Annals of Bangladesh Agriculture
Journal homepage: gau.edu.bd/aba

ORIGINAL ARTICLE

Perception, adoption determinants and challenges of combine harvesting in *haor* ecosystem: an empirical study on *boro* rice farming

Md. Taj Uddin[1], Andrila Sarker Shama[1*], Mahmuda Nasrin[1], Nanda Dulal Kundu[1,2] and Md. Touhedul Islam Tushar[1]

[1] Department of Agricultural Economics, Bangladesh Agricultural University Mymensingh 2022, Bangladesh
[2] Agricultural Economics Division, Bangladesh Agricultural Research Institute, RPRS, Madaripur 7901, Bangladesh

ARTICLE INFO.

Keywords:

farmers' perception, adoption determinants, combined harvester, *haor* ecosystem, Bangladesh.

Received : 19 November 2024
Revised : 19 October 2025
Accepted : 24 December 2025
Published : 05 January 2026

Citation:

Uddin, M. T., A. S. Shama M. Nasrin, N. D. Kundu, M. T. I. Tushar. 2026. Perception, adoption determinants and challenges of combine harvesting in *haor* Ecosystem: an empirical study on *Boro* rice farming. *Ann. Bangladesh Agric.* 29(2): 239-264

ABSTRACT

The use of combine harvester is a modern technological solution to current rice production in Bangladesh, especially in *haor* ecosystem where timely harvesting of paddy is very important for minimizing crop losses due to flash floods. An extensive field survey was conducted to assess the farmers' perception, adoption drivers and challenges of combine harvesters in three *haor* districts namely Sunamgonj, Kishorgonj and Netrokona. The field level data were collected from 360 rice growing farmers (239 adopter and 121 non-adopter) since November 2023 to April 2024 using multistage random sampling. A structured questionnaire survey was used for the collection of primary data. Descriptive statistics, the 5-point Likert scale and a binary logistic regression model were applied to achieve the objective of the study. The meeting point for mechanization in harvesting, being 92%, showed that a quicker adoption of technology occurred. Mechanization for harvest was seen by farmers to be beneficial in terms of reduced labor, decreased production costs and time, despite the high initial investment cost and on-going cost of maintaining such equipment. On the other hand, education, group membership, market information, access to credit, training and extension services strongly determined the adoption decision positively whereas, age had negatively significant effect. The major challenges in the study areas, were found to be limited credit facilities (91.0%), low custom hiring availability (88.0%), high machine prices (80.0%) and small fragmented plots (80.0%), respectively. The study also suggests some recommendations like improving credit access, farmers training, extension services and cooperative-based machinery ownership are vital to ensure sustainable mechanization for enhancing farmers' livelihood in *haor* ecosystem.

*Corresponding Author: Department of Agricultural Economics, Bangladesh Agricultural University Mymensingh 2022, Bangladesh. Email: andrila.23140155@bau.edu.bd

https://doi.org/10.3329/aba.v29i2.77847

Introduction

Rice (*Oryza sativa*) is the third major cereal crop in the world (Rahman *et al.,* 2021) and the staple diet of greater than half of the world's population (Khush, 2005). Large numbers of farmers grow rice, as it is highly compatible with many ecosystems and has lower cultivation risks. 14,886 MT food must be produced by 2050 to meet the food requirement for the increasing population in the world (Islam and Karim, 2020). The world rice production stands at 503.2 million tons, in which the contribution of China is 29.5%, followed by India (23.8%), Bangladesh (7.0%), Indonesia (6.9%), Vietnam (5.4%) and Thailand (3.7%) (USDA, 2020). In Bangladesh, rice is the country's most important crop, comprising about 78% of the total net cropped area. Nation becomes self-sufficient to meet the rice requirement of its 169. million population from 11.6 million ha of cultivated land (Kabir *et al.,* 2021; Nasim *et al.,* 2021) and food security means rice security (Kabir *et al.,* 2021). Rice is grown in a three-seasons: *Aus, Aman*, and *Boro* cycle. Bangladesh now ranks third in the world for rice production next to China and India with 36 million tons of annual rice production (Rahman *et al.,* 2021). The largest rice growing area in Bangladesh is the *haor* wetlands of north-eastern region and it contributes about 18% of national rice production (BBS, 2021; Mamun *et al.,* 2024; Kamruzzaman *et al.,* 2024).

The *haor* wetland is a relatively large basin of bowl or saucer shape with a subtropical monsoon climate (Bokhtiar *et al.,* 2024). There are about 0.7 million ha of net sown area in this region and about 5.3 million tons of paddy produced annually (BHWDB, 2012). In the *haor* areas, *Boro* rice is generally the most important crop and sometimes the only one (Alam *et al.,* 1970; Hoq *et al.,* 2021). The ecology, farming practices, economic activities and general lifestyle of farmers in wetland areas are quite distinct from other parts of the country (Hoq *et al.,* 2021). The production practices are governed by natural calamities, particularly for *Boro* plant with the winter season and photo-insensitive and transplanted additional irrigation rice. The irrigated *Boro* rice is grown in Rabi season (January to April/May) commonly known as *Boro* cultivation. Frost, rainstorms and drought at early stage are the major impediments for modern *Boro* rice (Islam *et al.,* 2022). According to statistical data, the total agricultural land area of seven wetland districts is nearly 1.3 million hectares, of which 0.7 million hectares (66%) is under wetland management (Alam and Sarker, 2011). Around 80% of this area (0.7 million hectares) is devoted to *Boro* rice cultivation and only 10% to T. Aman crop (Huda, 2004). *Boro* rice dominates and the flood-affected *haor* has contributed 15% to 25% of national *Boro* rice production (BBS, 2017). Subsequently, to augment or sustain rice productivity the use of region specific/rice-based technology is imperative.

Harvesting rice should be carried out timely for highest yields. However, acute labor shortage and increase in wage rates during peak season are major constraints (Nath *et al.,* 2017). In such a context, mechanization, not least the use of modern agricultural equipment like combined harvesters is essential. These systems are appreciated for their high performance, less costly and reduced labor needs (Huda *et al.,* 2019). They enhance the recovery of grain by minimizing losses in harvesting, threshing and cleaning operations.

Manual rice harvesting is a monotonous, time-consuming and costly operation which requires approximately 100 -150 human days to harvest one ha of paddy land (Hossain *et al.,* 2023). It has aggravated the shortage of labor during the peak agricultural period and led to reduction in the extent and level of rice production. To cope with this problem, combine harvesters present an automatic process to reduce the cost of production and increase worker performance (Alizadeh and Allameh, 2013). The Combine harvester is one of the important solutions to labor shortage for harvesting paddy and there exists an acute need in Bangladesh, where emergency solutions are immediately required (Nath *et al.,* 2022). This is a fully functional robot system that provides superior practicality, significantly reduced labor requirements and significant time savings from one-by-one collection. The speedy adaptation of modern mechanical harvesting such as combines and Mini combines, reapers among others has become an urgent need (Nath *et al.,* 2022). These methods reduce the time, manpower, investment and natural demand for labor and save harvesting losses. They further raise cropping intensity and crop yield and thus, contribute to the economic empowerment as well.

A review of the literature constitutes the basis for current study. Here, we have made a substantial effort to review previous studies. Islam *et al.* (2022) assessed the technical and financial performance of small combine harvester to solve natural disaster in *haor* region of Bangladesh labour scarcity. Baishakhy *et al.* (2020) also found that the effectiveness of the harvesting machines reduces the possibility of loss of produce to untimely harvesting. Islam *et al.* (2022) reported the diverse use of harvester in the *haor* areas depending on their size and weight. Day *et al.* (2022) reported that not all farmers have effectively adapted to this technology as it is still at its initial stage. Uddin and Dhar *et al.* (2018) studied attitudes of farmers for positive mechanization and significant resistance because of know-how, education. Nath *et al.* (2021b) observed that high cost of machineries and non-availability of loans are the key constraints in adoption of harvesting machinery. Rahman *et al.* (2022) evaluated that farmers are using harvesters with the advice of extension services helping them to take a sound decision. Malanon and Pabuayon, (2022) reported that higher educational attainment, income level, bigger farm size, and availability of lowland irrigation are significant determinants on the adoption of rice combined harvester. Raji *et al.,* (2024) found out that training, extension visit, market information, access to credit and group membership are determinant of farmers' adoption of combine harvesting and modern technology. Roy *et al.* (2024) noted that irrigation related problems, land fragmentation and flooding in case of *haor* basin work as a bottleneck of combine harvesting and low productivity for increasing the problem that already facing by the poor farming community. Kabir *et al.* (2020) found that combined harvesting in *haor* areas was hindered by limited machine availability, labour dependence and COVID-19 related health risk, affecting timely harvesting and workforce participation.

While the technical performance, economic viability and challenges of operation of mechanized harvesting have been addressed to some extent by several studies conducted in Bangladesh's *haor* regions. Most of the studies are confined only within the domain of efficiency implications or economic impact of combined harvester. Only marginal mention has been made of the behavioral determinants and perceptions of farmers affecting their adoption in general, given this different ecological and socioeconomic context of the *haor* basin. Furthermore, previous research did not holistically consider how education, training, credit access and institutional support together influence uptake decisions in these inundated landscapes. There is also minimal literature on the transition from traditional threshing to full master mechanized harvesting and why adoption may not be as widespread despite support by government and private sector. Thus, there is an empirical knowledge gap in understanding the influence of socioeconomic conditions, institutions and environmental factors towards their perception and adoption behavior on mechanized harvesting technologies within *haor* areas. This study fills that gap by supplying micro-level evidence of adoption determinants and perception dynamics based

Table 1. Distribution of sample size in the study areas

Districts	Upazilas	Unions	Villages	No.	No. of farmers
Netrakona	Madan	Govindoshree	Govindoshree, Kadamshree	30	60
		Madan	south madan, Fochika	30	
	Khaliajuri	Mendipur	Ichapur, Mendipur	30	60
Sunamganj	Tahirpur	Tahirpur	Tahirpur, Sujjergao	30	60
	Dharmapasha	Selbarash	Bogarpachur, Singpur	30	60
		Dharmapasha	Atkapara, Noagao	30	
Kishoreganj	Itna	Itna	Betega, Ershadhnogor	30	60
		Boribari	Diyarkandi, Shimulbak	30	
	Mithamoin	Mithamoin	Borohati, Sorkarhati	30	60
		Gopdighi	Katiapara, Bogadighi	30	
		Total sample size			360

on field-level data in three extensive *haor* districts from Bangladesh. So, this study was conducted on the ground of the following specific objectives to : i) assess the awareness of the farmers about combined harvesting in *haor* regions, ii) identify adoption drivers of combine harvesters, and iii) investigate the challenges of combined harvesting in *haor* regions.

Materials and Methods

Study areas and sample size

Three significant *haor* districts in Bangladesh Sunamganj, Kishoreganj and Netrakona representing the main rice-growing ecosystems in the area were the sites of the research. In order to ensure representativeness across a range of agroecological and socioeconomic circumstances, a multistage random selection technique was used. Based on the extent of mechanized rice harvesting, two upazilas were purposefully chosen from each district after consulting with the Department of Agricultural Extension (DAE).

Two unions were selected from each upazila and two villages were randomly selected for household surveys within each union, for a total of 20 villages throughout the research region. The sample size is calculated as the following and the total number of farm

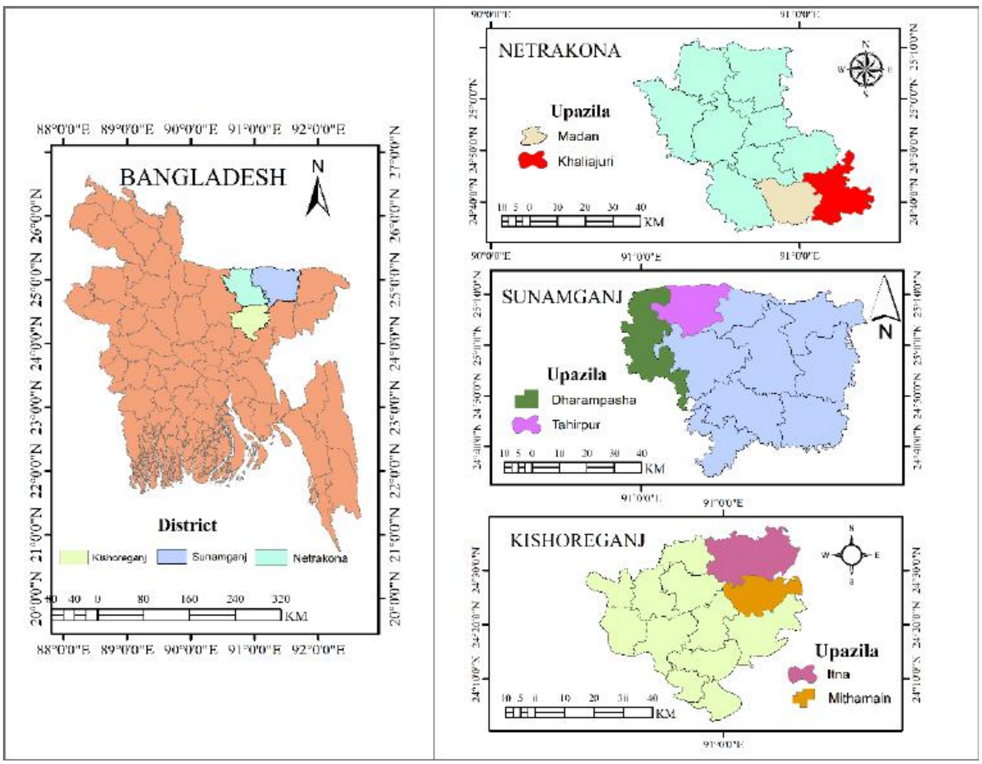

FIg. 1. Map of the study area

households is 6000. The conventional formula (Kothari, 1990) was used to get the sample size of 361 based on a 95% confidence level and a 5% margin of error:

$$n = \frac{z^2pqN}{e^2(N-1)+z^2pq} \text{..............}(1)$$

One incomplete example was eliminated, leaving 360 responses for the study. Interviews were conducted with 360 sample farmers (239 adopters and 121 non-adopters) in order to compare the adoption of combination harvesters and its impacts on farm performance. This made sure that the sample had a proportionate amount of each category. From November 2023 to June 2024, respondents were asked to complete a structured questionnaire in order to collect primary data. Focus group discussions (FGDs) were employed to evaluate the accuracy of the data.

Analytical techniques

Descriptive statistics: To determine the socioeconomic level of the farmers and address their farming practices, descriptive statistics such as sums, averages, percentages, etc., were computed.

Likert Scale: A 5-point Likert scale was used to examine the adoption of combined harvesters in *haor* areas. Respondents were asked to indicate the degree to which they agreed with the item's point of view using a 5-point Likert scale (Ahmed *et al.,* 2022). Each of the seven statements was assessed using a 5-point Likert scale, in which responses were assigned weights to reflect the degree of agreement: *Strongly disagree (−1)*, *Disagree (0)*, *Neutral (1)*, *Agree (2)*, and *Strongly agree (3)*. Higher scores indicated stronger levels of agreement and concern among farmers regarding the respective statements. The mean score of each statement was also estimated by applying the perception index. Based on the agreement level, each statement's perception index has been ranked in order (Vortia *et al.,* 2019).

Logit regression model: The Binary Logistic Regression Model (BLRM) is employed to analyze the influence of independent variables on farmers' adoption of combined harvesters. This method enabled us to evaluate the extent to which independent variables impacted the likelihood of adopting mechanized harvesting (Hosmer *et al.,*1989; LaValley *et al.,* 2008). According to Kundu *et al.* (2024) the model was chosen for this study because it avoided linear interactions with the explanatory variables and ensured that the estimated probability ranged between 0 and 1. As stated below, the cumulative logistic distribution function serves as the basis for the model.

$$P_i = E\left(Y = \frac{1}{X_i}\right)\alpha + \beta_1 \text{..}(2)$$

$$P_i = E\left(Y = \frac{1}{X_i}\right)\alpha + \frac{1}{1+e^{-z}} \text{..}(3)$$

Where, Pi = Probability of willingness to adopt mechanized harvesting.

The log of odd ratio or logit is

$$Logit\ (Z_i) = \frac{\{The\ probability\ of\ willingness\ to\ adopt\ mechanized\ harvesting\}}{\{The\ probability\ of\ unwillingness\ to\ adopt\ mechanized\ harvesting\}} = \alpha + \beta_i X_i + U_i$$

For ease of exposition

$$Z_i or Y_i = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ \ldots . + \beta_n X_n + U_i \ldots\ldots\ldots(4)$$

A dichotomous response variable, Y_i (dependent variable), is required to obtain Z_i. In the Binary Logistic Regression Model, the dependent variable represents farmers' adoption status, coded as 1 for adopters of combined harvesters and 0 for non-adopters, reflecting the binary nature of the response variable. To evaluate the willingness to adopt mechanized harvesting, the model included eight explanatory variables. These were the explanatory variables that were specified:

X_1 = Age of household head (years);

X_2= Educational level of household head (years of schooling);

X_3 = Family size (no.);

X_4 = Farm size (ha);

X_5 = Tenure status (Dummy = 1 if Household owns the land; 0 = Otherwise);

X_6= Cultivation frequency (Dummy variable: 1 if household cultivated two crops in a year; 0 otherwise);

X_7= Off farm income (Dummy = 1 if the farmer participates in off-farm income-generating activities; 0 otherwise);

X_8= Group membership (Whether the household joined in any farmer group: 1 = yes, 0 = otherwise);

X_9 = Market information (Dummy = 1 if the household had market information, 0 = otherwise);

X_{10}= Access to credit (Dummy = 1 if farmer accessed credit; 0 otherwise);

X_{11}= Access to training (Dummy = 1 if the head of the family farm has attended any technical training, 0 otherwise);

X_{12}= Extension services (Dummy = 1 if farmer accessed extension service; 0 otherwise).

U= error term.

According to Gujarati (1995), the following expressions obtained from the logit model were used to estimate the elasticity of the likelihood of adopting mechanized harvesting or the marginal probabilities of factors influencing that willingness:

$$\frac{dp}{dx} = \beta_i\{P_i(1 - P_i)\}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$E_p = \beta_i X_i(1 - P_i)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Where, B_i = estimated logit regression coefficient concerning the i^{th} factor; P_i is the estimated probability of farmers' adoption status; $\bar{X}_i$ is an arithmetic mean; and Ep is the elasticity of the probability of willingness to adopt the mechanized harvesting method.

Results and Discussion

Socioeconomic characteristics of the respondents

Socioeconomic characteristics of the respondents in *haor* areas are presented in table 1. The majority of respondents were in their

Table 2. Socioeconomic Status of the Respondents

Variables	Mean	Std. dev.	Min	Max
Age	43.811	9.696	25	68
Education	5.100	2.801	0	17
Family size	6.164	2.080	2	12
Farm size	1.390	0.962	0.06	7.34
Tenure status	0.747	0.435	0	1
Cultivation frequency	0.506	0.501	0	1
Off farm income	0.422	0.495	0	1
Group membership	0.622	0.486	0	1
Market information	0.461	0.499	0	1
Access to credit	0.456	0.499	0	1
Access to training	0.636	0.482	0	1
Extension services	0.533	0.500	0	1

Source: Author estimation, 2023-2024.

economically active phase and had sufficient agricultural experience, as evidenced by the farmers' average age of 43.81 years. The respondents had, on average, completed primary school, as shown by their mean education level of 5.10 years, which may have affected their capacity for accepting and understanding advanced farming methods. The average family size was 6.16, which is indicative of a somewhat larger household structure observed in Bangladesh's rural districts. The majority were smallholder farmers with little cultivable land, as seen by the mean farm size of 1.39 hectares, with lowest and maximum farm sizes ranging from 0.06 to 7.34 hectares. About 74.7% of the respondents were farmers who owned their land, and 50.6% cultivated their holdings more than once a year, according to institutional and socioeconomic characteristics. Off-farm earnings contributed around 42.2% of the total, which might help with financial stability and income diversity. About 62.2% of the farmers were found to be members of a group, indicating their participation in community social or cooperative groups that may promote information exchange and cooperation. A total of 46 percent had access to formal credit facilities, and 46% had access to market information. Additionally, 53.3% of respondents got extension services and 63.6% of respondents took part in training programs, indicating an acceptable level of institutional support in the research region. Overall, the statistical results show a farming community with middle-aged, somewhat educated smallholders who have sufficient resources but considerable access to informational and institutional services that are two important factors that influence the adoption of mechanized harvesting.

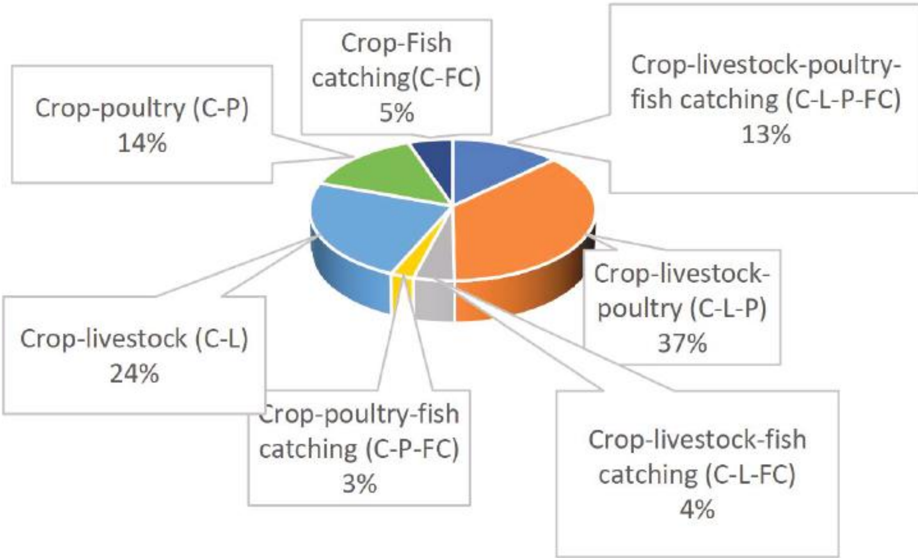

FIg. 2. Major farming systems

Major farming systems in haor areas

In the study area farmers used to practice variety of farming system. This study found seven major farming systems among the respondents. These include crop-livestock-poultry-fish catching (C-L-P-FC), crop-livestock-poultry (C-L-P), crop-livestock-fish catching (C-L-FC), crop-poultry-fish catching (C-P-FC), crop-livestock (C-L), crop-poultry (C-P) and crop-fish catching (C-FC). The most common farming system is crop-livestock-poultry. It is practiced by 36.7% of the respondents. Other prominent systems are crop-livestock, crop-poultry, crop-livestock-poultry-fish-catching and crop-fish catching. They are chosen by 23.6, 14.4, 13.1, and 5.3% of respondents. In addition, 4.4 and 2.5% of respondents use crop-livestock-fish catching systems and crop-poultry-fish catching systems, respectively (FIg. 2 and appendix Table 2). The findings indicated that *Boro* is the main crop of the farming system as the land in these areas is covered in water for long time and there exist less variation in farming system (Ali *et al.,* 2018).

Status of farm mechanization in haor areas

Results presented in Table 2 reveal household level farm mechanization between 2018-19 and 2023-24 reveals a heterogeneous pattern across different farming operations. Land preparation, pesticide application, and irrigation remained fully mechanized throughout the study period, indicating sustained technological integration in these stages. In contrast, operations such as planting, weeding, and fertilizer application continued

Table 2. Status of farm mechanization in *haor* areas

Farming operation	Percentage of farmers	
	Before (2018-19)	Present (2023-24)
Land preparation	100	100
Planting	0	0
Weeding	0	0
Fertilizer application	0	0
Pesticides application	100	100
Irrigation	100	100
Harvesting	0	92
Threshing	100	14

Source: Field survey, 2023-2024.

to rely entirely on manual labor, reflecting persistent mechanization gaps. According to the study of Rahaman *et al.*(2018) planting and weeding rice in Bangladesh's *haor* regions primarily involves human labor rather than machines. Significant progress was observed particularly in the case of mechanization of harvesting from no use (0%) in FY 2018-19 to 92.0% in 2023-24, indicating rapid technological uptake. The adoption of combined harvesters was primarily driven by GoB support, since in 2020, the MoA provided machines to facilitate harvesting *Boro* paddy as the labor force was limited due to the pandemic (Kabir *et al.,* 2020). This was in contrast with the mechanized threshing which fell from 100 to 14% between these two periods, indicating a fading importance for mechanized threshing compared either to operational preference or constraints that were coming at play in both periods Mechanized harvesting in *haor* region is getting more preference over traditional threshers because whole-feed combine harvesters offer higher efficiency, reduced losses, and greater profitability, particularly in larger fields. (Islam *et al.,* 2022). According to the study of Rahaman *et al.*(2018) planting and weeding rice in Bangladesh's *haor* regions primarily involves human labor rather than machines.

Table 3. Rice harvesting systems in *haor* areas

Particulars	Number of respondents	Percente of respondents
Combined harvesters	239	66
Reapers	6	2
Manual harvesting	115	32

Source: Field survey, 2023-2024.

Table 4. Participation in training related to combined harvesters

Study areas	Institutions	Duration (days)	Purposes	Trained farmers	Adoption rate among trained farmers	Untrained farmers	Adoption rate among untrained farmers
Netrakona n=120	DAE	1	Provide training about combined harvester and its' parts	75 (62.5)	71 (94.7)	45 (37.5)	24 (53.3)
Sunamganj n=120	SCBRMP: Local NGOs	5	Improvement of the livelihoods of rural communities and the introduction of combined harvester	54 (45)	39 (72.2)	66 (55)	31 (46.9)
Kishoreganj n=120	DAE, DAOC	3	Help to ensure farmers can effectively operate and maintain the equipment.	91 (75.9)	70 (76.9)	29 (24.1)	13 (44.8)

Source: Field Survey, 2023-2024.

This reflects traditional agricultural methods and farmers' preference for manual labor over mechanization. Besides, rice transplanting and weeding in the *haor* areas of Bangladesh is mainly conducted by human labor as reported by Rahaman *et al.* (2018). This is in line with the usual traditional way of farming that farmers prefer manual labor to machine.

Rice harvesting systems in haor areas

The Table 3 shows the distribution of rice harvesting system in the *haor* regions. Result presents that about 66%(n=239) surveyed farmers used combined harvesters which suggest heavy reliance on mechanization. Manual harvesting, on the other hand, remained substantial and employed 32% of respondents (n = 115), indicating further dependence on labour intensive traditional methods. Reapers were employed to a limited extent (2% of sample size, n = 6), showing poor adoption for this mid-harvest mechanization. These results emphasize the prevalence of mechanized harvesting in spite of continued manual practices in some regions.

Participated in training related to combined harvesters

Table 4 presents the training interventions on combined harvester usage across three study areas. In Netrakona, 120 farmers were given a day's training on the working procedure of a combined harvester by Department of Agricultural Extension (DAE). The adoption level recorded on technology was 94.7% for trained farmers and 53.3% for untrained farmers. In Sunamganj, a five-day training programme arranged by SCBRMP along with local NGOs was conducted to promote rural livelihood and introduce new technology like combined harvester. Adoption among the trained farmers was highes (72.2%), while that of untrained farmers was 46.9%. In Kishoreganj, 120 farmers participated in a three-day program organized by DAE and DAOC to enhance operational and maintenance skills for the equipment. Adoption rates were 76.9% for trained farmers and 44.8% for untrained farmers. Overall, the results indicate that targeted training significantly enhanced the adoption of mechanized harvesting technologies.

Note: The figures in parentheses denote percentages derived from the whole sample of each district for both trained and untrained farmers, whereas the adoption rate percentages indicate the proportion of farmers who adopted combined harvester within each category.

Farmers' perception about the adoption of combined harvesting

This study represents the respondents' opinions in the *haor* areas about various aspects of mechanized harvesting which is represented by figure 3 and appendix table 2. They agreed that 'Mechanized harvesting reduces the labor required for farming activities' is the most important indicator and has the highest perception index, which is 543. Mechanized harvesting reduces production costs is in the second position with the perception index of 522. The perception index of third-ranked is 506, which is 'Mechanized harvesting increases food production'. 'Mechanized harvesting improves living standards' and 'Mechanized harvesting decreases poverty' are ranked fourth and fifth, respectively, with a perception index of 479 and 437. On the other hand, 'Mechanized harvesting saves time' is sixth in position, and the perception index is 373. Finally, 'The cost of purchasing and maintaining harvesters are affordable' is in the last position, with a perception index of 357. This rating indicates that though respondents recognize that mechanized harvesting saves a lot of labor and time, they are still concerned

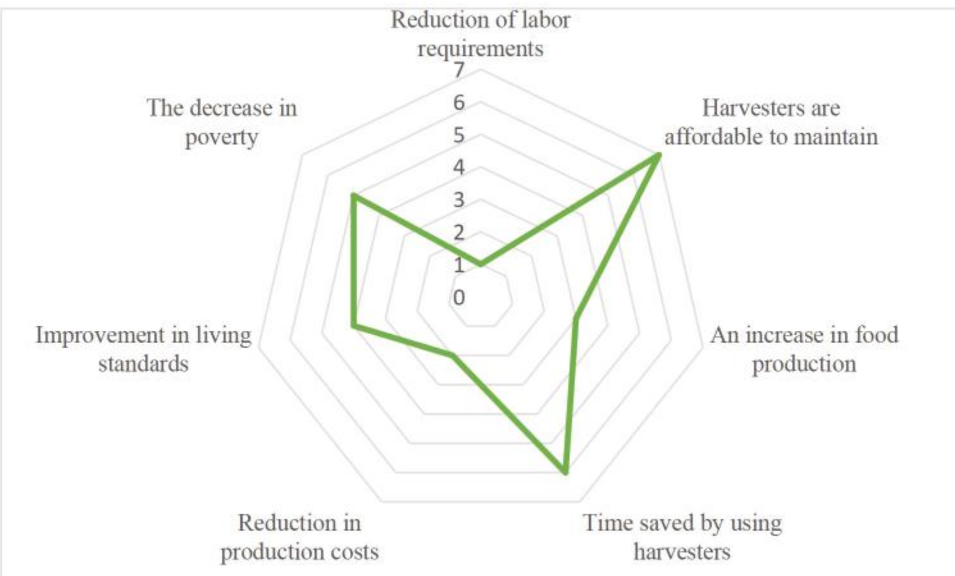

FIg. 3. Radar diagram showing farmers' perceptions toward the adoption of combined harvester

Factors affecting the adoption of combined harvesters in *haor* areas

Table 5. Logistic Regression of factors affecting the adoption of mechanized harvesting and marginal effects estimations

Mechanized harvesting	Coefficient	std. err.	dy/dx	Delta-method std. err.
Age	-0.111 ***	0.019	-0.013 ***	0.002
Education	0.183 ***	0.065	0.021 ***	0.007
Family size	0.136	0.083	0.016 *	0.009
Farm size	0.336	0.303	0.039	0.035
Tenure status	0.130	0.487	0.015	0.056
Cultivation frequency	0.150	0.390	0.017	0.045
Off farm income	-0.592	0.396	-0.068	0.045
Group membership	1.419 ***	0.330	0.163 ***	0.034
Market information	0.759 **	0.378	0.087 **	0.043
Access to credit	1.377 ***	0.342	0.158 ***	0.036
Access to training	1.867 ***	0.333	0.215 ***	0.031
Extension services	0.741 *	0.404	0.085 *	0.046
_cons	0.442	1.028		
Number of observations = 360				
Pseudo R2 = 0.431		LR chi2(12) = 198.1		
Log likelihood = -130.784		Prob > chi2 = 0.000		

Source: Author estimation, 2023-2024.

Note: *** and ** indicates significant at the 1% and 5% probability level, respectively.

about the expenditures involved in adopting new technologies. Many previous studies support the findings. Bautista *et al.* (2017) identified that most farmers who responded acknowledged that farming would be easier with agricultural mechanization. New technology for growing rice must be adopted and human resources would be replaced by machinery. Vortia *et al.* (2019) stated that some farmers have expressed concerns about the cost of production associated with using machinery. However, they believed it may reduce profit margins despite acknowledging the time-saving benefits of mechanization. Ghosh *et al.* (2023) explained that most farmers understood modern technologies' importance. Many of them agreed that maintaining an environment that is suitable for agricultural output requires the use of these technologies.

Table 5 presents the estimated coefficients and marginal effects from the logistic regression model examining the determinants of combined harvesters' adoption among farmers in the *haor* areas. The model is statistically significant, with a pseudo-R^2 of 0.431, indicating a good overall fit and explanatory power for cross-sectional data. Among the variables, age shows a negative

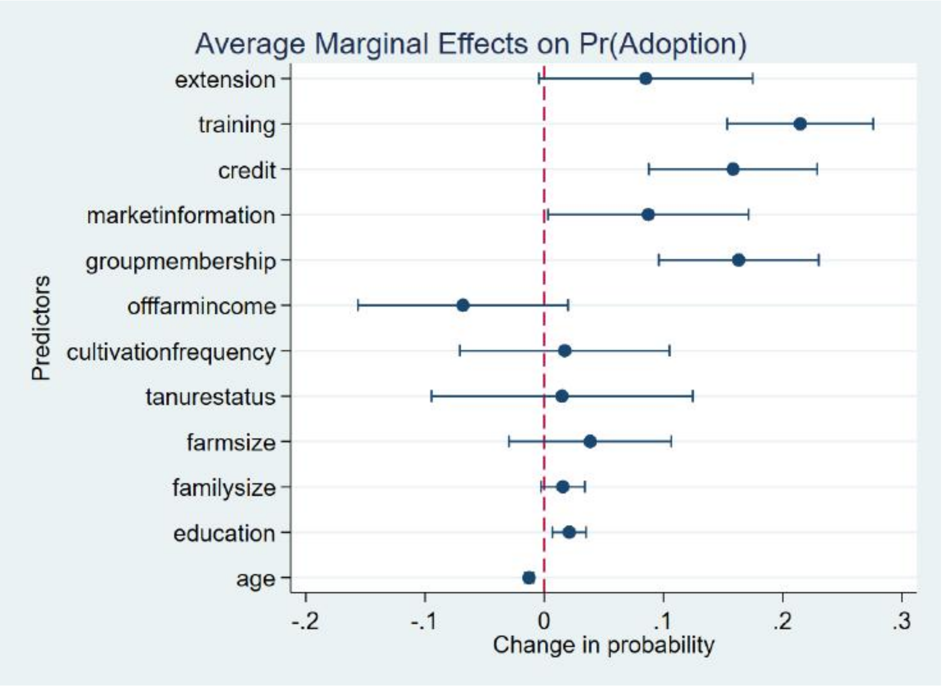

FIg. 4. Average marginal effects of variables on combined harvesters' adoption

and highly significant relationship with adoption at 1% statistical level, implying that younger farmers are more likely to adopt mechanized harvesting than older ones and this study is align with Biam *et al.* (2020) who explained that older respondents negatively impact farm mechanization adoption, indicating that the older respondents have less interest in adopting mechanization. In contrast, education has a positive and significant effect at 1% level, suggesting that higher educational attainment enhances farmers' understanding of and confidence in the adoption of combined harvesters and this finding is supported by Barman *et al.* (2019) who showed that farmers with higher education are more likely to adopt modern machinery, implementing different kinds of farming work. Family size exhibits a positive sign, indicating that larger households may provide additional labor and support that facilitate adoption of combined harvesters. Some variables like farm size, tenure status, cultivation frequency, and off-farm income were not statistically significant, implying limited influence on adoption decisions in this context. Group membership exhibited a highly significant positive relationship at 1% level, suggesting that participation in farmer organizations or cooperatives substantially enhances the likelihood of adoption of combined harvesters. Memberships facilitate peer learning, collective decision-making and exposure to modern farming practices, thereby reducing uncertainty and fostering confidence in using machinery and this study is align with Walker *et al.* (2024) who found that group membership was strongly and positively linked to education, household income, and broader socioeconomic conditions across countries. Access to market information which is significant at 5% level which positively influences adoption decisions. Farmers who receive timely and reliable information about input prices, service availability and machine rental opportunities are more capable of making informed choices regarding the adoption of harvesting machinery. This research is compatible with Fan and Garcia, (2018) who found that access to market information positively affects smallholder farmers' participation in markets, as knowledge about crops and land conservation boosts productivity and encourages commercial engagement. Kundu *et al.* (2025) found that market access positively affects outcomes, but its impact is smaller than that of credit, training, or agricultural specialization.

Access to credit is significant at 1% level and indicates financial support significantly increases adoption probability. Access to formal or informal credit allows farmers to overcome liquidity constraints, enabling them to rent or purchase machinery and bear associated operational costs. Access to training is positively significant at 1% level and implies that participation in training programs enhances farmers' technical knowledge and operational skills influence adoption decisions. Lastly, extension services is significant at 10% level also positively affect adoption, underscoring the importance of frequent contact between farmers and extension agents. Effective extension

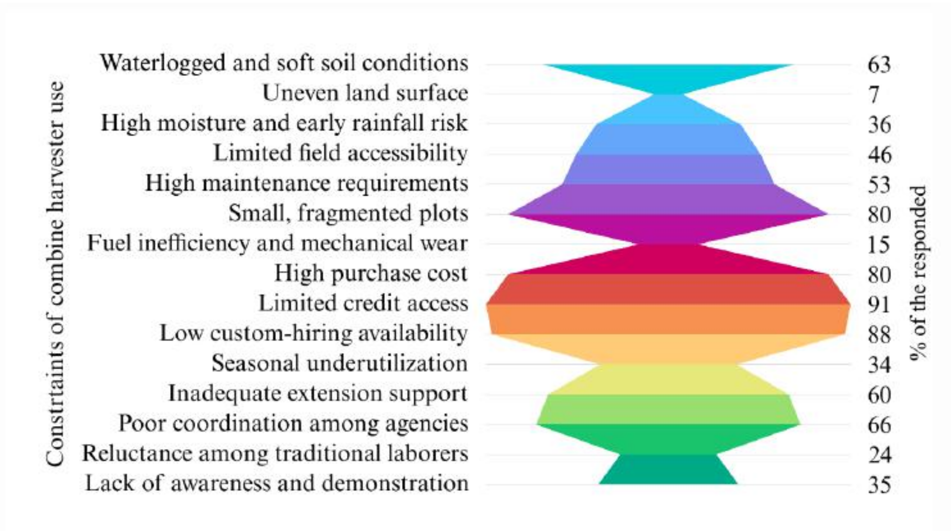

FIg. 5. Constraints in use combine harvester

communication disseminates information about modern machinery, demonstrations, and technical support, ultimately promoting adoption behavior. Aryal *et al.* (2021) also found that training helps to influence knowledge, attitude and perception, which control the decision of the farmers as to whether or not to adopt farm machinery. They can rent farm machinery because of credit facilities. The extension services increase the respondents' awareness.

Constraints to combined harvester usage in aor Areas

The adoption and efficient use of combine harvesters in the *haor* regions of Bangladesh face several technical, institutional and socioeconomic challenges, as reported by farmers. The findings are illustrated in F 5 and appendix Table 3. Access to credit is a vital problem in the study areas. As indicated by 91% of respondents, Majority of the respondents (91%) cannot purchase or rent combine harvesters for want of soft loans or favourable credit system. Relatively high prevalent interest rates and other complexities held by financial institutions also deter investments in mechanization, which is compatible with the result of Khan *et al.* (2024), who observe that the little access to formal credit, together with high interest rates and stringent collateral requirements limit farmers' capacity to invest on combine harvesters, thus slowing down the adoption of combined harvesters. About 88% of the respondents replied on the lack of offer on custom hiring services. Most farmers simply do not have the capacity to purchase individual harvesters, renting them on a shared basis instead. Limited number of service providers, logistics' weak service lines also limit the effective availability in harvesting peak seasons and cause delays and damage to harvest. This is consistent with the findings that the shortage of Custom Hiring Centers (CHC) at peak time leads to reduced availability of combined harvesters and hence losses for farmers using rental harvesters as reported by Kisku and Singh (2022). Besides, high purchase cost (80%) is one of the major challenges in the study areas. Combine harvesters are too costly to purchase by the small and medium farmers for use, especially in the *haor* (wetland) region. Farmers find it's too expensive to do without financial help or shared ownership models. This result is in line with the study conducted by Kabir *et al.* (2020) who reported that more machines are needed for timely *Boro* harvesting in *haor* regions but the high cost of combine harvester is the most important limitation especially for the financial constraints without any credit access or leasing option to get combined machine shared ownership. An equal number (80%) of farmers identified land fragmentation as a serious constraint. The scattered and irregular distribution of farm plots do not allow proper use of heavy machinery, e.g. combine harvesters. It is operationally unfeasible due to structure and increases time and fuel ha^{-1}. Our study is in line with the report by Zheng *et al.* (2023) who found that the land fragmentation increases labor and operational costs, limiting machinery usage, and hence force farmers to decrease cropland cultivation area or increase the whole production cost. A lack of coordination between agricultural departments, machinery suppliers and local government was cited by roughly two-thirds (66%) of the farmers. Disintegration amongst these stakeholders leads to machinery distribution pockets, absence of aftercare and awareness programmes, all inhibits mechanization pace. The study agrees with Islam *et al.* (2022) who reported that lack of coordination between agricultural agencies and service providers is an obstacle to the implementation of technology and dissemination of information, which thereby impedes mechanisation in Bangladesh.

Water logging and soft ground were reported as environmental limitations by 63.0% of the respondents. The constraint is consistent with Kundu *et al.* (2022) as both indicate that frequent waterlogging, 'soft' and unstable ground, and late field opening due to water stagnation severely constrain crop cultivation and mechanized harvesting in the chars of Bangladesh. More than half (60.0%) of farmers mentioned ineffective extension and technical support. Inadequate training, demonstration and communication with the agriculture officials doesn't allow farmers to fully appreciate or make most of combined harvesters. The restriction is compatible with the result of Khatun *et al.* (2014) since both claim that inadequate training of farmers, poor advisory services and low-level communication with institutions affect the farmer's knowledge, adoption of agricultural innovations and access to credit facilities. The maintenance costs and mechanical failures were high among farmers (53.3%). Scarcity of spare parts and trained repairmen raises downtime and costs, which discourage frequent machine use. Results of the study agree with those of Pagare *et al.* (2019), who found that increasing maintenance and repair costs shorten the economic lifetime of tractors, which impacts farmers' decisions concerning machinery management and replacement. Nearly half percent (46%) of the farmers responded on Restricted access to fields by small embankments, no roads and bad soil layout. Such infrastructural limitations hinder the mobility of the machine, in particular for remote or island-bound villages. This finding is coincident with Abirami *et al.,* (2023) who concluded that the insufficient structures-like narrow gullies, bad roads, uneven fields etc. limit machine mobility and adversely affect farm mechanizing. As many as 35.8% say high crop moisture and untimely rain delays harvesting plans. Combine harvesters work inefficiently in wet weather conditions, resulting in damage during grading. This work is similar to that in Chandra *et al.* (2024), high crop moisture and early rainfall disturb harvesting leading to post-harvest losses and reducing quality and quantity of the crop. 35% of the farmers reported on awareness and demonstration opportunities. Many farmers remain unfamiliar with how combine harvesters operate or the potential benefits, leading to hesitation and misinformation. The constraint aligns best with Khandoker *et al.* (2016) because both highlight that limited farmer training, inadequate demonstrations, and low awareness of improved practices restrict productivity and technology adoption in agricultural production. Besides some farmers34% also mentioned Concern about seasonal underutilization. In short harvesting seasons, machines stand idle for most of the year and are less cost-effective as a result; this acts as a deterrent to long-term investment. This supports Ruiz-Garcia (2023), who observed that underuse of combine harvesters during the dry season makes it economically less viable for farmers to invest in such expensive equipment. About 24% of farmers indicated opposition from traditional farm workers who are worried about job displacement. The social barrier discourages some smallholders to desist from taking up mechanization due to the need for community peace. This work is comparable to Bantelay *et al.* (2019), it is considered that resistance from the traditional laborers whom were afraid of job loss serves as a social obstacle to mechanization in smallholders farms in Ethiopia. A smaller portion (15%) of respondents cited fuel inefficiency and rapid mechanical wear as operational concerns. These problems contribute to higher running costs and lower profitability, especially when maintenance expertise is limited. This study aligns with Kareem *et al.* (2019), who found that 15% of farmers faced fuel inefficiency and mechanical wear, raising operational costs and reducing profitability where maintenance skills were limited. The lowest number (7%) of farmers responded uneven land surfaces, while some places have already been levelling their lands. However, it still locally faces the challenges in some *haor* areas because of soil undulation which makes machine balance and performance course. This is in agreement with Bokhtiar *et al.* (2024) stated that irregular terrain land in *haor* areas affect machine performance and productivity, even though leveling of the land have mitigated this problem to some extent in certain regions.

Conclusion

This paper evaluates farmers' perceptions and the determinants for adoption of mechanized harvesting technologies in *Haor* ecosystem of Bangladesh, particularly combined harvesters during *Boro* rice season. The results indicated that the mechanical harvesting is most widely adopted because of its saving in labor, timely nature and to minimize post-harvest losses. However, the adoption process is patchy due to high cost of machines, low access to credit, poor custom-hiring arrangement and lack of training / extension services. The outcomes of the logit model showed that education, access to credit, training, group membership and contact with extension agent were significant predictors for adoption and they had a positive effect while age appeared to have a negative effect. Despite the apparent advantages, mechanization in *haor* regions is constrained by structural and environmental barriers such as inadequate credit access, low custom-hiring availability, high purchase price and small land fragmentation. It is suggested that the Bangladesh Bank and

Appendix Table 2: Farmers' perception on practice of combined harvesting in *haor* areas

Indicators	Nature of Opinion										PI	Rank
	SA (3)	A (2)	N (1)	D (0)	SD (-1)	SA	A	N	D	SD		
Reduction of labor requirements	65	119	110	66	0	195	238	110	0	0	543	1
Harvesters are affordable to maintain	11	95	157	74	23	33	190	157	0	-23	357	7
An increase in food production	53	109	129	69	0	159	218	129	0	0	506	3
Time saved by using harvesters	30	89	134	78	29	90	178	134	0	-29	373	6
Reduction in production costs	58	98	152	52	0	174	196	152	0	0	522	2
Improvement in living standards	36	127	117	80	0	108	254	117	0	0	479	4
The decrease in poverty	19	97	186	58	0	57	194	186	0	0	437	5

N. B.: Score of perception index (PI) for Reduction of labor requirements = $(65 \times 3) + (119 \times 2) + (110 \times 1) + (66 \times 0) + (0 \times (-1)) = 543$;

Source: Author estimation, 2023-2024.

Appendix Table 3. Constraints of combine harvester use (% of farmers responded)

Constraints	No of farmers responded	Percent of farmers responded
Waterlogged and soft soil conditions	225	63
Uneven land surface	26	7
High moisture and early rainfall risk	128	36
Limited field accessibility	164	46
High maintenance requirements	189	53
Small, fragmented plots	287	80
Fuel inefficiency and mechanical wear	53	15
High purchase cost	287	80
Limited credit access	329	91
Low custom-hiring availability	318	88
Seasonal underutilization	124	34
Inadequate extension support	216	60
Poor coordination among agencies	238	66
Reluctance among traditional laborers	87	24
Lack of awareness and demonstration	127	35

Source: Author estimation, 2023-2024.

banks lend off-season credit for machinery purchase. The DAE, BRRI and NGOs involved in farming should continue to ensure training and extension services for improving the farmers' skill on farm mechanization. Farmer cooperatives and local government institutions would be encouraged to organize cooperative ownership of the machines or custom-hiring arrangements, while the Ministry of Agriculture will plan, coordinate, monitor and issue incentive policies for the promotion of mechanization in *haor* areas.

Acknowledgments: The authors truly appreciate the participants and study area stakeholders for their cooperation and support in conducting surveys and gathering data and information.

Farming systems (FS)	**Percentage (%) of farmers**
Crop-livestock-poultry-fish catching (C-L-P-FC)	13.1
Crop-livestock-poultry (C-L-P)	36.7
Crop-livestock-fish catching (C-L-FC)	4.4
Crop-poultry-fish catching (C-P-FC)	2.5
Crop-livestock (C-L)	23.6
Crop-poultry (C-P)	14.4
Crop-Fish catching(C-FC)	5.3

Source: Author estimation, 2023-2024.

Appendix Table 4: Multicollinearity test (VIF)

Variable	VIF	1/VIF
extension	1.61	0.620
Off farm income	1.56	0.641
Cultivation frequency	1.5	0.665
Tenure status	1.47	0.681
Farm size	1.42	0.706
Market information	1.26	0.791
Access to training	1.2	0.834
Access to credit	1.18	0.845
Age	1.11	0.897
Group membership	1.11	0.898
Education	1.08	0.925
Family size	1.06	0.946
Mean VIF	1.3	

Source: Author estimation, 2023-2024.

Competing interests: The authors acknowledged that they had no competing interests.

Author Contributions

Md. Taj Uddin: Writing – review & editing, Supervision, Investigation. Andrila Sarker Shama Writing – original draft, Visualization, Software, Resources, Methodology, Formal analysis, Data curation, Conceptualization. Mahmuda Nasrin: Writing – review & editing, Supervision, Investigation. Nanda Dulal Kundu: Writing – review & editing, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. Md. Touhedul Islam Tushar: Writing – review & editing, Visualization, Methodology, Formal analysis, Data curation, Conceptualization.

Appendices

Appendix Table 1: Distribution of the respondant farmers based on major farming system

References

Abirami, S., P. Jaisridhar, A. P. M. Kumar, M. S. Sheela and P. S. Ganapati. 2023. Pioneering Challenges: Exploring Multifaceted Obstacles in Agricultural Mechanization in Tamil Nadu, India. *Int. J. Environ. Clim. Chang.* 13 (10):3745–3753. https://doi.org/10.9734/ijecc/2023/v13i103047

Ahmed, T., M. Nasrin, M. T. Uddin and A. Rahma. 2022. Farmers' Perception and Factors Influencing Adoption of Homestead Vegetable Farming in Mymensingh District. *Bangladesh J. Agric. Econ. 43*(1), 73-84.

Alam, M. S., M. Quayum and M. Islam. 1970. Crop Production in the *Haor* Areas of Bangladesh: Insights from Farm Level Survey. *The Agriculturists*, *8*(2), 88–97. https://doi.org/10.3329/agric.v8i2.7582

Alam, M., and S. K. Sarker. 2011. Homestead Agroforestry in Bangladesh: Dynamics of stand structure and biodiversity. *J. Sustain. For. 30*(6), 584–599. https://doi.org/10.1080/10549811.2011.571606

Ali, S., M. A. Kashem and M. A. Aziz. 2018. A Scenario of Agricultural Technologies Practiced in *Haor* Area of Sunamganj District in Bangladesh. *Agricultural Research & Technology: Open Access Journal,* 19(2): 556087. DOI: 10.19080/ARTOAJ.2018.19.556087

Alizadeh, M. R. and A. Allameh. 2013. Evaluating rice losses in various harvesting practices. *Int. Res. J. Appl. Basic Sci. 4*(4), 894-901.

Aryal, J. P., G. Thapa and F. Simtowe. 2021. Mechanisation of small-scale farms in South Asia: Empirical evidence derived from farm households survey. *Technol. Soc. 65*, 101591.

Baishakhy, S. D., M. A. Islam, M. R. Amin and F. H. Choudhur. 2020. Combating flash flood in *Haor* areas: Strategic adaptation towards sustainable crop production. *Asian J. Agric. Hort. Res.* 7(1): 29-37. https://doi.org/10.9734/AJAHR/2020/v7i130087

Bangladesh *Haor* and Wetland Development Board (BHWDB). 2012. Master Plan of *Haor* Area. Ministry of Water Resources, Government of the People's Republic of Bangladesh. Bantelay, D. T., T. Dedimas, and N. Kelemu. 2019. An Integrated Approach to Solve Small Farm Holder's Mechanization Barriers in Ethiopia. *Adv. Sci. Technol. ICAST.* 308: 42–58. https://doi.org/10.1007/978-3-030-43690-2_.

Barman, S., N. Deka and P. Deka. 2019. Factors affecting farm mechanization–A case study in Assam, India. *Asian J. Agric. Ext. Econ. Sociol.* **32**(1), 1-7.

Bautista, E. G., J. S. Kim, Y. J. Kim and M. E. Panganiban,. 2017. Farmer's Perception on Farm mechanization and Land reformation in the Philippines. *J. Korean Soc. Int. Agric*, *29*(3), 242-250.

BBS. 2017. Statistical yearbook of Bangladesh, Bangladesh bureau of statistics, statistics division, ministry of planning. Dhaka: Government of the People's Republic of Bangladesh.BBS. 2021. Yearbook of Agricultural Statistics. Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh. https://bbs.gov.bd/site/page/3e838eb6-30a2-4709-be85-40484b0c16c6/Yearbook-of-Agricultural-Statistics.

Biam, C. K., P. Onah and G. C. Aye. 2020. A Comparative Analysis of Mechanized and Non-mechanized Rice Production in Benue State, Nigeria. *Journal of Agricultural Economics, Extension & Science,* 6(2): 95-108.

Bokhtiar, S. M., Md. J. Islam, S. Samsuzzaman, M. Jahiruddin, G.M. Panaullah and Md. A. Salam. 2024. Constraints and Opportunities of Agricultural Development in *Haor* Ecosystem of Bangladesh. Ecologies. 5(2): 256-278. https://doi.org/10.3390/ecologies5020017

Chandra, R. J., P. Masilamani, B. Suthakar, P. Rajkumar, S. D. Sivakumar and V. Manonmani. 2024. Effect of Moisture Content on Combine Harvested Seed Crop and its Quality. *J. Exp. Agric. Int.* 46 (3):114–138. https://doi.org/10.9734/jeai/2024/v46i32331

Day, M., M. Z. Haider and A. K. Datta, 2022. Modern technology adoption by the rice farmers in the South-West Region of Bangladesh. *Khulna University Studies*, 175-188. https://doi.org/10.53808/KUS.2022.ICSTEM4IR.0057-se

Fan, Q., and V. B. Salas Garcia. 2018. Information Access and Smallholder Farmers' Market Participation in Peru. *J. Agric. Econ.* 69(2), 476–494. https://doi.org/10.1111/1477-9552.12243

Ghosh, M. K., M. R. Karim, F. U. R. Orpita, M. L. Jahan, F. Simi and M. A. A. Sony. 2023. Exploring Farmers Perspectives on Modern Agricultural Technology: A Study in Chapainawabganj District. *European Journal of Agriculture and Food Sciences*, **5**(4), 19-27.

Gujarati, D. N. 1995. Basic econometrics (4th ed.). United State Military Academy.

Hoq, M. S., S. K. Raha and M. I. Hossain. 2021. Livelihood Vulnerability to Flood Hazard: Understanding from the Flood-prone *Haor* Ecosystem of Bangladesh. *Environ. Manag.* 67(3), 532–552. https://doi.org/10.1007/s00267-021-01441-6

Hosmer, D.W., S. Lemeshow, R. X. Sturdivant, 1989. Applied logistic regression, 3rd Edition. Wiley Ser. Probab. Stat. 528 https://www.wiley.com/enus/Applied+Logistic +Regression%2C+ 3rd+Edition-p-9780470582473.

Hossain, M.A., H. Rahman, M. M. Ahmmed, A. U. Khan, M. A. Hossen and B. C. Nath. 2023. Development of a Power Tiller Operated Safe Grain Cleaner. *American Journal of Pure and Applied Biosciences,* 5, 116-123. https://doi.org/10.34104/ajpab.023.01160123

Huda, M. K. 2004. Experience with modern and hybrid rice varieties in *haor* ecosystem: Emerging Technologies for Sustainable Rice Production. In *Twentieth national workshop on rice research and extension in Bangladesh. Bangladesh Rice Research Institute. Gazipur-1701* (pp. 19-21).

Huda, M.D., B. C. Nath, S. Paul, M. G. K. Bhuiyan, S. Islam and M. M. Islam. 2019. Design and Development of a Head Feed Mini Combine Harvester Suitable in Bangladesh Condition. *J. Agric. Eng*. 42, 73-92.

Islam, A., J. Rana, Z. Hasan, J. A. Soeb, S. Kayshar and F. Jubayer. 2022. Challenges towards raising agro-machinery industries in Bangladesh: Conceptualizing a multitasking framework for action. *Multidisciplinary Reviews,* 5(3), 1–6. https://doi.org/10.31893/multirev.2022015

Islam, M. M., K. Ujiie, R. Noguchi and T. Ahamed. 2022. Flash flood-induced vulnerability and need assessment of wetlands using remote sensing, GIS, and econometric models. *Remote Sens. Appl. Soc. Environ.*, 25, 100692. https://doi.org/10.1016/j.rsase.2021.100692

Islam, S. M. F. and Z. Karim. 2019. World's demand for food and water: The consequences of climate change. In *IntechOpen eBooks*. https://doi.org/10.5772/intechopen.85919

Kabir, M. J., M. S. Kabir, M. A. Salam, M. A. Islam, M. I. Omar, M. A. R. Sarkar, M. C. Rahman, A. Chowdhury, M. S. Rahaman, L. Deb, M. A. Aziz, A. B. Siddique, M. A. Mandal.

2020. Harvesting of *Boro* Paddy in *Haor* Areas of Bangladesh: Interplay of Local and Migrant Labour, Mechanized Harvesters and COVID-19 Vigilance in 2020. *Bangladesh Rice Research Institute.* https://hdl.handle.net/10419/243304

Kabir, M. S., M. Salam, A. Islam, M. A. R. Sarkar, M. Mamun, M. Rahman, B. Nessa, M. Kabir, H. Shozib, M. Hossain, A. Chowdhury, M. Nasim, K. Iftekharuddaula, M. H. Bhuiyan, B. Karmakar, M. R. Haque, M. Khatun, . . . N. Rahman. 2021. Doubling rice productivity in Bangladesh: a way to achieving SDG 2 and moving forward. *Bangladesh Rice Journal*, *24*(2), 1–47. https://doi.org/10.3329/brj.v24i2.53447

Kamruzzaman, M., H. M. T. Islam, M. S. Rahman, S. Ahmed, L. F. Lipi, M. a. R. Khan, L.P Tran and A. M. K. Z. Hossain, 2024. Assessing the impacts of future climate extremes on *Boro* rice cultivation in the northeastern *Haor* region of Bangladesh: insights from CMIP6 multi-model ensemble projections. *Theor. Appl. Climatol.* *156*(1). https://doi.org/10.1007/s00704-024-05270-5

Kareem, J. A. H., J. A. H. Kareem, K.F.A. Saeed and . Faraj. 2019. Maintenance Practices in Poor Uptime of Operating Equipment Toward Dynamic of Business Issues. *Int. J. Innov. Technol. Manag.* 16(02): 1950017. https://doi.org/10.1142/S0219877019500172

Khan, F. U., M. Nouman, L. Negruț, J. Abban, L. M. Cismaş and M. F. Siddiqi, 2024. Constraints to agricultural finance in underdeveloped and developing countries: a systematic literature review. *Int. J. Agricult. Sustain.* 22(1). https://doi.org/10.1080/14735903.2024.2329388

Khandokar, S., M. A. M. Miah, K. M. Khatun, N. Akhter and N. D. Kundu. 2016. Profitability and Resource Use Efficiency of Winter Vegetables Production in Selected Areas of Bangladesh. *Bangladesh Med. Res. Counc. Bull.*12(2):127-137.

Khatun, M., M. B. Hossain Tanvir, S. Khandoker and N. D. Kundu. 2014. Constraints to Access credit and its Impact: A Study of Farm Households. *Int. J. of Bus. Soc. Sci. Res*. 1(3): 195-204.

Khush, G. S. 2005. What it will take to Feed 5.0 Billion Rice consumers in 2030. *Plant Molecular Biology*, *59*(1), 1–6. https://doi.org/10.1007/s11103-005-2159-5

Kisku, U. and A. Singh. 2022. A Review on Custom Hiring Services under Indian Conditions: Farmer’s Perception, Associated Factors, Constraints, and Suggestions. *Asian Journal of Agricultural Extension, Economics and Sociology,* 8–27. https://doi.org/10.9734/ajaees/2022/v40i111680

Kothari, C. R. 1990. Research Methodology: Methods & Techniques (First Edition), Ansari Road, Daryaganj, New Delhi 110002

Kundu, N. D.. M. S. Uddin, M. M. Islam, M. Khatun, S. Khandoker and M. S. Hoq. 2022. Determinants, Challenges and Opportunities of Pulses Crop in Southern Char Land Areas of Bangladesh. *The Journal of the Bangladesh Agricultural Economists Association.* Volume XVII, Page: 91-102.

Kundu, N.D., M. H. K. Sujan, M. R. Sarker, M. Sultana, M. T. Uddin, H. Bhandari, M. A. R. Sarker. 2024. Climate-smart practice: level of effectiveness and determinants of *Sorjan* farming adoption in coastal Bangladesh. *Environ. Dev. Sustain.* https://doi.org/10.1007/s10668-024-05780-2

Kundu, N. D., M. T. Uddin, A. S. Shama, M. N. Sattar, M. K. Majumder, M. T. I. Tushar, and M. M. Islam, 2025. Does the adoption of improved pulse technologies increase farm profitability in the face of climate risk? Evidence from coastal Bangladesh. *Environ. Chall.* 101384. https://doi.org/10.1016/j.envc.2025.101384

LaValley, M. P. 2008. Logistic Regression. Circulation 117 (18), 2395–2399. https://doi.org/10.1161/CIRCULATIONAHA.106.682658.

Malanon, H. G., and M. I. Pabuayon. 2022. Pattern and Determinants of Rice Combine Harvester Adoption in Isabela, Philippines. *Asian J. Appl. Sci.* 10(5). https://doi.org/10.24203/ajas.v10i5.7050

Mamun, M. a. A., S. a. I. Nihad, M. R. Sarker, M. a. R. Sarkar, M. I. Hossain, and M. S. Kabir, 2024. Spatiotemporal mapping of rice acreage and productivity growth in Bangladesh. *PLoS ONE*, *19*(3), e0300648. https://doi.org/10.1371/journal.pone.0300648

Nasim, M., A. Khatun, M. Kabir, A. Mostafizur, M. Mamun, M. Sarkar, M. Salam, and Kabir. 2021. Intensification of Cropping through Utilization of Fallow Period and Unutilized Land Resources in Bangladesh. *Bangladesh Rice J.* 25(1), 89–100. https://doi.org/10.3329/brj.v25i1.55181

Nath, B. C., M. D. Huda, M. M. Rahman and S. Paul. 2021b. Essential Steps for DevelopingRiceHarvestMechanization in Bangladesh. *Cutting-Edge Research in Agricultural Sciences,* 7, 109-125. https://doi.org/10.9734/bpi/cras/v7/1535F

Nath, B. C., Nam, M. D. Huda, M. M. Rahman, P. Ali and S. Paul. 2017. Status and Constraint for Mechanization of Rice Harvesting System in Bangladesh. *Agric. Sci.* 8, 492-506. https://doi.org/10.4236/as.2017.86037

Nath, B. C., S. Paul, M. D. Huda, M. A. Hossen, M. Bhuiyan. and A. S. Islam. 2022. Combine Harvester: Small Machine Solves Big Rice Harvesting Problem of Bangladesh. *Agric. Sci.* 13, 201-220. https://doi.org/10.4236/as.2022.132015

Pagare, V., S. Nandi, and D. K. Khare. 2019. Appraisal of Optimum Economic Life for Farm Tractor: A Case Study. *Econ. Aff.* 64(1), 117–124. https://doi.org/10.30954/0424-

2513.1.2019.15

Rahaman, Md. S., A. R. Sarkar, L. Deb, J. Kabir, Sarker, Siddique. 2018. Economic Investigation of BRRI dhan29 and Hybrid Rice Production in Bangladesh: The Case of *Haor* Area. *Int. J. Nat. Soc. Sci.* 5(1):35-43. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3128122

Rahman, M., M. Islam, M. Rahaman, M. Sarkar, R. Ahmed and M. Kabir. 2021. Identifying the threshold level of flooding for rice production in Bangladesh: An Empirical analysis. *J. Bangladesh Agric. Univ. 0*, 1. https://doi.org/10.5455/jbau.53297

Raji, E., Ijomah and . Eyieyien. 2024. Improving agricultural practices and productivity through extension services and innovative training programs. *Int. J. Appl. Res. Soc. Sci.* 6(7), 1297–1309. https://doi.org/10.51594/ijarss.v6i7.1267

Roy, S. 2024. Farmland Challenges in the *Haor* Basin of Bangladesh: Nature and Solutions. *Turkish JAF Sci. Tech.* 12(12), 2501–2507. https://doi.org/10.24925/turjaf.v12i12.2501-2507.6957

Ruiz-Garcia, L. 2023. Agricultural Combine Remaining Value Forecasting Methodology and Model (and Derived Tool). *Agriculture,* 13(4), 894.https://doi.org/10.3390/agriculture13040894

Uddin, M. T., Dhar. 2018. Government input support on Aus rice production in Bangladesh: impact on farmers' food security and poverty situation. *Agric. Food Sec.* 7(1): 14.

Uddin, M. T., Dhar, N. Hossain. 2018. A Socioeconomic Study on Farming Practices and Livelihood Status of *Haor* Farmers in Kishoreganj District: Natural Calamities Perspective. *Bangladesh Journal of Extension Education,* 30(1): 27-42.

USDA (United State of Department of Agriculture). Rice production by country—world agricultural production 2020/2021. World agricultural production. Available: http://www. http://www.worldagriculturalproduction.com/crops/rice.aspx

Vortia, P., M. Nasrin, Bipasha, Islam. 2019. Extent of Farm Mechanization and Technical Efficiency of Rice Production in Some Selected Areas of Bangladesh. *Geo Journal*. 86: 729-742.

Walker, E., D. Fancourt and , Mak. 2024. Individual- and country-level socioeconomic predictors of community group membership across 50 countries in the World Values Survey. https://doi.org/10.31235/osf.io/8v5wc

Zheng, L., L. Su, and S. Jin. 2023. Reducing land fragmentation to curb crop land abandonment: Evidence from rural China. *Can. J. Agric. Econ.* 71, 355–373. https://doi.org/10.1111/cjag.12335.