increases the probability of households' food security status both adopters and non-adopters will increase. Farm income was positively and significantly influenced food security status of both adopters and non-adopters household. This means that if farm income increases the probability of households' food security both adopters and non-adopters will increase. This results is consistent with Babatunde *et al*. [6] who found that total annual household income had positive and significant influence on household food security. Rice area had positively and significantly influenced food security status of adopters household. That means, if the rice area increases the probability of adopters' food security status will increase. On the other hand, rice area had positively but not significantly influenced food security status of non-adopters household. The coefficient of livestock ownership had positively and significantly influenced food security status of adopters household. It means that if number of livestock increases food security status of adopters household will increase. Livestock ownership had positively but insignificantly influenced food security status of non-adopters household. Government assistance had positively and significantly influenced food security status of non-adopters household. That means if government assistance increases food security status of non-adopters household will increase. Government assistance had positive but insignificant influence on food security status of adopters household. The estimates of rho (p_1 and p_2) show that the coefficient of correlation between the random errors and the system of equations. The estimates of p_1 (= 0.171**) represent the estimated coefficient of correlation between the adoption equation and the food security equation of adopters, which was positive and significant. This implies that adoption and food security variable were positively correlated. The estimates of p_2 (= -0.028) represent the estimated coefficient of correlation between the adoption equation and the food security equation of non-adopters, which was negative. This implies that non-adoption and food security variable were negatively correlated. The wald test ensures the overall significance of all independent variables, except for those are constant. The likelihood ratio test (LR test), which was significant at 1% level, it is clearly indicates that the endogenous switching regression was a better fit for these data set.

3.4. Impact of BADC *Boro* Rice Seed Adoption on Food Security

The robustness of the estimated effect of BADC Boro rice seed adoption on food security was also examined using the propensity score matching (PSM) method because the results obtained from the endogenous switching regression model (ESRM) could be susceptible to instrumentation. The propensity scores have been originate from the outcomes of the probit estimation process, as presented in Table 5. The average treatment effect on the treated (ATT) of BADC *Boro* rice seed adoption on farm household food security was estimated using the propensity score matching (PSM) method. The results of the average treatment effect of adoption on food security have been shown in Table 6. The common support restriction was imposed to improve the quality of the matching in estimation of propensity score. The study employed three different estimation methods such as nearest neighbor matching (NN), kernel-based matching (KB) and radius or caliper matching (RM) to ensure robustness of the estimated treatment effects (Table 6). The results of the study indicated that an average treatment effect on the treated (ATT) ranging between 0.046 and 0.059. It is observed that the estimated ATT from NNM was lower than from the other two methods (KBM & RM). The adoption of BADC *Boro* rice seed significantly improved farm household food security, according to the results of the NNM, KBM and RM algorithms. To be more precise, the NNM, KBM and RM algorithms showed that the adoption of BADC *Boro* rice seed had boosted farm household food security by 4.60%, 5.80%, and 5.90%, respectively. Based on average treatment effect on the treated (ATT), it is concluded that adopters were more food secure than non-adopters. Hence, adoption of BADC *Boro* rice seed enabled adopters to enhance food security situation significantly. The results of the study provide sufficient indications that the estimates were fairly robust, thus reflecting the average treatment effect of BADC *Boro* rice seed adoption on farm household food security. Our empirical findings coincide with a study by Kabunga *et al.* [10] who found that tissue culture banana technology adoption had significantly increased farm household food security in Kenya.

Table 5. *Probit estimation results of BADC Boro rice seed adoption (PSM).*

Variables	Coefficient	Standard error	Z	P-value
Constant	0.989	0.412	2.400	0.016
Age	-0.015**	0.007	-2.142	0.032
Education	0.021**	0.010	2.100	0.035
Family size	0.009	0.032	0.281	0.778
Farm size	0.981***	0.165	5.945	0.000
Rice farm size	0.694***	0.134	5.179	0.000
Earning member	- 0.009	0.103	- 0.087	0.930
Member in farming	0.141	0.109	1.293	0.196
Farm income	0.0079*	0.004	1.975	0.048
Non-farm income	0.0038	0.0068	0.558	0.576
Amount of credit	0.0004	0.0015	0.266	0.790
Livestock ownership	0.039*	0.019	2.052	0.040
Government assistance	0.435**	0.215	2.023	0.043
Extension service	0.307**	0.123	2.495	0.012
Farm machinery	0.002	0.121	0.016	0.987
Market distance	0.004	0.031	0.129	0.897

Note: ***, ** and * indicates at 1%, 5% and 10% level, respectively.
Source: Authors' estimation, 2023.

Table 6. *Propensity score matching estimation.*

Matching method	Adopters	Non-adopters	ATT	S.E	t-value
Nearest neighbor matching Food security outcome	0.697	0.651	0.046	0.027	1.703*
Kernel-based matching Food security outcome	0.697	0.639	0.058	0.031	1.870*
Radius or caliper matching Food security outcome	0.698	0.639	0.059	0.028	2.107**

Note: ** and * indicates at 5% and 10% level, respectively.
Source: Authors' estimation, 2023.

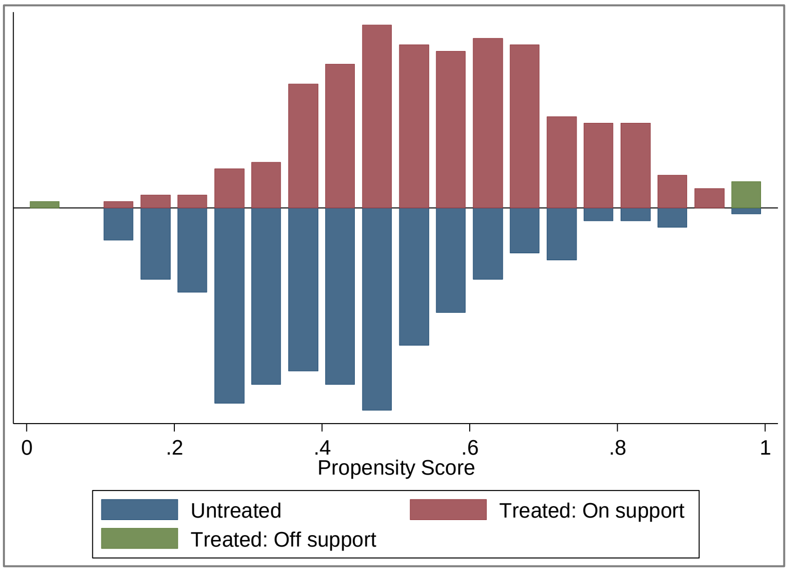

Figure 2. *Distribution of propensity score between adopters and non-adopters.*

3.5. Consideration of Multicollinearity and Endogeneity

At first, sixteen independent variables including age, education, farming experience, family size, farm size, rice area, earning members, members in farming, farm income, non-farm income, amount of credit, livestock ownership, government assistance, extension service, farm machinery and market distance were initially taken into consideration for the model. But, multicollinearity was existed between age and farming experience variable (r = 0.90). To remove multicollinearity, farming experience variable was eliminated from the model. The age variable was kept in the model since its Variance Inflation Factor (VIF) was lower than that of farming experience variable. To identify endogeneity problem from the model, the Wu-Hausman and Durbin test were conducted [16]. The findings showed that Wu-Hausman score was 0.779 (p=0.03779) and Durbin score was 0.791 (p=0.03738). The Wu-Hausman and Durbin score was significant which indicates that there was endogeneity problem existed in the model.

4. Conclusion and Recommendations

The study looked at the factors that influence the adoption of BADC *Boro* rice seed and its impact on farm household food security in Bangladesh. To achieve the goal of the study, 480 rice farmers were chosen at random from eight districts of Bangladesh. The results of the study revealed that the usage of BADC *Boro* rice seed had significantly and positively improved farm households' food security. The study found that adopters of BADC *Boro* rice seed had more likelihood of food security than the non-adopters. Therefore, the research recommends that suitable strategies should be implemented through BADC which will promote *Boro* rice seed production so that food security situation improve in Bangladesh. The study was not covered all the ecosystem of Bangladesh so future studies can be carried out to explore the adoption effects of BADC *Boro* rice seed on farm household food security covering all the ecosystem of Bangladesh.

Abbreviations

BADC: Bangladesh Agricultural Development Corporation
DAE: Department of Agricultural Extension
NGO: Non-Government Organization
MT: Metricton
Km: Kilometer
Tk: Taka
Kcal: Kilo calorie

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Conflicts of Interest

The authors declare no conflicts of interest.

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