Received: 16 January 2024 | Revised: 15 August 2024 | Accepted: 20 August 2024

DOI: 10.1002/jsf2.216

RESEARCH ARTICLE

JSFA Reports SCI

Determinants of crop diversification and its impact on farmers' income: A case study in Rangpur District, Bangladesh

Md Sayemul Islam[1] | Hasneen Jahan[2] | Nishat Sultana Ema[2] | Md. Rubel Ahmed[2]

[1]Department of Agricultural Economics & Economics, Montana State University, Bozeman, Montana, USA

[2]Department of Agricultural Economics, Bangladesh Agricultural University, Mymensingh, Bangladesh

Correspondence
Hasneen Jahan, Department of Agricultural Economics, Bangladesh Agricultural University, Mymensingh, Bangladesh.
Email: hasneenjahan@gmail.com

Funding information
Australian Centre for International Agricultural Research, Grant/Award Number: WAC/2020/148

Abstract

Background: In the face of rising global food demand, climate change, and economic uncertainties, crop diversification has emerged as a crucial tool for achieving both economic and environmental sustainability. In Bangladesh, where the economy heavily relies on agriculture, crop diversification can play a vital role in enhancing farmers' livelihoods and domestic food production.

Results: This study focuses on Rangpur district, an agricultural hub in Bangladesh, analyzing data from 122 farmers to assess the status, determinants, and effects of crop diversification. The Simpson Diversification Index (SDI) analysis revealed that 29% and 68% of the farmers exhibit very high and high degrees of crop diversification, respectively. The Tobit model identified significant drivers of crop diversification, including education, household size, farming experience, non-farm income, mobile phone information access, experience with climatic shocks, and land type. Additionally, the Log-Linear model indicated that each unit increase in the SDI score corresponds to a 2.41% increase in farmers' income.

Conclusion: The study demonstrates that crop diversification is a key strategy for enhancing economic sustainability and increasing income among farmers in Bangladesh. By improving both economic outcomes and resilience, crop diversification supports sustainable agricultural practices in the region.

KEYWORDS
Bangladesh, crop diversification, economic resilience, farmer's income, Simpson diversification index, Tobit

INTRODUCTION

As the world population expands and the demand for food and proper nutrition increases, ensuring food security has become a crucial challenge for agricultural systems, particularly in developing countries like Bangladesh. With ∼38% of the labor force engaged in farming, Bangladesh's economy heavily depends on the agriculture.[1] To meet the rising food demands of its growing population, it is essential for the nation to not only fulfill basic food requirements but also enhance farming profitability and ensure nutritional security. Globally, the decline in crop diversity poses significant risks to food security, especially in economies like Bangladesh. The heavy reliance on a narrow range of staple crops, driven by global agricultural practices and market dynamics, has decreased resilience to pests, diseases, and climate change. This reduction in crop diversity undermines the sustainability of agricultural systems, making them more vulnerable to various shocks and stresses.

Despite rapid reductions in poverty, hunger and food insecurity continue to be major issues in Bangladesh. Over 42.3 million people are experiencing Emergency levels of hunger, with more than 1.1 million individuals enduring catastrophic hunger conditions[2] Children under the age of five have remarkably high rates of stunting, with 36% experiencing chronic malnutrition and 14% experiencing acute malnutrition.[3]

Historically, the country has been primarily reliant on a few primary crops, including rice, jute, and wheat. To maximize farmers' income and enrich the nation's basket of food choices, crop diversification should receive ardent attention from the authority level. Crop diversification is the process of farming multiple varieties of crops from the same or other species in the same or different species in each region through rotations and/or intercropping. The fundamental feature and most well-understood idea of crop diversification is the addition of more crops to the existing cropping system, also known as horizontal crop diversification. It can also be defined as the substitution or addition of more crops to an existing farming system.[4]

While crop diversification is a prevalent and dominant practice in the developed world, and in some cases in developing nations, Bangladesh is still lagging, despite having suitable land and environmental features. Gosle (2020) used the crop effective richness (CER) index to illustrate crop diversification in the USA. The study found that the Lake States had the highest average CER of 5.3, while California boasted the highest maximum CER per grid cell at 17.5.[5] Significant diversity was also noted in the Northern Great Plains and Northern Atlantic Slope. In Poland, the crop diversification index is 0.59, indicating an average level of diversification[6]. In developing nations, Gebiso et al. (2023) reported an average SDI score of 0.48 for Ethiopia.[7] Similarly, Abdulla and Iroda (2021) found that Uzbekistan's SDI score of 0.56 reflected satisfactory crop diversification.[8] Bellon et al. (2020) noted a moderate SDI score of 0.54 for Ghana.[9] In contrast, India demonstrated a very high level of diversification, with an SDI score of 0.76 over the years 1995–1996 to 2019–2020.[10]

Since the production of important staples like cereals alone cannot satisfy sustainable development and the requirement to provide food security, diversifying crops has been vital for developing countries.[11] Bangladesh's government has implemented several measures and regulations to encourage farmers to diversify their crop production. These efforts have included the adoption of high-yielding crop varieties, investment in Research and Development (R & D), and the provision of farmer training and extension services.[12] The Crop Diversification Program (CDP) was initiated by the Bangladeshi government in the 1990s and has been carried out in various sections of the country to this day.

Crop diversification is extremely effective in resolving the various negative repercussions of rice monoculture and maintaining agricultural sustainability. It increases public access to food and nutrition while also promoting rural and agricultural growth.[13] Fertile soil conditions, in particular, allow farmers to grow a greater diversity of crops with a high potential for profitability, especially given the abundant water sources, including surface water and groundwater extracting technology. It was thought that growing a single crop over a vast region would boost production and streamline agricultural operations[14].

High-yielding varieties of staple crops such as rice, wheat, and maize became the focus of agricultural production as the objective of achieving food security for fast-rising populations became a driving force. However, the downsides of monocultures quickly became obvious. Monocropping resulted in soil nutrient depletion, increased vulnerability to pests and diseases, and decreased resilience to environmental pressures.[15] Furthermore, monocultures' high reliance on synthetic fertilizers, pesticides, and herbicides had negative consequences on ecosystems and human health. It became clear that a more sustainable and resilient agriculture system was required.

Diversification of crops has received renewed attention in recent years because of the multiple benefits it provides for agricultural sustainability, resilience, and food security. Crop diversification can boost production, enhance farmers' livelihoods, enrich biodiversity, and assist the delivery of ecosystem services when combined with agricultural techniques, including intercropping, rotations, and agroforestry.[16] Farmers may also improve soil health, minimize pest and disease pressures, adapt to climate change, and assure a more stable and diverse food supply by producing various crops. In numerous situations, it has been discovered that diverse cropping systems are stronger, better able to manage potential climatic hazards, and capable of stabilizing and increasing farm revenue in the face of adverse climate changes.[17] Crop diversification benefits farmers and ecosystems while also helping to construct a more sustainable and resilient agriculture system for the future.

Recent studies collectively underline the ongoing transformation in crop diversification with a notable emphasis on high-value and commercial crops at both state and household levels. Studies in Northern Ghana[18] and West Bengal[19] revealed a growing trend of agricultural diversification, measured by the Herfindahl Diversification Index. Himachal Pradesh's case[20] aligned with this pattern, showing a state-level shift toward fruit and vegetable crops. Further, another study[21] revealed Maharashtra's diversified grains, stagnant pulses, and expanding commercial crop diversification from 1960 to 2013, using Herfindahl and Modified Entropy indices.

A myriad of articles has attempted to explore the determinants of crop diversification. Baba and Abdulai[18] in Northern Ghana identifies key determinants such as occupation, technology adoption, labor, extension contact, and farm size. He also emphasized the positive correlation between crop diversification and improved household food security. Rahman and Chima's study[22] in Southeastern Nigeria underscores the role of farm size as a major driver of crop diversification and profitability, alongside variables like market access and extension services. Research led by Thayaparan[23] in Kotagala delves into the determinants of crop diversification among vegetable farmers, revealing the positive influence of education, land size, and market distance. A study[24] in Zambia's Dundwa Agricultural Camp highlights the positive impact of gender, cash crop production, and investment in farming equipment on crop diversity, while age, farm size, and market access exhibit negative associations.

Further, Dube and Guveya's study in Zimbabwe[25] emphasizes gender, education, livestock units, irrigation access, farmer association membership, and market access as critical factors influencing crop diversification. A research[26] in Ethiopia's Sinana District identifies family size, access to fertile farm plots, and extension services as favorable factors, contrasting with the negative influence of household head age and engagement in non-farm activities. These findings resonate with an assessment of eastern India[27], where a gradual shift toward high-value crops is observed, influenced by technology, education, and infrastructure. Another study in Malawi and Tanzania[12] reveals that historical diversification decisions, coupled with rainfall shocks, impact subsequent diversification, with land and household assets influencing farmers' choices. Mesfin et al. (2011) in eastern Ethiopia underscore the importance of factors like access to market information, irrigation intensity, machinery ownership, livestock size, extension contact, number of farm plots, and farm location in shaping crop diversification patterns.[28]

Lastly, Kemboi et al.'s (2020) study in Kenya underscores age, crop types, cropping systems, access to financing, and irrigation facilities as constraints affecting farmers' participation in diversified cropping systems. Together, these studies provide a comprehensive picture of the complex interplay of factors influencing agricultural diversification globally, offering valuable insights for policymakers and practitioners seeking sustainable agricultural development.[29]

Meanwhile, some literature has tried to link crop diversification with farmers' increased income. Li et al. (2021) in Southern China found that farmers with larger land and diverse crops had higher incomes.[30] Wang et al. (2021) in South Dakota noted 34.87% of farmers experienced a 5%–15% profit increase through crop diversification.[31] Basantaray and Nancharaiah (2017) in Odisha revealed highly diverse districts had higher average agricultural incomes, emphasizing the positive link between crop diversification and income, with medium and marginal farmers playing crucial roles.[32] These studies collectively showcase the positive relationship between crop diversification and farm income, considering factors like crop variety, region, and specific crop choices. However, on the contrary, Sen et al. (2017) in India highlighted that diversifying farm revenue, especially with auxiliary and horticultural crops, does not universally boost income.[33]

The existing literature lacks a dedicated study on the status and drivers of crop diversification in Bangladesh, and also about its impact on farmers' income. Given Bangladesh's challenges in ensuring food security, exacerbated by climate change projections affecting rice and wheat production, understanding the dynamics of crop diversification is crucial. This study focuses on northern Bangladesh, aiming to fill this research gap. The findings are expected to offer insights into the current state of crop diversification, the driving factors behind this agricultural practice, and its effect on farmers' income. This information not only benefits stakeholders seeking a comprehensive overview of crop diversification in the region but also aids in developing strategies to protect economically sustainable farm ecosystems.

The significance of this study extends to providing guidance for authorities, government agencies, planners, academicians, and students, contributing to a better understanding of the future of agricultural diversification in Bangladesh. As the nation grapples with population density and climate-related challenges, this research becomes a valuable resource for informed decision-making and sustainable agricultural practices. The objective of this research is thus to explore the state of crop Diversification, identify the factors of the degree of crop diversification, and study the effect of crop diversification on farmers' income. The rest of the paper is organized as the following sections: Section 2 discusses the Materials and methods, Section 3 underscores Results and discussion, followed by Section 4 with conclusions.

MATERIALS AND METHODS

Study area and data collection

We conducted our study in Rangpur district, which is situated in the northern part of Bangladesh (Figure 1). Motivations behind selecting this region was this northern Bangladesh is the agricultural hub of the country and lion share of the agricultural produce come from this region. Additionally, Rangpur district is known for its diverse range of crops and farming practices, making it an ideal location to study agricultural processes and their impact on the local economy. Moreover, the region's geographical location provides unique insights into the challenges faced by farmers in terms of climate change and natural disasters, further emphasizing the significance of our study in this specific area. Hence, incorporating this area will help us better explore crop diversification. Moreover, communication facilities were good,

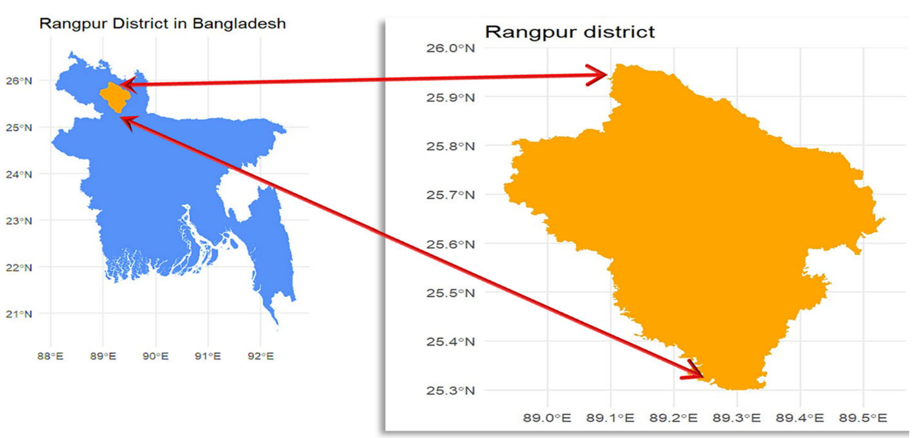

FIGURE 1 Map of the study area.

and the study areas were easily accessible, allowing the researcher to complete the field work.

The data collection period lasted from June to July 2023 using a multistage sampling technique. In the first stage, the Mithapukur upazila in Rangpur district was purposefully chosen. In the second stage, 122 farmers were chosen at random from various villages in this upazila. To ensure the robustness of our study's sample size in detecting significant effects, we conducted a power calculation using the "pwr" package in R. Setting the parameters at a default effect size ($d = 0.5$), alpha level of 0.05, and a desired power of 0.8, our analysis indicated that a minimum of 34 participants would be sufficient to detect significant effects. This requirement is considerably lower than our actual sample size, affirming the adequacy of our sample size for the study's objectives.

An interview schedule was meticulously designed to gather the required information through a questionnaire. Initially, a draft schedule was formulated, and the Kobo Tool Box was used for questionnaire development. Subsequently, the schedule underwent pretesting to validate the relevance of questions and responses. Later, Excel, STATA 15.0, and R software were used to perform the analyses.

Simpson diversification index

This study utilizes the Simpson Diversification Index (SDI) to measure the state crop diversification. The SDI is calculated as follows:

$$\mathrm{SDI} = 1 - \sum\nolimits_1^n P_i^2 \tag{1}$$

P is the proportionate area of the ith crop in the overall cultivated area; n represents the total number of crops grown by the household. The SDI value ranges from 0 to 1. A higher value denotes a high degree of crop diversification, whereas a lower value indicates the flipside.

Tobit model

To estimate the key determinants of crop diversification following model is used:

$$\mathrm{CD} = F(X, D, Z) \tag{2}$$

where CD is the crop diversification index, X_i is the set of socio economic variables, D_i is the set of demographic variables, and Z_i is the set of infrastructure and topological variables.

Because crop diversification is measured by the SDI, its values were used as the dependent variable. The indices' values are censored because some of the values cluster at the limit. This censoring could be caused by an underlying unobserved (latent) variable that determines farm-level diversity. A censored regression (Tobit) model is an appropriate econometric model for such a variable. It accounts for dependent variable censoring, which occurs at both the lower and upper limits of each of the indices. It describes the relationship between the independent variables and a non-negative dependent variable. It is a Probit model expansion.[34] The Tobit model is defined by the latent variable Y^*. Tobit specifications are typically expressed in terms of index function.[35] The model is as follows:

$$\boldsymbol{Y_i^*} = \boldsymbol{\beta}' \boldsymbol{X_i} + \boldsymbol{\varepsilon_i} \tag{3}$$

where Y_j^* is a latent variable (unobserved for values smaller than lower limit and greater than upper limit) representing crop diversification index, X_i is a vector of explanatory variables, β' is a vector of unknown parameters to be estimated, and ε_i represents the disturbance term which are independently and identically normally distributed with zero mean and constant variance σ 2, that is, $\epsilon_i \sim$ NID $(0, \sigma^2)$. In addition, we report the marginal effects associated with the outcome of the Tobit model.

The stated model for our analysis is as follows:

$$\boldsymbol{Y}_i = \boldsymbol{\beta_0} + \sum \boldsymbol{\beta_i X_i} + \sum \boldsymbol{\delta_i D_i} + \boldsymbol{\varepsilon_i} \tag{4}$$

Y_i^* is the dependent variable, and it indicates the value of the Simpson Diversification Index (SDI). In the case of the Simpson index value, the researcher used 0 as the lower limit and 1 as the upper limit of the dependent variable. X_is are continuous explanatory variables, whereas D_is are dummy explanatory variables, ϵ_i the error term, β_0 represents intercept of the model, β_i represents the coefficients of continuous explanatory variables, and δ_i represents the coefficients of dummy explanatory variables to be estimated.

Incorporating socio-economic variables (X) into the Tobit model offers a robust framework for analyzing crop diversification determinants among farmers. These variables, including income level, access to credit, and land ownership, are hypothesized to influence diversification through their effects on resource endowments, risk preferences, and opportunity access. Higher income levels enable investment in diverse crops, mitigating price fluctuation risks, aligning with diversification as a risk management strategy. Access to credit supports new crop ventures by facilitating necessary investments, while land ownership impacts the scale of diversification, with larger holdings allowing more flexibility. Secure land tenure encourages long-term diversification strategies. Demographic factors like age, education, and experience affect farmers' responses to economic incentives, with younger, more educated farmers potentially adopting new technologies and diversifying more. Multicollinearity among variables was assessed using variance inflation factor (VIF) diagnostics, confirming that it is not a significant issue, thereby enhancing model reliability.

Log-Lin model

To analyze the effect of crop diversification on farmers' income, we resorted to a Log-lin model. There are many reasons for choosing this. First, the distribution of the dependent variable (income) seems to be

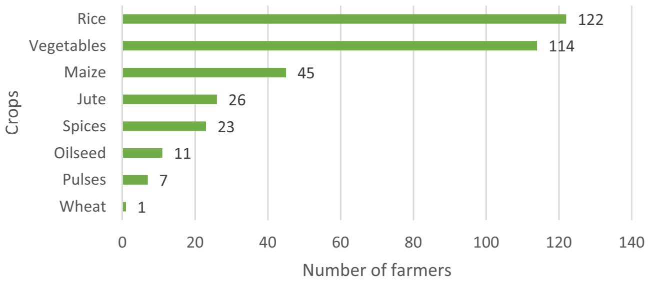

FIGURE 2 Type of crops grown in study area.

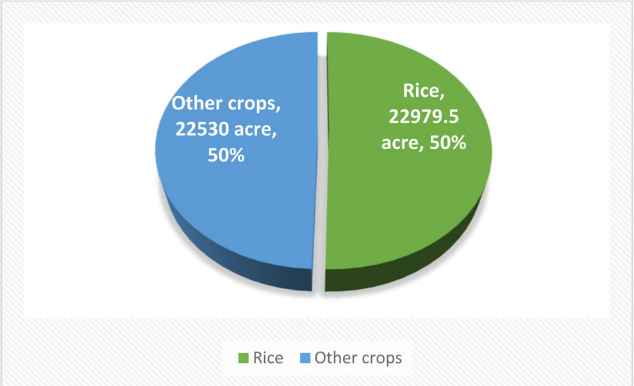

FIGURE 3 Crop acreage of the study area.

non-linear. Hence, to linearize its value, we converted it to log form. Second, the rest of the independent variables are linear in general, hence we kept them in the base form.

The model is structured according to the following equation:

$$\mathrm{Ln}Y_i = \beta_0 + \beta_i X_i + \mu \quad (5)$$

where Y_i is the dependent variable; β_0 and β_i are the constant and coefficients, respectively, μ is the error term, and X_i is the set of independent variables.

The dependent variable is the farmers' annual income. The main independent variable of interest is Degree of crop diversification (SDI). We have also controlled for Farmer's age, Farmer's education, Farm size, Farming experience, Access to training, and Off-farm income.

RESULTS AND DISCUSSION

Status of crop diversification

Figure 2 depicts the crops grown in the research area. In addition to rice, a substantial number of other crops are grown. Rice is grown by 122 farmers. Vegetables are claimed to be grown by 114 farmers. 45 farmers cultivate maize, 26 farmers cultivate jute, 23 farmers cultivate oilseed, 11 farmers cultivate pulses, and 1 farmer cultivates wheat. It should be noted that one farmer usually tends to cultivate more than one crop.

Further, Figure 3 highlights the crop acreage concerning rice and other crops for an entire year. It is depicted that both rice and the rest of the other crops equally share the total cultivated area. This finding refers to the fact that the sample farmers are not prone to monoculture, and they are diversely utilizing their land.

TABLE 1 Results of Simpson Diversification Index (SDI).

Diversification type (index score)	Number of farmers	Percentage of the farmers
Very high (0.8 and above)	35	28.69
High (0.6 to 0.79)	83	68.3
Moderate (0.4 to 0.59)	4	3.28
Low (below 0.4)	0	0
Particulars		**Value**
Average SDI score		0.729
Average number of crops cultivated		4.87 ~ 5

We classified farmers into four levels of crop diversification based on the SDI score. Farmers with an index score of 0.8 or above were considered Very High diversified, those with a score of 0.6 to 0.79 were considered highly diversified, those with a score of 0.4 to 0.59 were considered moderately varied, and those with a score of less than 0.4 were labeled Low diversified. Table 1 shows that the crop diversification status of 35 farmers (29%) was very high. Following that, 83 farmers (68.3%) had a high level of crop diversification. Further, just four farmers were discovered to have Moderate crop diversification. Surprisingly, our finding indicates that no farmers fall under the "Low Diversification" category, implying that all surveyed farmers have some level of crop diversification on their lands. Besides, the mean SDI score is 0.729 and the average number of crops produced by farmers is 5, which also signifies that on average farmers practice high crop diversification and most of them cultivate a various range of crops. This is a positive sign as it indicates a shift from traditional mono-cropping practices that have inherent risks. Our findings show an SDI score that is comparable to Rajshahi's score of 0.75, and it significantly surpasses those of Thakurgaon (0.62), Kurigram (0.45), and Naogaon (0.37).[36] Furthermore, our SDI score is higher than Assam's, where Choudhury and Dey (2021) reported a score of 0.59.[37] These results indicate that crop diversification in our study area is exceptionally high. It is evident from the results that most farmers engage in extensive crop diversification, with only a small fraction practicing no diversification at all.

Determinants of the degree of crop diversification

Table 2 reports the results of the Tobit model. Several significant variables shed light on the complex dynamics present in agricultural systems influencing farmers' crop diversification levels. The farmer's age

TABLE 2 Results from Tobit model on the determinants of the degree of crop diversification.

Variable	Coefficient	Std. error	Marginal effect	*t*-stat	*p*-value
Age of the farmer	−0.0031**	0.0014	−0.0023	−2.21	0.034
Education of the farmer	0.0198*	0.0098	0.0269	2.0200	0.0870
Household Size	0.0095*	0.0049	0.0140	1.9070	0.0580
Farm size	0.00003	0.00008	0.00001	0.3800	0.7040
Farming experience	0.0031**	0.0014	0.0042	2.2400	0.0270
Non-farm income	−0.0002**	0.0001	−0.0002	−2.0200	0.0460
Access to credit	−0.0122	0.0242	−0.0151	−0.5000	0.6150
Received agricultural information using mobile phone	0.0543*	0.0242	0.0681	2.243	0.0627
Experience of climatic shocks	0.0792*	0.0421	0.0597	−1.8812	0.0825
Land type					
High	0.0495***	0.0182	0.0347	2.7200	0.0080
Medium High	0.026**	0.009	0.0294	2.88	0.0216
Medium Low	0.109	0.165	0.197	0.66	0.318
Low	0.270	0.487	0.294	0.5541	0.398
Access to extension services	0.0145	0.0246	0.0258	0.5900	0.5580
Cons	1.0400	0.1240		8.3700	0.0000
Model diagnostics					
Log likelihood					77.667
p > Chi-square					0.026
Number of observations					122

***Statistically significant at 1% level.
**Statistically significant at 5% level.
*Statistically significant at 10% level.

stands out as a significant factor, as evidenced by the negative coefficient of −0.0031. This suggests that the expected probability of crop diversification falls with increasing farmer age. Age has a marginal effect of −0.0023, which means that for every year the farmer ages, the probability of diversification decreases by 0.23% points. This observation is consistent with earlier research, which highlights the older farmers' resistance to crop diversification and their recurrent adherence to conventional farming practices.[26,36] These studies suggest that older farmers may be more resistant to change and less likely to adopt new farming practices, including crop diversification. This could be due to the factors such as risk aversion, lack of knowledge or resources, or a preference for traditional methods that they are familiar with. It also implies that older farmers may have difficulty adapting to modern farming techniques or may be limited by conservative farming practices. For example, an older farmer who has traditionally grown rice may be less open to switching to high-value cash crops, fearing that new methods could jeopardize their established income. Additionally, older farmers might face physical limitations or lack the technological skills needed to manage diversified cropping systems. These factors can make them more resistant to change and less likely to diversify their crops, preferring to stick with familiar and less risky options. Tailor-made training programs and technology adoption initiatives, for example, could potentially mitigate the negative impact of age on diversification.

Education, on the other hand, emerges as a positive driver of crop diversification, with a coefficient of 0.0198. The predicted probability of diversification increases by 2.69% for each additional year of education. Educated farmers have a better ability to access information, which leads to the adoption of diverse cropping systems, according to the research from Kenya by Aheibam et al. (2017) and Kemboi et al. (2020).[29,38] The positive association between education and crop diversification highlights the pivotal role of knowledge in shaping agricultural practices. Educated farmers are more likely to be aware of high-yielding crop varieties, modern farming techniques, and the benefits of diversification. Furthermore, education equips farmers with the skills to effectively manage risks and adapt to changing environmental conditions, which are crucial factors in successful crop diversification. Additionally, educated farmers are more likely to have access to credit and financial resources, enabling them to invest in diverse cropping systems and maximize their agricultural productivity. In the context of Bangladesh, previous literature indicates that educated farmers are inclined toward modern agricultural practices and are more willing to take risks.[39,40] Educated farmers in Bangladesh have greater access to online resources and are more open to innovation. Policymakers can leverage these insights by promoting educational initiatives within farming communities, fostering a culture of continuous learning and innovation. Policymakers can leverage these insights by promoting educational initiatives within farming communities, fostering a culture of continuous learning and innovation.

Household size also plays a role, with a coefficient of 0.0095 and a marginal effect of 0.0140 indicating that an additional household member correlates with an increase in diversification probability by 1.4% points. As Mesfin et al. (2011) and Rehima et al. (2013) found, larger households can manage a more diverse crop portfolio, facilitating the cultivation of high-value non-rice and cash crops.[28,41] The positive relationship between household size and crop diversification has implications for family-based agricultural systems. In the context of Bangladesh, where many farming households are family-based, larger households have the advantage of more labor resources. This enables them to grow a wider variety of crops, enhancing the resilience of their farming enterprise. The positive relationship between household size and crop diversification emphasizes the importance of considering social and economic factors in agricultural decision-making.

Further, farming experience demonstrates a significant effect, with a coefficient of 0.0031 and a marginal effect of 0.0042. An additional year of farming experience correlates with a 0.42% point increase in crop diversification probability. This finding is consistent with studies by Kanyua et al. (2013) and Dube et al. (2015), which emphasize the importance of experience in promoting crop diversification.[25,42] The positive relationship between farming experience and diversification suggests that seasoned farmers are more likely to experiment with various crops, possibly due to a better understanding of local conditions and market dynamics. This finding suggests that farmer mentorship programs or knowledge-sharing initiatives could boost the positive impact of experience on crop diversification even further.

Non-farm income has a negative coefficient, implying that farmers who earn extra money from other sources are less likely to diversify their crops. As noted by Mishra & Goodwin (1997) and Mishra et al. (2004), this aligns with the risk-reducing aspect of off-farm employment, which reduces the financial unpredictability associated with farming.[43,44] The inverse relationship between nonfarm income and crop diversification raises concerns about possible trade-offs between financial stability and agricultural diversity. A farmer who earns a steady income from a small business or remittances may feel less compelled to diversify their crops as a way to spread risk or increase income. The security of non-farm income might lead to a preference for sticking with fewer, more familiar crops rather than investing in the research and resources required for diversification. This financial cushion can diminish the urgency to explore new cropping options, ultimately limiting their engagement in crop diversification. Policymakers should carefully consider the implications of encouraging off-farm employment without jeopardizing agricultural practices' sustainability and resilience. Balancing income diversification with crop diversity strategies remains a critical challenge in fostering sustainable agriculture.

Mobile phone usage for receiving agricultural information emerges as a strong positive influencer, with a coefficient of 0.0543 and a marginal effect of 0.0681. Farmers who receive information via mobile phones witness a 6.27% point increase in diversification probability. This aligns with the role of technology in disseminating modern agricultural techniques, as observed by Conley and Udry (1998) and Dube and Guveya (2016).[25,45] The positive relationship between mobile phone usage and crop diversification underscores the transformative potential of technology in agriculture. In Bangladesh, technological interventions, particularly mobile phone use for accessing agricultural information, are pivotal in promoting crop diversification. For instance, a farmer receiving regular updates on weather patterns and market prices through a mobile app can plan better and diversify crops, accordingly, resulting in higher productivity and resilience. These tools can significantly enhance farmers' ability to adopt diverse cropping systems. However, challenges such as limited digital literacy and infrastructure gaps persist. Many farmers may not know how to use these apps effectively or lack reliable Internet access. To address these issues, government and NGO initiatives can focus on improving digital literacy by training farmers on how to use mobile technology for agricultural purposes. Additionally, investing in robust Internet infrastructure and providing subsidies for technology adoption can help bridge these gaps. Policymakers should consider these steps to fully harness the benefits of technology for sustainable agriculture in Bangladesh.

Climatic shocks positively relate to diversification, with a coefficient of 0.0792 and a marginal effect of 0.0597. Farmers facing climate shocks are 5.97% points more likely to diversify, adapting their crop selection to changing climate conditions, in line with Mulwa and Visser (2020).[46] The positive association between climatic shocks and crop diversification signals the adaptive response of farmers to environmental challenges. This finding suggests that farmers recognize the need to mitigate the risks associated with climate shocks by diversifying their crops. By diversifying, farmers can potentially reduce their vulnerability to extreme weather events and ensure a more stable and sustainable agricultural production system. As climate change becomes increasingly prevalent, farmers may proactively diversify their crops to mitigate the impact of unpredictable weather patterns. Policymakers should prioritize climate-resilient agricultural practices and provide support for farmers navigating the complexities of climate variability.

Land type, particularly higher elevation, exhibits a positive association with diversification. Farmers with high land and Medium high land witness a 3.47% and 2.94% point increase in diversification probability, respectively. This outlines the role of topographical characteristics in shaping farming practices (Islam, 2015; Derso et al., 2022).[26,36] The positive relationship between higher-elevation land and crop diversification suggests that topographical considerations, such as water logging, significantly influence farmers' crop choices. However, Access to credit, despite a positive coefficient of 0.0122, is statistically insignificant, suggesting no significant impact on diversification probability. Similarly, extension services exhibit no clear association with crop diversification.

To fully understand the results and their implications, it is essential to account for confounding factors such as regional economic conditions, market access, and infrastructure. Farmers in prosperous regions typically have better access to financial resources, technology,

TABLE 3 Result of Log-Lin regression model.

Variable	Coefficient	Std. error	*t*-stat	*p*-value
Degree of crop diversification (SDI)	0.024**	0.012	2.14	0.034
Age	−0.020***	0.007	−2.90	0.005
Education	0.054***	0.021	2.571	0.002
Farming experience	0.019***	0.006	2.770	0.007
Farm size	0.004***	0.001	4.28	0.000
Access to training	0.072*	0.037	1.904	0.081
Off-farm income	0.094***	0.026	3.615	0.000
R^2	0.768			
Adjusted R^2	0.746			
Prob > F	0.000			

***Statistically significant at 1% level.
**Statistically significant at 5% level.
*Statistically significant at 10% level.

and markets, enabling more effective crop diversification. Conversely, those in disadvantaged areas may face financial and resource constraints, limiting their ability to diversify. Market access is also crucial; farmers with better access can sell a broader range of crops, while those in remote areas might be restricted to staples. Additionally, well-developed infrastructure supports diverse agricultural practices, whereas poor infrastructure can limit diversification. Policymakers should consider these regional differences to design targeted interventions that address local needs and challenges, promoting effective crop diversification across varied contexts.

Impact of crop diversification on farmers' income

Table 3 depicts the result of the regression model highlighting the factors of farmers' yearly income. Here, the variable of interest is the degree of crop diversification of the studied farmers. However, the study also controlled farmers' age, education, farming experience, total land under cultivation, access to training, and off-farm income.

In this study, the degree of crop diversification, as measured by the SDI score, demonstrated a significant positive association with farmers' income. The coefficient of 0.024, with a *p*-value of 0.034, indicates that for every one-unit increase in the SDI score, farmers' income is expected to increase by 2.14%, holding other factors constant. This finding aligns with existing literature, highlighting the economic benefits of crop diversification. Diversifying crops allows farmers to navigate varying growing seasons and market cycles, ensuring a stable income stream throughout the year. Moreover, it opens avenues for tapping into diverse markets, catering to local demand, regional preferences, and even export opportunities. The practice of crop diversification is also linked to reduced input costs, improved ecological services, and the potential for value-added processing, contributing to long-term sustainability and aligning with the goal of poverty reduction.[47,48] By diversifying their crops, farmers can also mitigate the risks associated with climate change and pest outbreaks, as different crops have varying tolerances and resistances to these challenges. Additionally, crop diversification promotes soil health and biodiversity, as different crops have different nutrient requirements and attract diverse populations of beneficial insects.[49]

Farmer's age exhibits an inverse association with income, with a coefficient of −0.020 and a *p*-value of 0.005, indicating that younger farmers are more likely to achieve higher incomes. This is attributed to the receptiveness of younger farmers to modern agricultural technologies, accessibility to education and credit, and their inclination toward diversification, fostering innovation and boosting productivity.[47] Education plays a crucial role in income generation, as indicated by a positive association with a coefficient of 0.054 and a *p*-value of 0.002. Educated farmers benefit from modern knowledge, technology adoption skills, and informed decision-making, leading to increased efficiency, reduced costs, and higher yields. Education facilitates access to information, supports financial resilience, and empowers farmers to engage in value-added ventures, contributing to sustainable agricultural growth.[50] Farming experience is another significant determinant, with a coefficient of 0.019 and a *p*-value of 0.007. Experienced farmers leverage accumulated knowledge for skill development, decision-making, and efficiency, resulting in improved resource allocation, higher-quality yields, and access to better financing and markets. This cumulative experience enhances productivity and profitability over time. Farm size is positively associated with income, with a coefficient of 0.004, a *t*-value of 4.24, and a *p*-value of 0.000. Increasing the total area under cultivation by one decimal raises farmers' revenue by 0.4%. Larger farms can adopt modern technologies and sustainable practices, leading to enhanced productivity, reduced costs, and improved market access, emphasizing the importance of balanced land management for sustainable gains.[51] Access to training is statistically significant at the 10% level, with a coefficient of 0.072 and a *p*-value of 0.081. Farmers with training access are predicted to earn 7.2% more than those without. Training equips farmers with improved knowledge, skills, and techniques, enabling the adoption of modern agricultural practices, efficient resource management, and innovative technologies, contributing to higher income and improved livelihoods.[44] Off-farm income, with a coefficient of 0.094, is statistically significant at the 1% level. A one BDT increase in off-farm income corresponds to a 9.4% rise in farmers' income. Off-farm income acts as a crucial buffer, providing a steady cash flow, reducing dependency on seasonal agricultural earnings, and contributing to financial stability. It enables investment in farming, improving productivity, sustainability, and overall living standards.[52]

CONCLUSION

This study establishes a strong link between recent agricultural advancements in Rangpur, Bangladesh, and national interests, demonstrating how crop diversification impacts farm income and socio-economic factors. However, the study has several limitations: it focuses on a single district, which restricts its generalizability and relies on the Simpson Diversification Index (SDI), which, while useful, treats all crops equally and overlooks their economic value, labor requirements, risk profiles, and environmental impacts. The SDI also ignores temporal variability and regional contexts such as local market demands, soil types, and climate conditions, and may not capture larger-scale economic and environmental impacts. To enhance understanding, future research should use complementary indices like the Shannon-Weaver Index and Margalef's Richness Index, along with economic diversification indices, qualitative assessments, detailed case studies, and environmental impact evaluations. The study highlights the need for tailored interventions and sustainable practices, with practical recommendations for farmers to implement crop rotation, adopt intercropping strategies, and diversify crop portfolios to manage market and climate risks. Policymakers should consider subsidies for diversified crops, establish training programs for younger farmers, provide access to affordable credit, and enhance digital infrastructure for agricultural information. Promoting climate-resilient practices and supporting farmers facing climatic shocks will help mitigate risks associated with climate variability. Future research should address these limitations with longitudinal and comparative studies focusing on the environmental impact of diversification and its effects on poverty reduction and food security, providing valuable insights to guide policymakers in promoting sustainable agriculture, enhancing farmer livelihoods, and achieving national goals in poverty eradication, food self-sufficiency, and nutritional balance.

ACKNOWLEDGMENTS

This paper was made possible through the Rupantar project funded by ACIAR, Project No: WAC/2020/148.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Hasneen Jahan https://orcid.org/0000-0001-6464-5498

REFERENCES

1. Eskander SM, Barbier EB. Adaptation to natural disasters through the agricultural land rental market: evidence from Bangladesh. Land Econ. 2023;99(1):141–60.
2. World Food Programme. A global food crisis. 2024 Retrieved from: https://www.wfp.org/global-hunger-crisis
3. De Pinto A, Seymour G, Bryan E, Bhandari P. Women's empowerment and farmland allocations in Bangladesh: evidence of a possible pathway to crop diversification. Clim Change. 2020;163:1025–43.
4. Adjimoti GO, Kwadzo GT. Crop diversification and household food security status: evidence from rural Benin. Agricul Food Sec. 2018; 7(1):1–2.
5. Goslee SC. Drivers of agricultural diversity in the contiguous United States. Front Sustain Food Syst. 2020;4:75.
6. Kurdyś-Kujawska A, Strzelecka A, Zawadzka D. The impact of crop diversification on the economic efficiency of small farms in Poland. Agri. 2021;11(3):250.
7. Gebiso T, Ketema M, Shumetie A, Leggesse G. Crop diversification level and its determinants in Ethiopia. Cogent Food Agric. 2023;9(2): 2278924.
8. Abdulla P, Iroda R. Crop diversification analysis at the farm level: empirical evidence from different regions of Uzbekistan. Am J Bus. 2021;9(1):9–14.
9. Bellon MR, Kotu BH, Azzarri C, Caracciolo F. To diversify or not to diversify, that is the question. Pursuing agricultural development for smallholder farmers in marginal areas of Ghana. World Dev. 2020; 125:104682.
10. Chaudhuri AS, Singh N, Patel MJ. Socio-economic determinants of crop diversification in South Gujarat: an empirical analysis. Int J Agri Ext Soc Dev. 2023;7(1):261–4.
11. Deka S, Khan S. Status of crop diversification in Assam. Assam EcoRev. 2017;10:244–253.
12. United Nations. Crop diversification for Bangladeshi farmers boosts climate resilience and profits. 2021 Retrieved from: https://bangladesh.un.org/en/160715-crop-diversification-bangladeshi-farmers-boosts-climate-resilience-and-profits (Accessed July 25, 2024)
13. Miah MM, Haque AE, Hossaim TM, Hossain S, Rahman MS. Policy options for supporting agricultural diversification in Bangladesh. National Food Policy Capacity Strengthening Programme (NFPCSP), Food Planning and Monitoring Unit (FPMU), Ministry of Food, FAO_Bangladesh. 2013.
14. Mustafa MA, Mayes S, Massawe F. Crop diversification through a wider use of underutilised crops: a strategy to ensure food and nutrition security in the face of climate change. Sustainable Solutions for Food Security: Combating Climate Change by Adaptation. Dhaka, Bangladesh: Ministry of Food, People's Republic of Bangladesh Government; 2019. p. 125–49.
15. Gomiero T. Soil degradation, land scarcity and food security: reviewing a complex challenge. Sustainability. 2016;8(3):281.
16. Vernooy R. Does crop diversification lead to climate-related resilience? Improving the theory through insights on practice. Agroecol Sustain Food Syst. 2022;46(6):877–901.
17. Makate C, Angelsen A, Holden ST, Westengen OT. Evolution of farm-level crop diversification and response to rainfall shocks in smallholder farming: evidence from Malawi and Tanzania. Ecol Econ. 2023;205:107736.
18. Baba AR, Abdulai AM. Determinants of crop diversification and its effects on household food security in Northern Ghana. Arthaniti: J Econ Theory and Prac. 2021;20(2):227–45.
19. De UK, Chattopadhyay M. Crop diversification by poor peasants and role of infrastructure: evidence from West Bengal. J Dev Agric Econ. 2010;2(10):340–50.

20. Sharma HR. Crop diversification in Himachal Pradesh: patterns, determinants and challenges. Indian J Agric Econ. 2011;66(1):97–114.
21. Gaikwad SK, Gaikwad SP, Wagh VM, Meshram DC, Kadam AK, Muley AA, et al. Appraisal of groundwater from lithological diversity of the western coastal part, Maharashtra, India: an integrated hydrogeochemical, geospatial and statistical approaches. Mar Pollut Bull. 2022;178:113595.
22. Rahman S, Chima CD. Determinants of food crop diversity and profitability in southeastern Nigeria: a multivariate tobit approach. Agri. 2016;6(2):14.
23. Thayaparan A. Determinants of crop diversification decision and crop intensity among vegetable farmers. 2022.
24. Dube L, Numbwa R, Guveya E. Determinants of crop diversification amongst agricultural co-operators in Dundwa agricultural camp, Choma district, Zambia. Asian J Agric Rural Dev. 2016;6(1):1–3.
25. Dube L, Guveya E. Factors influencing smallholder crop diversification: a case study of Manicaland and Masvingo provinces in Zimbabwe. Int J Reg Dev. 2016;3(2):1–25.
26. Derso D, Tolossa D, Seyoum A. A double hurdle estimation of crop diversification decisions by smallholder wheat farmers in Sinana District, Bale Zone, Ethiopia. CABI Agri Biosci. 2022;3(1):1–4.
27. Kumar R, Krishna B, Sundaram PK, Kumawat N, Jeet P, Singh AK. Crop diversification: an approach for productive and climate-resilient production system. Sustain Agric Syst Technol. 2022;28:63–80.
28. Mesfin W, Fufa B, Haji J. Pattern, trend and determinants of crop diversification: empirical evidence from smallholders in eastern Ethiopia. J Eco Sustain Dev. 2011;2(8):78–89.
29. Kemboi E, Muendo K, Kiprotich C. Crop diversification analysis amongst smallholder farmers in Kenya (empirical evidence from Kamariny ward, Elgeyo Marakwet County). Cogent Food Agri. 2020;6(1):1834669.
30. Li C, Chen X, Jiang A, Lee MB, Mammides C, Goodale E. Socioeconomic determinants of crop diversity and its effect on farmer income in guangxi, southern China. Agri. 2021;11(4):336.
31. Wang T, Jin H, Fan Y, Obembe O, Li D. Farmers' adoption and perceived benefits of diversified crop rotations in the margins of US Corn Belt. J Environ Manage. 2021;293:112903.
32. Basantaray AK, Nancharaiah G. Relationship between crop diversification and farm income in Odisha—an empirical analysis. Agri Eco Res Rev. 2017;30:45–58.
33. Sen B, Venkatesh P, Jha GK, Singh DR, Suresh A. Agricultural diversification and its impact on farm income: a case study of Bihar. Agric Econ Res Rev. 2017;30(conf):77–88.
34. Gujarati DN, Porter DC. Basic Econometrics. New York: McGraw-Hill; 2003.
35. Greene WH. Econometric analysis. 4th ed. International edition New Jersey: Prentice Hall; 2000. p. 201–15.
36. Islam MM. An economic analysis of crop diversification in northern Bangladesh. (Doctoral dissertation, University of Rajshahi) 2015.
37. Choudhury S, Dey S. Crop diversification in Assam: an analysis. Stock Market Indices: An Analytical Study. Assam, India: Banijya; 2021. p. 50.
38. Aheibam M, Singh R, Feroze SM, Singh NU, Singh RJ, Singh AK. Identifying the determinants and extent of crop diversification at household level: an evidence from Ukhrul district, Manipur. Economic Affairs. 2017;62(1):89–95.
39. Sarker SA, Wang S, Adnan KM, Sattar MN. Economic feasibility and determinants of biogas technology adoption: evidence from Bangladesh. Renew Sustain Energy Rev. 2020;123:109766.
40. Farid KS, Tanny NZ, Sarma PK. Factors affecting adoption of improved farm practices by the farmers of Northern Bangladesh. J Bangladesh Agril Univ. 2015;13(2):291–8.
41. Rehima M, Belay K, Dawit A, Rashid S. Factors affecting farmers' crops diversification: evidence from SNNPR, Ethiopia. Int J Agric Sci. 2013;3(6):558–65.
42. Kanyua MJ, Ithinji GK, Muluvi AS, Gido OE, Waluse SK. Factors influencing diversification and intensification of horticultural production by smallholder tea farmers in Gatanga District, Kenya. Curr Res J Soc Sci. 2013;5(4):103–11.
43. Mishra AK, El-Osta HS, Sandretto CL. Factors affecting farm enterprise diversification. Agri Finance Rev. 2004;64(2):151–66.
44. Mishra AK, Goodwin BK. Farm income variability and the supply of off-farm labor. Am J Agric Econ. 1997;79(3):880–7.
45. Conley TG, Udry CR. Learning about a new technology: pineapple in Ghana. Am Ec Rev. 2010;100(1):35–69.
46. Mulwa CK, Visser M. Farm diversification as an adaptation strategy to climatic shocks and implications for food security in northern Namibia. World Dev. 2020;129:104906.
47. Spangler K, Burchfield EK, Radel C, Jackson-Smith D, Johnson R. Crop diversification in Idaho's Magic Valley: the present and the imaginary. Agron Sustain Dev. 2022;42(5):99.
48. Kremen C, Miles A. Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. Ecol Soc. 2012;17(4).
49. Lin BB. Resilience in agriculture through crop diversification: adaptive management for environmental change. Bioscience. 2011;61(3):183–93.
50. Ali J. Factors affecting the adoption of information and communication technologies (ICTs) for farming decisions. J Agric. Food Infor. 2012;13(1):78–96.
51. Shiferaw BA, Okello J, Reddy RV. Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices. Environ Dev Sustain. 2009;11:601–19.
52. Rai P, Maharjan S. Empowering South Asian agricultural communities: a comprehensive approach to IOT-driven agriculture through awareness, training, and collaboration. Q J Emerg Technol Innov. 2023;8(3):18–32.

How to cite this article: Islam MS, Jahan H, Ema NS, Ahmed MR. Determinants of crop diversification and its impact on farmers' income: A case study in Rangpur District, Bangladesh. JSFA Reports. 2024. https://doi.org/10.1002/jsf2.216