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Determinants of the Adoption of Climate-Smart Agricultural Technologies in Tala Upazila, Bangladesh

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***Abstract* - Climate-resilient agri-farming practices are essential for achieving sustainable agriculture in response to climate change in Bangladesh. Accordingly, this study aims to examine the factors influencing the adoption of climate-smart agriculture (CSA) practices among paddy farmers in Tala Upazila, Satkhira, Bangladesh. Using a structured questionnaire and a convenience sampling method, data were collected from 120 paddy farmers. A binary logistic regression model was employed to estimate the factors influencing CSA adoption. The results of the regression analysis indicate that farmers' age, off-farm income, farm size, access to extension services, and financial inclusion significantly affect decisions to adopt CSA technologies. Specifically, younger farmers, those with secondary income sources, those with access to agricultural extension services, and farmers with larger landholdings are more likely to adopt CSA practices. Conversely, financial inclusion appears to reduce the likelihood of adopting CSA technologies. The study suggests that promoting economic diversification through supplementary income sources, enhancing agricultural extension support for smallholder farmers, and providing targeted training programs are critical for encouraging CSA adoption. Additionally, targeted policies for older farmers, financial incentives, and improved rural infrastructure can further support CSA uptake in Bangladesh.**
Keywords: Climate-Smart Agriculture (CSA), Technology Adoption, Paddy Farmers, Extension Services, Bangladesh

I. INTRODUCTION

Sustainable food consumption and production under the United Nations' Sustainable Development Goals (SDG 12) have been termed pressing global issues, as one-third of the world's population suffers from severe hunger. This presents significant challenges for ensuring food security in the future. The situation is worsening at a time when the world is also confronting the issue of climate change, which severely impacts the agricultural sector and food security in developing countries (Sanogo *et al.,* 2023). Developing countries are often characterized by rapid population growth, reliance on rainfed agriculture, and exposure to recurrent droughts and heavy rainfall (Kifle *et al.,* 2022; Ayal, 2021).
To meet growing food demands while mitigating the negative effects of climate change, agricultural production practices require urgent transformation (Ngoma *et al.,* 2019). Climate-smart agriculture (CSA) practices offer a long-term solution by addressing the impacts of climate change on agriculture and enhancing agricultural sustainability (Li *et al.,* 2024). CSA simultaneously addresses climate change adaptation and mitigation while promoting food security (Sanogo *et al.,* 2023; Kifle *et al.,* 2022). It is a productive approach to transforming and revitalizing agricultural systems. CSA enhances productivity in a sustainable manner and increases adaptive capacity, thereby improving farmers' resilience to climate-related challenges-an essential component of rural development. Therefore, it is crucial to promote the use of climate-smart agricultural technologies to reduce the effects of climate change and increase crop production (Li *et al.,* 2022).

Bangladesh is one of the most climate-vulnerable countries in the world (Majumder *et al.,* 2024; Mahasin & Roy, 2017). As an agrarian country, approximately 75% of its population lives in rural areas and largely depends on agriculture for their livelihoods (Ali & Hossain, 2019). However, the country's agriculture-particularly crop farming-is significantly affected by climate change. Bangladesh faces recurring natural disasters, including floods, cyclones, erratic rainfall, salinity intrusion, extreme temperatures, river erosion, and droughts. In this context, ensuring sustainability in the agricultural sector and achieving food security are critical concerns (Majumder *et al.,* 2024).

As such, adaptation measures are essential to mitigate the impacts of climate change on agriculture (Saha *et al.,* 2019). Compared to traditional farming, CSA practices offer a promising approach to tackling climate-related issues in agriculture. The adoption of CSA practices not only promotes sustainable farming but also contributes to poverty reduction (Mahasin & Roy, 2017). Against this backdrop, identifying the factors that influence the adoption of CSA practices in Bangladesh is essential. Farmers' adoption of CSA practices depends on a range of factors.

These include demographic, socioeconomic, and environmental variables such as age, gender, family size, access to weather information, land ownership, livestock holdings, perception of climate change, soil fertility, and soil erosion (Belay *et al.,* 2023; Musafiri *et al.,* 2022; Ojoko *et al.,* 2017). Other influencing factors include crop yield, farm size, household income, and food insecurity (Msweli *et al.,* 2024). Sisay *et al.,* (2023) found that older age, higher income, better access to credit, climate information, training programs, larger farm sizes, better educational opportunities, and interactions with credit specialists are significantly and positively associated with CSA adoption.

Several studies also report that farming experience, education level, farm income, communication with agricultural extension agents, affiliation with agricultural associations, and climate change perception are positively correlated with CSA adoption (Negera *et al.,* 2022; Waaswa *et al.,* 2024; Abegunde *et al.,* 2019). Diro *et al.,* (2022) found that access to extension services and ownership of communication devices significantly determine CSA adoption. Similarly, Tran *et al.,* (2020) revealed that factors such as the nature of the farm, market distance, access to climate information, social group membership, and risk attitude influence CSA adoption. Therefore, CSA adoption is determined by a combination of social, economic, environmental, institutional, and cultural factors (Anuga *et al.,* 2019).

In the context of Bangladesh, several studies have identified key factors influencing CSA adoption, including crop income, crop vulnerability, input management training, extension services, household size, farming experience, irrigation infrastructure, embankment quality, occupation, education, livestock ownership, climate change perception, and organizational affiliation (Majumder *et al.,* 2024; Islam & Farjana, 2024; Kundu *et al.,* 2024; Biswas *et al.,* 2024; Saha *et al.,* 2019). However, empirical research specifically focused on the determinants of CSA adoption among rice farmers in coastal regions of Bangladesh remains limited. Therefore, this study aims to assess the factors influencing the adoption of CSA practices among paddy farmers in the Satkhira district.

II. MATERIALS AND METHODS

A. Study Area and Data

The study area is Tala Upazila in the Satkhira district. This region was selected due to its particular significance in rice cultivation and its high vulnerability to climate change, including salinity intrusion, recurrent flooding, and frequent cyclones. The environmental challenges unique to Tala Upazila provide a critical context for investigating the factors influencing the adoption of climate-smart agriculture (CSA) technology practices. The adoption of CSA practices in paddy farming in this area could significantly enhance food security, improve livelihoods, and serve as a model for other regions facing climate-induced challenges.

Within this Upazila, two unions-Jalalpur and Khalilnagar-were selected to examine the factors influencing CSA adoption. Two villages from each union were chosen for the farmer survey. Specifically, the study purposively selected four villages: Ataroi and Ziala from Jalalpur Union, and Harish Chandra Kathi and Mohandi from Khalilnagar Union, for the collection of primary data. Using a structured questionnaire and a convenience sampling method, the study surveyed 120 paddy farmers from the four villages.

Table I presents descriptions of the variables used in the study. The study considers nine CSA technology practices: conservation tillage, mulching, crop diversification, crop rotation, integrated pest management, improved seed varieties, crop calendar, irrigation, and organic fertilizer. A farmer is considered a CSA adopter if they have adopted six or more of these nine practices (Wang *et al.,* 2016).

TABLE I DEFINITION OF SELECTED VARIABLES

Variable	Description	Types
CSA adoption	=1 if adopted CSA, 0 otherwise	Dummy
Age	Age of the farmer in years	Continuous
Household size	Number of family members	Continuous
Education	Schooling year	Continuous
Off-farm income	=1 if has access to off-farm income, 0 otherwise	Dummy
Farm size	Amount of land in bigha	Continuous
Access to training	=1 if has access to agricultural training, 0 otherwise	Dummy
Access to extension service	=1 if has access to agricultural extension services, 0 otherwise	Dummy
Financial inclusion	=1 if has access to bank account, 0 otherwise	Dummy

B. Econometric model

This study employed a logistic regression model to estimate the probability of adopting climate-smart agriculture (CSA) practices based on selected variables. The dependent variable is defined as y, where y = 1 or y = 0, with 1 indicating a positive outcome with probability Pr, and 0 indicating a negative outcome with probability $(1 - Pr)$. The odds of observing a positive outcome are then expressed as:

$$\Omega = \frac{P_r\,(y=1)}{P_r(y=0)} = \frac{P_r\,(y=1)}{1-P_r(y=1)} \tag{1}$$

The logarithm of the odds ratio, known as the logit, is a function of the independent variables. Equation (2) presents the logit model:

$$l_n\left[\frac{P_r(y=1|x)}{1-P_r(y=1|x)}\right] = l_n\,\Omega(x) = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_8X_8 \quad (2)$$

Here, X_1 = age, X_2 = household size, X_3 = education, X_4 = off-farm income, X_5 = farm size, X_6 = training, X_7 = extension service, and X_8 = financial inclusion. These independent variables may influence a farmer's adoption decisions regarding climate-smart agriculture (CSA) technology practices. By analyzing the coefficients (β) from the logit model, we can assess the direction and magnitude of the relationship between each variable and the likelihood of CSA adoption. However, to quantify the impact of the independent variables on the probability of CSA adoption, the model requires the calculation of the marginal effect (ME), which is as follows:

$$\text{ME} = \frac{\partial P_r(y=1|x)}{\partial x_k} \quad (3)$$

The marginal effect measures the change in the probability of an outcome resulting from a one-unit change in an independent variable, holding all other variables constant. Marginal effects offer a clear indication of how changes in these variables influence adoption rates. They are particularly useful for prioritizing factors based on their relative importance, helping to identify which variables have the most significant influence on paddy farmers' decisions to adopt climate-smart agriculture (CSA) technology practices.

III. RESULTS

A. Descriptive Statistics

Table II presents the descriptive statistics of the paddy farmers. The mean age of the farmers is approximately 48 years, ranging from 30 to 65 years, indicating that a predominantly middle-aged population is engaged in agricultural activities. The average household size is seven members, varying from four to fifteen, which reflects typical rural family structures where larger households may influence labor availability. The average monthly household income is 43,550 BDT, with a range from 20,000 to 75,000 BDT, revealing economic disparities that may affect access to agricultural resources and technologies.

Farmers have an average of 8.5 years of education, with educational attainment ranging from 3 to 16 years, suggesting diverse levels of literacy and exposure to modern agricultural practices. Farm sizes vary significantly, with an average of 6.81 bighas and a range from small-scale farms of 1 bigha to larger holdings of 35 bighas, which may influence resource utilization and the adoption of climate-smart practices.

Regarding additional livelihood sources, 50.83% of farmers have non-farm income, indicating efforts to diversify household income, while 49.17% rely solely on farming. Access to financial inclusion is limited, with only 14.17% of farmers having access to a bank account, potentially constraining investments in innovative farming techniques. Similarly, only 29.17% of farmers receive agricultural extension services, highlighting gaps in institutional and government support. Training participation is also low, with just 33.33% of respondents having received any form of training, which may hinder their ability to adopt new technologies.

The adoption rate of climate-smart agriculture (CSA) technology practices is 42.50%, indicating that the majority (57.50%) of farmers have not yet implemented these practices. These findings underscore the need for targeted interventions to address financial, educational, and institutional barriers in order to enhance CSA adoption and promote agricultural sustainability in Tala Upazila.

TABLE II DESCRIPTIVE STATISTICS OF THE SELECTED VARIABLES

Continuous Variables	**Mean**	**Std. Dev.**	**Min**	**Max**
Age (Years)	47.925	7.401	30	65
Household size (Number)	6.575	2.499	4	15
HH income (BDT)	43550	14374.26	20000	75000
Education (Years)	8.5	3.114	3	16
Farm size (Bigha)	6.808	5.709	1	35
Dummy Variable	**Frequency**		**Percentage (%)**	
	No	**Yes**	**No**	**Yes**
Off-farm income	59	61	49.17	50.83
Financial inclusion	103	17	85.83	14.17
Access to extension services	85	35	70.83	29.17
Access to training	80	40	66.67	33.33
CSA Adoption	69	51	57.50	42.50

B. Result of the Logit Model

Table III presents the results of the logit model. The farmer's age has a statistically significant negative effect on CSA adoption at the 1% significance level. The coefficient indicates that each additional year of age decreases the log-odds of adopting CSA by 0.123. The marginal effect shows that an additional year of age reduces the probability of CSA adoption by 2.87%, holding other factors constant. This suggests that younger farmers are more likely to adopt CSA technologies.

Having off-farm income-defined as participation in a subsidiary occupation-significantly increases the likelihood of adopting CSA practices at the 1% significance level. The positive coefficient indicates that farmers with off-farm income are more likely to adopt CSA technologies. The marginal effect reveals that having off-farm income increases the probability of CSA adoption by 5.8%, highlighting the role of economic diversification in facilitating technology adoption.

Farm size also has a positive and statistically significant effect on CSA adoption at the 5% level. The coefficient suggests that a one-unit increase in farm size raises the log-odds of CSA adoption by 0.221. The marginal effect indicates that each additional unit of farm size increases the probability of CSA adoption by 5.2%, implying that larger farms may possess more resources to invest in climate-smart practices.

Access to extension services positively influences CSA adoption at the 1% significance level. The marginal effect shows that farmers with access to extension services are 4.6% more likely to adopt CSA practices than those without such access. In contrast, financial inclusion negatively affects CSA adoption at the 1% significance level. The marginal effect indicates that farmers with access to financial services are 5.7% less likely to adopt CSA practices compared to those without such access. This counterintuitive finding may reflect limitations in how financial services are utilized or accessed in the study area. The overall model fit is strong, as indicated by a highly significant likelihood ratio chi-square statistic ($\chi^2 = 59.09$, $p < .01$), confirming that the independent variables collectively explain a significant portion of the variation in CSA adoption. The pseudo-R-squared value of 0.361 suggests that the model explains approximately 36.10% of the variability in CSA adoption, indicating a reasonable fit for cross-sectional data.

TABLE III DETERMINANTS OF CSA ADOPTION

Variables	Coefficient Estimate		Marginal Effects	
	Coef.	Std Error	Coef.	Std Error
Age	-0.123***	0.0377	-0.0289***	0.00869
Household size	0.0735	0.171	0.0173	0.0403
Education	0.00350	0.0990	0.000823	0.0233
Off-farm income	2.473***	0.866	0.581***	0.201
Farm size	0.221**	0.0917	0.0520**	0.0214
Access to training	-0.0155	0.657	-0.00365	0.154
Access to extension service	1.957***	0.727	0.460***	0.172
Financial inclusion	-2.436***	0.892	-0.573***	0.206
Constant	3.127	1.999	0	0
Observations	120	0	0	0
Log-likelihood	-52.278	0	0	0
LR chi^2	59.09	0	0	0
Prob > chi^2	0.000	0	0	0
Pseudo R^2	0.361	0	0	0

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

IV. DISCUSSION

Key determinants of CSA adoption include age, off-farm income (or subsidiary occupation), farm size, access to extension services, and financial inclusion. Younger farmers, those with secondary income sources, larger farms, access to extension services, and those with limited financial inclusion tend to adopt CSA technologies more frequently. The negative and significant effect of age indicates that as age increases, the likelihood of adopting CSA technologies decreases. This suggests that older farmers may prefer to continue using familiar farming methods. Such resistance may stem from various factors, including a stronger reliance on traditional practices, limited awareness of the benefits of CSA, or a reduced willingness or capacity to invest in new technologies. Additionally, older farmers may be more risk-averse, particularly when it comes to unfamiliar agricultural innovations, making them less likely to adopt such practices. The significant influence of age on CSA adoption has also been noted by Sanogo *et al.,* (2023), although the direction of the effect varied by practice. Similar findings were reported by Li *et al.,* (2024), Tran *et al.,* (2020), Ma and Rahut (2024), and Tadesse and Ahmed (2023). Having off-farm income significantly increases the likelihood of CSA adoption. Farmers with secondary income sources-such as small businesses or non-farm employment-may have greater economic stability, enabling them to invest in new agricultural technologies. This additional income provides a financial safety net, reducing the perceived risk associated with adopting new or unfamiliar practices. Such farmers may also view CSA technologies as a means to diversify operations or improve productivity, supported by the security of an alternative income stream. Studies by Li *et al.,* (2024), Ma and Rahut (2024), and Tadesse and Ahmed (2023) have similarly identified off-farm income as a significant factor influencing CSA adoption. Farm size also plays an important role in CSA adoption, with larger farms more likely to implement CSA technologies. This is likely due to the greater availability of resources on larger farms, including labor, equipment, and capital. Larger farms are better positioned to absorb the initial costs of adoption, such as purchasing advanced equipment or investing in farmer training.

Moreover, with more land to manage, these farmers may be more inclined to adopt CSA practices that promote long-term sustainability, improved resource efficiency, and better climate resilience. This finding is consistent with research by Kassa and Abdi (2022), Kifle *et al.,* (2022), Li *et al.,* (2024), Ma and Rahut (2024), Sardar *et al.,* (2021), Sisay *et al.,* (2023), and Tadesse and Ahmed (2023). Access to extension services also enhances the likelihood of CSA adoption. Extension services provide farmers with knowledge, information, and technical assistance that improve agricultural practices. Farmers with access to such services are more likely to be informed, empowered, and open to adopting new technologies. This result aligns with the findings of Kifle *et al.,* (2022), Li *et al.,* (2024), Ma and Rahut (2024), Mbanasor *et al.,* (2024), Sisay *et al.,* (2023), and Tadesse and Ahmed (2023). Unexpectedly, financial inclusion was found to negatively affect CSA adoption. One possible explanation is that most farmers in the study are middle-aged (with an average age of 48 years) and have limited engagement with formal banking institutions, particularly in the coastal zones. However, empirical literature generally reports a positive association between financial inclusion and CSA adoption (Li *et al.,* 2024; Ma & Rahut, 2024; Mbanasor *et al.,* 2024; Sardar *et al.,* 2021; Sisay *et al.,* 2023). In summary, the findings suggest that younger farmers with subsidiary income sources, larger farms, and access to extension services are more likely to adopt CSA technologies. These results have important policy implications, particularly for regions with high climate vulnerability.

V. CONCLUSIONS AND POLICY IMPLICATIONS

Climate-smart agriculture (CSA) technology practices play a vital role in promoting sustainable agricultural development and enhancing resilience to climate change. However, their adoption varies significantly among farmers due to socio-economic and structural factors. This study identifies age, subsidiary occupation, farm size, access to extension services, and financial inclusion as key factors influencing the adoption of CSA practices. Based on these findings, targeted interventions and policies can help improve adoption rates, thereby contributing to the development of more sustainable farming systems. Older farmers are more likely to rely on traditional farming methods rather than adopt CSA practices. Their awareness and attitudes toward CSA can be improved through various training and awareness programs. The Upazila agricultural extension office, along with non-governmental organizations (NGOs), can play a crucial role in implementing such initiatives. Increased access to agricultural training and extension services is associated with higher CSA adoption rates. Additionally, promoting rural non-farm employment through both public and private sector initiatives can be beneficial. Off-farm employment opportunities enhance household income and significantly encourage CSA adoption in rural areas. Therefore, by supporting older farmers, promoting economic diversification, assisting smallholders, and strengthening training and infrastructure, policymakers can create an enabling environment that fosters sustainable farming practices and enhances the resilience of agricultural households in coastal Bangladesh.

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