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ADOPTION AND SUSTAINABILITY OF BINA RELEASED SALT-TOLERANT RICE VARIETIES: IMPACTS AND CHALLENGES

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ABSTRACT

A large portion of land in Bangladesh's coastal region is available for development purposes. As Bangladesh is highly dependent on rice as its main meal, rice production must be increased. The study was conducted in the coastal districts of Khulna, Satkhira, and Bagerhat, which are situated in Bangladesh's agroecological zone 13. To identify the time-variant adoption growth rate of BINA-developed salt-tolerant rice varieties Binadhan-8 and Binadhan-10, indicating the sustainability of the new varieties. Using primary data, the benefits of variety development and its sustainability in adoption were examined. A multi-stage sampling procedure was employed for the farm survey, involving 400 farmers who participated in the Binadhan-8 and Binadhan-10 variety extension program under the climate change adaptation program. The factors affecting the sustainability of adoption were identified using a simple time series econometric model. Results revealed that the adoption sustainability of two distinct salt-tolerant rice varieties, Binadhan-8 and Binadhan-10, was 23% and 38% per annum, respectively. These varieties may potentially maintain the highest yields, like the threshold before climate shocks appeared. Moreover, forecasting models of the adoption trajectory indicate continued and sustained growth in the uptake of these salt-tolerant varieties over time, reflecting their adaptability and relevance in the context of climate resilience.

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INTRODUCTION

Bangladesh is a deltaic country with an area of 147,570 km², which includes more than 30% of its net cultivable land. Approximately 20% of the total area is covered by the coastal region, which spans around 2.85 million hectares. Out of this area, about 0.83 million hectares of land can be utilised for crop production (SRDI, 2024). Agriculture plays a vital role in the economy. Besides providing food, agriculture offers raw material for industries and a source of livelihood. It contributes approximately 11.38% of our GDP (BBS, 2022), while also supplying a sufficient amount of rice for the population's consumption (Sarkar et al., 2024). Rice is a key crop in Bangladesh, as approximately 90% of the population relies on rice, and the average daily per capita rice consumption is 328.9g (HIES, 2022). This is possible due to our diverse land types and fertile soil. In Bangladesh, rice is grown throughout three distinct seasons, namely Boro, Aus, and Aman, which cover 74.85% of the total cultivable area (BBS, 2017).

In Bangladesh, an increasing level of salinity is creating hurdles in the production of crops, such as rice, which require more water to reach maturity. According to Rabbani et al. (2013), 53% of Bangladesh's coastal areas are affected by salinity, and the government is promoting local farmers to bring these areas under rice cultivation, in addition. 4,530 km^2 is affected by a higher level of salinity (more than 8 dS/m), which accounts for 43% of the total salt-affected areas. Out of 2.85 million hectares of the coastal and offshore area, 0.83 million hectares, which covered less than 30% of the total cultivable land of our country (Haque, 2006). Out of about 1.689 million hectares of coastal land, 1.056 million hectares are affected by various degrees of soil salinity. In 1973, the total salt-affected area was 833,000 hectares, which had drastically increased by 2009, when the saline-affected area reached 1,056,000 hectares and subsequently expanded to 1,252,000 hectares. The rate of increasing saline-affected area is alarming for Bangladesh, particularly for the agricultural sector (SRDI, 2021). In Bangladesh's coastal areas, where land holdings are few and dispersed, natural hazards, rising temperatures, erratic and unpredictable rainfall, shorter winters, rising sea levels, and rice monoculture are exacerbating salinity intrusion, making it a more serious threat to rice production (Mondal et al*.,* 2012).

The Bangladesh Institute of Nuclear Agriculture (BINA) has developed two salt-tolerant varieties, Binadhan-8 in 2010 and Binadhan-10 in 2012, to address the salinity problem in Bangladesh's coastal areas. The Government of Bangladesh has approved these varieties for cultivation in areas with saline soils. Since Binadhan-8 and 10 are salt-tolerant, high-yielding, photo-insensitive, and improved grain quality Boro rice varieties. It takes 130-135 days and 125-130 days to mature, respectively. It can be grown in both saline and non-saline areas of the country. It can tolerate 8-10 dS/m and 10-12 dS/m at the vegetative stage and 10-12 dS/m and 12-14 dS/m at the seedling stage, respectively. However, yield is higher in non-saline compared to saline zones. Sandy loam and clay loam soil is ideal for cultivating this variety.

Two-thirds of the time, flushing saline soil with non-saline water during land preparation will reduce salinity. When soil salinity is above 10 dS/m at the time of tillering, heading, and ripening, then the field must be flashed with non-saline water to reduce soil salinity. Water should be drained 10-12 days before the fruit is ripe. Salt-affected field, yield is 5.0-5.5 t/ha for Bina dhan-8 and 5.5-6.0 t/ha for Binadhan-10, and in a non-saline field, yield is 7.5-8.5 t/ha (BINA, 2025).

Previous studies in 2019, have found the highest coverage of salt-resistant rice varieties (Binadhan-8 and Binadhan-10) in Cox's Bazar district (3.7% of total cultivated land), followed by Chattogram (2.62%), Bagerhat (2.40%), Patuakhali (2.18%), and Khulna (1.53%). These studies also analyzed the income impact, showing the highest increase in Satkhira (27.1%) and the lowest In Patuakhali (12.91%). These also outlined the farming technologies used and profitability assessments (Haque et al., 2019). As it has already been over thirteen years, the adoption and sustainability of those varieties have not been assessed. In this study, researchers aim to investigate the diffusion, suitability, and factors associated with the adoption of these two varieties. Everyone will benefit from the study's findings, which highlight the factors that have the most significant influence on the adoption of new varieties.

METHODOLOGY

Study area

The study areas were the Khulna, Satkhira, and Bagerhat districts of the coastal region, which belong to agro-ecological zone 13. The regional attributes are mainly tidal floodplain agricultural land. The topographical ecology of the river is linked with the seacoast and tides, which come through canals twice a day from the Bay of Bengal. From the three districts, four upazila (sub-districts) were purposively selected for the study. The selection of locations was 82ationalized based on the extent of climate variability. In response to climate change, farm households located near the BINA (Bangladesh Institute of Nuclear Agriculture) extension canopy have adopted salt-tolerant rice varieties as an alternative adaptation strategy.

Sampling distribution

This study purposively selected areas in the coastal region affected by salinity. The multistage sampling technique was used to choose the respondent households. At the first stage, Binadhan-8 and Binadhan-10, growing in 4 upazilas, were randomly selected from 3 districts. Then, from each selected upazila, 4 villages were chosen purposively. From each sampled village, a list of BINA extension beneficiaries and lists of Binadhan-8 and Binadhan-10 growers were compiled by the Bangladesh Institute of Nuclear Agriculture (BINA). From the list, 25 farmers of each village were randomly selected. Finally, 400 farmers were selected from the 16 villages using a semi-structured interview schedule designed to ensure comprehensive data collection. The interview schedule included various types of questions, like binary and Likert scale items: binary questions were used for capturing adaptation decisions, while Likert scale items were employed to assess farmers' perceptions. The questionnaire was developed based on an extensive review of the literature and expert reviews.

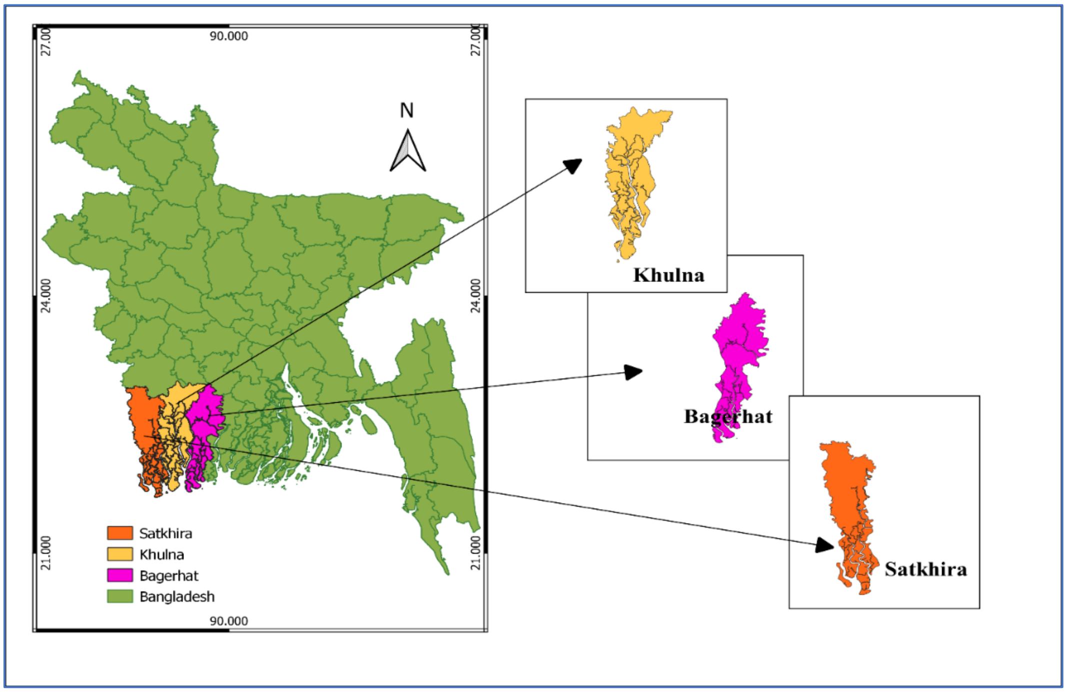

Figure 1. Geographical area of the study.

Analytical methods

The body of adoption and diffusion literature has steadily increased since the first articles by Ryan and Gross (1943) and subsequent articles by Griliches (1960). Reviews on the topic are given by Rogers (1995), and Zilberman (1984). The existing state-of-the-art for analyzing innovation adoption focuses on the following areas. There are two main areas of research in the literature on adoption and diffusion: one involves tracing the diffusion path of various innovations, and the other consists of identifying the determinants of adoption and the characteristics of adopters and non-adopters. The most commonly used method for tracing the diffusion path is by estimating a logistic function that produces the S-shaped adoption pattern (Geroski, 2000).

In this study, statistical inference was used to identify the time-variant adoption growth rates of BINA-released salt-tolerant rice varieties Binadhan-8 and Binadhan-10, which indicate the sustainability of the new varieties. The time series econometric model was then extended to incorporate the dynamics of adoption diffusion by identifying the determinants. This part of the study presents a time series quantitative econometric model for analyzing factors that affect the sustainability of adoption.

Sustainability analysis of the adoption

The study used Traxler and Byerlee's analysis technique, which was developed in 1993. The method was used in a retrospective questioning of a representative sample of farmers. In the retrospective questioning, two key aspects are inquired about: the year the farmer began farming and the year they started using the innovation interventions. The present study used a survey technique and official time series data on adoption. Total 400 farms were surveyed in 2019-2020, and retrospective information for Binadhan-8 and Binadhan-10 was collected in 2010 and 2012, respectively, to consider innovation and field-level extension information by year.

Tools of adoption measurement

The year-specific cumulative adoption was calculated by using the formula as follows:

$$Zt = \frac{Y_t}{Z_{t-i}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where Zt = cumulative adoption at time t, and Yt = adoption at time t. The present study used retrospective sampling from 2011 to 2022 for Binadhan-8 and from 2012 to 2021 for Binadhan-10 (Byerlee and Polanco, 1986).

The value of K is assumed to be 100, as it is believed that 100% of farmers would eventually adopt the innovation. This estimated adoption curve would represent the sustainability of a technology innovation at the farm level.

$$\ln\left|\frac{Z_t}{K - Z_t}\right| = c + \phi t + \mu_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where Ln = natural log, Zt = Cumulative adoption, K = adoption ceiling (maximum attainable adoption rate), t = time, i = constant, = coefficient to be estimated and μt = disturbance terms or error.

Dynamics of variety adoption, sustainability path analysis

In most cases, adoption sustainability path analysis helps develop technology transfer systems. It is almost a synonym for adoption diffusion path analysis, developed by Jarvis (1999), which used the cumulative net hectares of improved variety adopted as a dependent variable, regressed on time t and the price of output. The present study used two more explanatory variables: production cost and yield. Two empirical models were developed and fit according to variety. Farmers are more likely to adopt a variety based on profits that increase overall enterprise profits. These models were provided a way to obtain an empirical estimate of the benefits from variety development research and relate these benefits to the research and extension costs of developing and disseminating management information.

The analysis of sustainability paths can also benefit from the use of non-linear forms of regression analysis.

$$Ln(Z_t/(K-Z_t) = c+\phi_t+\phi_1 P_t+\phi_2 I_t+\phi_3 \gamma_{t+}\mu_t \ldots\ldots\ldots\ldots (3)$$

Ethical consideration

Before initiating the study, all participants were fully informed of its objectives, protocols, and benefits. They were also assured that only the research team would have access to the information and that electronically stored information would be protected with adequate security controls. They were allowed to ask questions and provided their informed consent to participate in the research willingly. Respondents can decline or withdraw at any time during the interview. When a respondent refused to be interviewed, an attempt was made to interview another head of the farm household.

RESULTS

Adoption sustainability of Binadhan-8

Through retrospective sampling in 2021, the study determined the adoption rates of Binadhan-8 (Yt) from 2011 to 2022, which are presented in Table 1. The study estimated the adoption curve using OLS, as per equation 1, with K = 100, assuming that 100% of the farmers would eventually adopt the Binadhan-8 for adapting to the effects of climate change due to salinity.

Regression was run after transforming the dependent variable (Table 1). Use OLS to estimate the transformed variable as a function of time t. for the years 2012 to 2022. The OLS estimate indicates that the adoption rate of Binadhan-8 in selected sample areas of Bangladesh has increased during the period from 2011 to 2022. The yearly growth rate of adoption for this variety was estimated at 23%, assuming other factors remained constant. The study also traces the diffusion path for the year 2030 through forecasting. It would be the last period of the SDG, predicting the adoption value and measuring the diffusion path that Bangladesh will implement. As shown in Figure 2, almost all forecasting values of Binadhan-8 adoption rate sustainably increase for selected farms where the BINA disseminated the variety. The new variety, Binadhan-8, will develop an S-shaped diffusion path over time. The percentage of farms delaying the adoption of Binadhan-8 over time was determined using least squares regression, which suggested the long-term viability of this salt-tolerant rice cultivar. According to the predicted results, adoption rates are higher for this type when there are more previous adopters, a higher relative yield, and lower initial investments.

Adoption sustainability of Binadhan-10

Using the same method as in the previous section, the study's retrospective observation of 2022 revealed the adoption rates of Binadhan-10 (Y_t) from 2012 to 2022 (Table 2). The study estimated the adoption curve using OLS, assuming a ceiling value of K = 100. The value of K = 100% means that farmers would eventually adopt the Binadhan-10. Because the ceiling value could be a function of several parameters (Mahajan and Petersonm, 1978). The regression was fitted and estimated after transforming the dependent variable, which appears in

Table 2. Use OLS to estimate the transformed variable as a function of time t. for the years 2012 to 2022. The yearly growth in the adoption of this variety was estimated at 38%, assuming other factors remained constant.

Table 1. Diffusion rate of salt-tolerant rice variety Binadhan-8 over time.

Year	Diffusion rate of BINA released salt-tolerant rice variety hectare (Z_t)	Transformed variable ln (Z_t/(100-Z_t))
	Binadhan-8	Binadhan-8
2011	7	-1.427
2012	7	-1.427
2013	14	-2.347
2014	23	-2.649
2015	31	-2.851
2016	40	-3.046
2017	49	-3.209
2018	58	-3.457
2019	68	-3.695
2020	78	-3.883
2021	88	-4.240
2022	100	-4.681

Source: Own estimation based on study data

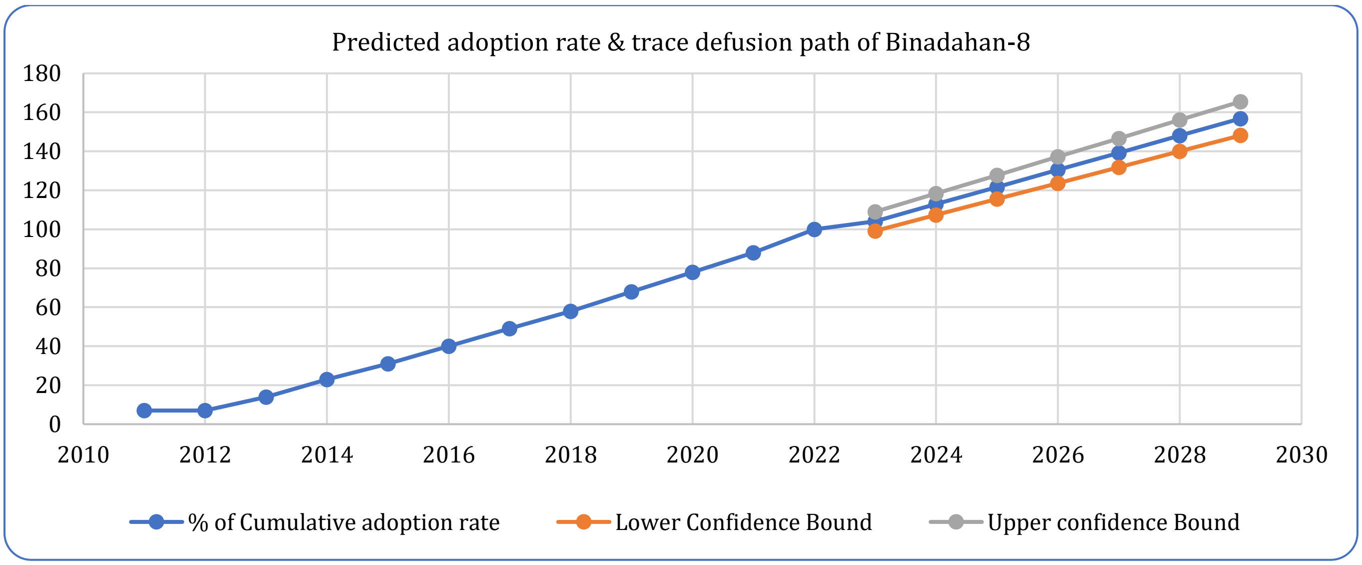

Figure 2. Predicted adoption value and trace diffusion path of Binadhan-8.

Dynamics adoption sustainability path of the selected BINA release salt-tolerant rice variety

The study also examined the sustainability of innovation using dynamic diffusion path analysis. The innovation path analysis estimates the logistic curve with explanatory variables in addition to time. The life cycle of new species is thought to be influenced by many performance traits. To start with, yield is typically the most crucial factor influencing a producer's selection of rice varieties (McClung, 2004). Per-acre high yields offer producers the potential to generate greater revenue. As revenue is equal to *price* x *production*, and production is equal to *yield* x *acres* planted, yield becomes a proxy for revenue. It can represent some of the economic reasoning within the industry. Additionally, yield serves as a proxy for other factors, including pest resistance and stress tolerance resulting from climate change.The plants are less stressed and may produce more since the climate change stress tolerance variety can withstand increased salt salinity. The yield ratio (YR) is expected to have a positive influence on the proportion of total acreage allocated to each variety.

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Table 2. Diffusion rate of salt-tolerant rice variety Binadhan-10 over time.

Year	Diffusion rate of BINA released salt-tolerant rice variety hectare (Z_t)	Transformed variable ln ($Z_t/(100-Z_t)$)
	Binadhan-10	Binadhan-10
2012	5	-4.820
2013	8	-6.724
2014	10	-6.500
2015	20	-6.318
2016	30	-6.117
2017	40	-5.988
2018	50	-5.651
2019	125	-5.492
2020	140	-5.293
2021	200	-4.820
2022	250	-4.410

Source: Own estimation based on study data

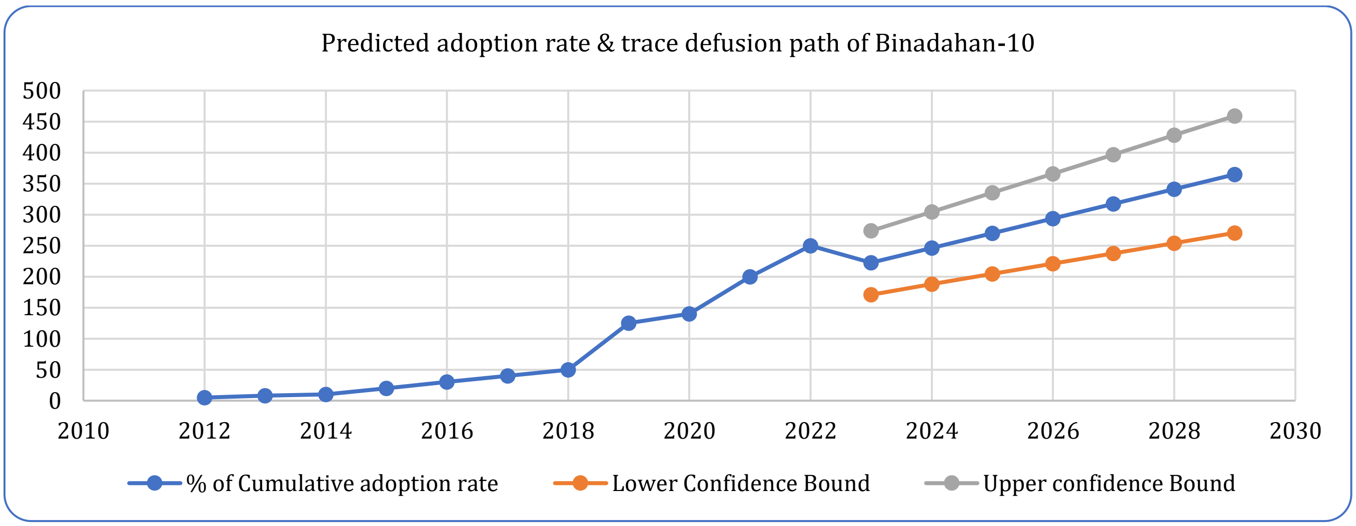

Figure 3. Predicted adoption value and trace diffusion path of Binadhan-10.

Milling yield (rice after husking) is one of those traits that is anticipated to affect cumulative variety adoption, despite being significantly correlated with the variety's overall yield. Farmers obtain better grades for whole, or unbroken, rice kernels when it is brought to the mill. All types of rice may have the same minimum price, but those with a larger proportion of whole kernels can be sold at a higher price. Despite that, most producers pay more attention to quantity than to quality. If the variety planted yields more, producers can often compensate for lower quality. Therefore, yield would be expected to have a greater effect than milling yield. However, there should be a positive correlation between the proportion of acres planted and the milling yield ratio (MYR). The price represents this milling rate.

Furthermore, the industry considers the number of days before the rice plant reaches maturity to be a significant factor. Harvesting a second crop in the same season is possible with varieties that mature early. Furthermore, if a variety reaches maturity early, the crop will have less time to be negatively impacted by calamities such as hurricanes, disease outbreaks, and pest attacks. On the other hand, the plant needs sufficient time to mature and reach its full yield potential. There may be a lower risk to the main crop with varieties that mature relatively early. At experiment sites, the number of days to heading is typically the selected metric for indicating the earliness of maturity due to its simplicity of measurement. For this research, the maturity time was measured in days to head, or when the panicle emerged for pollination, for the varieties. As fewer days to maturity are preferable, the maturity ratio (MR) must bear an inverse relationship to the percentage of acres planted. In the study, production cost was a proxy for maturity ratio.

Table 3. Variety profile/ attributes of Binadhan-8 and Bindhan-10.

Variety Name	Characteristic
Binadhan-8	In 2010, the high-yielding, salt-tolerant rice variety Binadhan-8 was introduced for the boro season. It can withstand electrical conductivity (EC) levels of 8–10 dS/m. It is a medium to bold grain rice cultivar that matures early. The cultivar has upright, deep-green flag leaves. It has a modest resistance to stem borer, brown plant hopper, sheath blight, and bacterial leaf blight. The maximum grain production under salt stress is 5 to 5.5 tons per hectare.
Binadhan-10	Binadhan-10, a cultivar with better resistance to salt, was introduced in 2012 for the boro season. It can withstand 10–12 dS/m of EC. The cultivar can produce higher seed yields. The maximal grain yield under salt stress is 5–6 tons per hectare, with maturation taking 127–132 days. The variety's flag leaves are deep green and upright, and its durable trunks and stems hold up well even during harsh weather without breaking. Attacks by pests and diseases are sporadic.

Finally, it is reasonable to expect that adopting could be affected by a variety's yield stability. If the per-acre yield is volatile from year to year, the farm will find the variety too risky. The standard deviation of the yield per acre for each variety in different places along the coast of Bangladesh. The data were taken to be a good approximation of the relative stability of each variety. A smaller standard deviation reflects a variety with more consistent yields. So, the stability ratio and percentage of planted acres should be negatively correlated. While it would make sense to include yield stability in the study, one must note that our currently available producer data set is not detailed enough for us to calculate this variable.

The yields of the research's producers are not site-specific, but rather for the whole region. The study uses equation 3 for estimating the model. The cumulative number of farms that adopt the variety (Jarvis, 1999). The details of the estimates of the models described in Table 4.

Table 4. Factors affecting the adoption and sustainability of Binadhan-8 and Binadhan-10.

Varieties	Constant (C)	Co-efficient (ϕ) time	Co-efficient (ϕ1) price	Co-efficient (ϕ2) of the cost of production	Co-efficient (ϕ3) Yield
Binadhan-8	-8.67***	0.22***	0.08*	-0.03	0.11
Binadhan-10	-8.67***	0.24***	0.08*	-0.05	0.14

The estimate suggests that the farmer would respond more to the adoption of a variety that yields a profit, which is approximated by the product's price and the cost of production. Thus, an upward trend in output prices has a positive effect on the adoption of this variety. The inclusion of product price, production cost, and yield improves the regression results. The estimated time coefficient of the dynamic adoption model for Binadhan-8 implied that the yearly adoption diffusion was 22%. The Binadhan-8 price also contributes to 6 % adoption diffusion. While the estimated time coefficient of the dynamic adoption model for Binadhan-10 implied that this variety’s yearly adoption diffusion was 24%. The Binadhan-10 price also significantly contributes to 8% adoption diffusion or annual growth. The milling ratio is approximated by the production cost coefficient, which follows the Theory of adoption; however, both Binadhan-8 and Binadhan-10 were found to be insignificant. The contribution of yield was found to be positive but insignificant in the analysis.

The coastal regions of Bangladesh rely heavily on the rice industry for their economic sustainability. Over the last 15 years, there has been a notable decline in the amount of land used for rice cultivation. For the sectors affected by climate change to survive, performance-enhanced salt-tolerant rice cultivars that maintain threshold yields must be developed. The present study has made significant contributions to identifying the sustainability of salt-tolerant rice variety adoption through the creation of a model that predicts the

Binadhan-8 and Binadhan-10. The study first focused on using a logistic function to estimate the growth rate, or diffusion, of the two varieties. Then a dynamic adoption model was fitted to analyse some of the factors that are commonly viewed as determinants of cumulative adoption.

DISCUSSION

Agronomic characteristics (such as yield and salt tolerance), post-harvest characteristics (including milling rate and profitability), and institutional elements (particularly peer influence and extension services) all contribute to the sustainability of adoption. Both Binadhan-10 and Binadhan-8 reached full adoption in the sampled locations, with Binadhan-10 exhibiting the highest yearly adoption growth rate (38%) and Binadhan-8 coming in second (23%). Moreover, adoption projections indicate that the spread will continue until 2030. Economic factors, particularly cumulative exposure and output price, were crucial in promoting adoption, whereas yield and cost had predicted but statistically negligible effects.

Agronomic and economic drivers of sustained adoption

The findings demonstrate that while choosing long-term adoption, farmers take into account a variety of characteristics in addition to output. Varietal preferences are significantly influenced by factors such as milling rate, profitability, and salt tolerance. Rice farmers in the Philippines prefer cultivars with high milling recovery and pest resistance, highlighting the importance of resilience and processing quality (Laborte et al., 2015). Ghanaian cassava farmers prioritise stability and lower risk over high yields, giving priority to disease resistance and the length of in-soil storage (Acheampong et al., 2013). The idea that trait stacking improves adoption sustainability was validated by Binadhan-10's rapid spread, which was aided by its increased yield potential (5–6 t/ha) and good salt tolerance (EC 10–12 dS/m).

Role of extension and peer diffusion

During the early dispersion phase, institutional dissemination primarily through BINA's extension activities was essential. However, the econometric model's time coefficient also indicated that as adoption increases, horizontal diffusion, or peer-to-peer learning, becomes increasingly prevalent. Rogers' theory, which posits that relative advantage and ease of experimentation are important adoption factors, is further supported by the strong trialability and observability of Binadhan-10 and Binadhan-17, which allow farmers to observe and evaluate results on neighbouring plots. Programs for agricultural extension can help farmers access markets and obtain the necessary information, thereby increasing adoption rates (Bonjean, 2017).

Profitability, costs, and perceptions

The favourable and significant impact of the output price on adoption highlights the relevance of market incentives in maintaining the use of varietals. For example, Binadhan-10 saw an 8% increase in adoption for every unit price increase, demonstrating that farmers' expectations of profit play a crucial role in their decision-making. Although yield had a favourable but statistically negligible effect, this could be due to constraints in location-specific yield variability or comparatively consistent yield performance across varieties under saline circumstances. Increased adoption rates are directly correlated with higher output prices (Miller and Tolley, 1989).

Implications for breeding and policy

Due to its high tolerance, Binadhan-10 appears to be more suitable for high-salinity zones, whereas Binadhan-8 would be more suitable for moderately saline areas where shorter-duration cropping is preferred. The adoption process can be further accelerated by policy initiatives including input subsidies, output price stabilisation, and the development of regional seed systems (Ladeiro, 2012).

CONCLUSION

The static growth rate of both varieties followed the theory of sustainable variety adoption. Based on its yield performance and ability to withstand saline stress, it would be equivalent to other types available on the market. The yield then rose and became a more favourable variety in areas affected by climate change. By maintaining yields at or above the threshold before climate shocks emerged, these varieties would offer the opportunity for numerous changes in the rice industry. The study would provide a guideline for understanding the potential impacts on the adoption and diffusion of variety.

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