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Research article

# Linking farm production diversity to household dietary diversity controlling market access and agricultural technology usage: evidence from Noakhali district, Bangladesh

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## HIGHLIGHTS

- In subsistence farming, diverse agricultural production can play a vital role in ensuring diversified food consumption.
- In this study, a generalized Poisson regression estimator was used for modeling count data with under-dispersion.
- Study findings indicated that higher farm production diversity (FPD) was associated with higher dietary diversity.
- Farmer's reliance on FPD reduces when the market is more accessible and improved irrigation is used for production.
- Nutrition-sensitive agricultural practices aimed at subsistence farmers could help to achieve food diversity.

## ARTICLE INFO

*Keywords:*
Production diversity
Household dietary diversity
Smallholder farm households
Market access
Agriculture technology
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## ABSTRACT

*Background and objective:* Diversified agricultural production is considered a means to enhance food diversity at the household level, particularly in developing countries where subsistence farming is common. Given the importance of a diversified diet for human health and the persistent malnutrition problem in Bangladesh, a pressing issue is how different crops and livestock production affect household food diversification, and this study sought to answer that question.

*Methods:* Using a multistage sampling procedure, data were collected from 190 small farm holder households from Hatiya (a coastal rural sub-district of Noakhali, Bangladesh). Farm production diversity (FPD) is measured using the household biodiversity index (HBI), a simple count of all crops and livestock produced on the farm. The household dietary diversity score (HDDS) is calculated, according to Food and Agriculture Organization (FAO) guidelines, by counting 12 food groups consumed by the households in the last 24 h preceding the survey.

*Results:* On average, households consumed 6.49 food groups during the reference day, according to the household biodiversity index (HBI). The generalized Poisson log-linear regression results indicated that farm production diversity had a positive association with HDDS; one group of farm production increased the household dietary diversity (HDD) by 0.084 unit [β: 0.084, 95% CI: 0.064, 0.106; Exp (B): 1.087], an 8.7% increase in dietary diversity. Total land size, less time to reach the district market, and improved irrigation process affect dietary diversity in bivariate analysis. Farmer's reliance on production diversity reduces when the market is more accessible and improved irrigation is used for production.

*Conclusion:* Smallholder farm households in Bangladesh could benefit from context-specific, food-based nutrition-sensitive agriculture policies that focus on triangulation of diversified production, greater market access, and updated agricultural technology utilization.

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## 1. Introduction

The concept of "Agriculture-Nutrition Linkages" on strengthening food and nutrition security has become an emerging field of research due to the reciprocal interdependence of their essential components (Balaji et al., 2017). Several approaches (for instance, nutrition-sensitive programs) have been highlighted for improving food quality and lowering malnutrition through planned agricultural policies and activities. Agriculture has long been used to combat hunger, and it can be utilized to meet the nutritional needs of smallholder farmers who rely on their crops and livestock to make a living (Gillespie et al., 2012; Hawkes and Ruel, 2006).

Despite significant agricultural achievements in the recent decade, particularly in the production of staple foods, undernutrition in Bangladesh remains as a major concern. According to a recent Bangladesh Demographic Health Survey, 31% of children under the age of five are stunted; 9% of them have severe stunting, an indication of chronic malnutrition (Research, Training - NIPORT, Health, Family Welfare, & ICF, 2020). Preschoolers, adolescents, and pregnant women continued to experience micronutrient deficiencies, with low food quality cited as a contributing factor (Ahmed et al., 2017). Various nutrition-specific interventions and initiatives have been implemented in Bangladesh in response to the persistent problem of undernutrition, resulting in significant decreases in child mortality and morbidity. However, insufficient emphasis has been made on combining agriculture and nutrition in order to steer agriculture toward the development of nutrient-dense foods. Agriculture, which is the primary source of income for a large proportion of the population in Bangladesh, may be critical in addressing nutrition concerns (Yosef et al., 2015).

Although post green revolution, the agricultural policy response to hunger and malnutrition primarily focused on the production of more staple crops to feed a growing population; however, the staple crop remained as a major food source in subsistence farming resulted in nutrition deprivation (Jacques and Jacques, 2012; Pingali, 2015). This strategy has increased people's accessibility to stable food and reduced hunger a great deal. But the agricultural diversification has been impeded, as a consequence, due to the homogenous staple food production (Khoury et al., 2014; Pingali, 2015). Diversified agricultural production is seen as a strategy to ensure the availability of a wide range of food, particularly in rural areas (Ayenew et al., 2018; Jones, 2016). Thus, bidirectional causal relationships between agricultural productivity and dietary diversification can be exploited to build a strategy for smallholder farmers to enhance household dietary diversity (HDD). Consumption of nutritious, diverse foods produced by agriculture can help improve nutrition security, and produced foods can also be sold to generate income, thereby improving rural people's economic standing (Ayenew et al., 2018). A number of empirical research has looked at the nature of the relationship and indicated that production variety impacts enhancing the food quality of a household (Bellon et al., 2016; Jones et al., 2018; Koppmair et al., 2017; Luna-Gonzalez and Sorensen, 2018; M'Kaibi et al., 2017; Romeo et al., 2016; Sibhatu and Qaim, 2018). Some of these studies found a positive relationship between agricultural production diversity and dietary diversity, while others found conflicting outcomes, leaving empirical findings ambiguous (Habtemariam et al., 2021). The magnitude and direction of the HDDS and production diversification effects are unclear, and the significance of other confounding factors has to be examined further.

Market access, a significant confounding variable, is critical in understanding the relationship between production and dietary diversification. Increased market access and involvement in market activities enable smallholder farmers to sell a portion of their harvested crops and use the proceeds to acquire more diverse food. Occasionally, market access has been found to have a greater impact on dietary diversity than production diversity. Residents who reside near markets have easier access to a wider variety of foods throughout the year. According to a study on the nature and influence of farm output on HDD conducted in rural and peri-urban areas of Kenya and Tanzania, dietary diversity was found greater in peri-urban areas with better market access, despite lower production variety (Kissoly et al., 2020). Agricultural technology adoption has also been identified as a propitious strategy for ensuring a diverse diet for farm households (Koppmair et al., 2017; Sibhatu et al., 2015). One study reported that adopting agricultural technologies (improved seed and inorganic fertilizers use) significantly impacted food production and availability (Magrini and Vigani, 2016). Intercropping, another significant agricultural approach that entails growing two or more crop species concurrently, has a number of benefits, including increased yield, production sustainability, and ecosystem enhancement. Intercropping, according to the study, can increase yields while consuming less resources (Maitra et al., 2021). Besides these factors, one study conducted in Bangladesh reported the association of household wealth and literacy with household dietary diversity and improved food security (Harris-Fry et al., 2015).

Considering all of these factors into account, this study attempted to assess the extent to which and the direction in which production diversity affects household dietary diversity in Noakhali district, Bangladesh. With its huge rural population and subsistence farming, Bangladesh is an important place to study this issue. Additionally, the study also seeks to adjust for and investigate the effect of market access, agricultural technology use, farm size, and other significant socioeconomic characteristics such as household income, family size, and the educational status of the household head. The study was extended to examine how the influence of production diversity on HDD varies with conditional market access and agricultural technology use.

## 2. Method and materials

Between January and December 2019, a survey was undertaken among smallholder farmers in Hatiya, Noakahli, Bangladesh. The study area was selected randomly after clustering the region in distinct numbers. Using the local agriculture extension office's farmer identification number, a multistage sampling technique was employed to randomly choose farm households. A total of 190 farm households were chosen to collect data. A pre-tested questionnaire was used to collect data on socio-demographics, crop and livestock production, market access, and agricultural technology.

### 2.1. Ethical consideration

The ethics board of Noakhali Science and Technology University, Bangladesh, approved this work. Permission to perform the study was also obtained from the local administration. This observational study was conducted in accordance with ethical guidelines (Declaration of Helsinki). A written agreement was obtained from participants, and the study aims were verbally explained in accordance with the guidelines.

### 2.2. Measurement of farm production diversity

The household biodiversity index (HBI) was used to calculate farm production diversity (FPD), which takes into account all crops and livestock produced on the farm over a 12-month period. Farmers were requested to report agricultural and livestock production information for the previous 12 months as part of the survey. Crops that were cultivated for food consumption or income creation were included. Each agricultural and livestock species would be assigned a numerical value of one, and the count would be totaled. The household crops biodiversity index (CBI) is calculated by adding all of the crops farmed by the household (Equation 1), the livestock biodiversity index (LBI) is also calculated by the addition of all reared livestock (Equation 2). The household biodiversity index (HBI), which is employed in this work as a proxy for farm production diversity, is calculated by adding these two indices (CBI and LBI) (Equation 3) (Table 1) (Ekesa et al., 2008; Gonder, 2011; Herforth,

**Table 1.** Equations.

| Equations | Statements |
|---|---|
| $\sum_1^K Crop\ Species_i = CBI_i$ (1) | $CBI_i$ is the number of crop species in total grown by household i$^{th}$ |
| $\sum_1^J Livestock\ Species_i = LBI_i$ (2) | $LBI_i$ is the number of livestock species in total reared by household i$^{th}$ |
| $CBI_i + LBI_i = HBI_i$ (3) | $HBI_i$ is the total score of production diversity (Biodiversity) by household i$^{th}$ |

2010; Jones et al., 2014; M'Kaibi et al., 2017; Sibhatu et al., 2015; Walingo and Ekesa, 2013).

### 2.3. Dietary diversity measurement

Dietary diversity is considered to be a qualitative indicator of dietary sufficiency that reflects a household's access to a diverse range of foods (Kennedy et al., 2011; Sibhatu et al., 2015). Individual or household dietary diversity scores can be determined based on the type of data provided. The household dietary diversity score is a simple, low-cost assessment tool that aims to accurately reflect a family's economic access to a variety of foods. Individual dietary diversity scores, on the other hand, are used to determine whether or not a person is nutrient deficient. In this study, the household dietary diversity score (HDDS) was used to assess dietary diversity according to Food and Agriculture Organization guidelines (FAO, 2013). HDDS simply counts 12 food groups consumed by the household in the past 24 h prior to the survey. Foods consumed in the 24 h leading up to the interview were divided into 12 equally weighted categories: (i) cereals, (ii) White tubers and Roots, (iii) vegetables, (iv) fruits, (v) Meat, (vi) Egg, (vii) fish and Seafood, (viii) Legumes, Nuts, and Seeds, (ix) Milk and Milk Products, (x) Oils and Fats, (xi) Sweet. The household's HDDS (0–12) was calculated by summing the number of categories reported.

### 2.4. Measurement of market access and adoption of agricultural technology

To analyze the effect of market access on dietary diversity, two market access variables have been constructed, i) time required to reach the local market and ii) time required to reach the district market. This categorization is to explain that farm households might use the local markets to purchase and sell for smaller quantities on a more frequent basis. On the other hand, district markets are to buy and sell for large quantities, involving food and non-food items that farm households might occasionally do. Time to reach these markets might affect the overall participation of farm households. For instance, if it takes longer to reach the district market, farm households may not be inclined to go there more often, which might affect their diversified food consumption. Three agricultural technology adoption variables have been used in this study: usage of improved seed varieties, intercropping, and irrigation process. These variables were chosen to assess their effect on farm production (Koppmair et al., 2017).

### 2.5. Analytical approaches and data analysis

The following regression model was used to investigate the link between agricultural production diversity and dietary variety:

$$HDDS_i = \alpha_0 + \alpha_1 HBI_i + \varepsilon_i \quad (4)$$

HDDSi and HBIi are the household biodiversity and biodiversity index representing production diversity. $\alpha_0$ and $\alpha_1$ are coefficients, and εi denote a random error (Equation 4). A positive estimate for the equation above is indicative of increased dietary diversity. Since the above equation only estimates production diversity's contribution as a predictor, an extended model has been developed to consider other explanatory variables, including market access, agricultural technology usage, and farm size. The extended model is to assess the influence of all the explanatory variables on HDDS:

$$HDDSi = \alpha_0 + \alpha_1 HBIi + \alpha_2 MAi + \alpha_3 ATi + \alpha_4 FSi + \varepsilon i \quad (5)$$

MAi is the dummy variable indicating market access; ATi captures agricultural technology adoption; FSi indicates farm size (land area for cropping & livestock species raring) (Equation 5). The outcome variable in this study is a count variable; hence, a Poisson logistic regression is chosen as a Poisson estimator is commonly used to estimate count data (Cameron and Trivedi, 2013). Descriptive statistics of study variables are presented in numbers and percentages. Mean and standard deviation (sd) of continuous variables are also presented. Bivariate and multivariate

**Table 2.** Descriptive statistics of continuous variables (190 farm households).

| Variables | Mean | ±Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|
| **Farm Production characteristics** | | | | |
| Biodiversity score (production diversity) | 7.11 | 2.78 | 2.00 | 15.00 |
| Total farm size (dcm) | 70.21 | 44.97 | 8.80 | 310.54 |
| Crop species count | 4.28 | 2.27 | 1.00 | 12.00 |
| Land area for crop species (dcm) | 66.43 | 43.87 | 8.50 | 300.00 |
| Harvesting amount of crops (Maund) | 104.7 | 66.23 | 3.75 | 488.25 |
| Consuming amount of produced crops (Maund) | 32.40 | 15.12 | 1.05 | 107.50 |
| Selling amount of crop species (Maund) | 72.30 | 54.24 | 2.70 | 380.75 |
| Livestock species count | 2.83 | .98 | 1.00 | 5.00 |
| Land area for livestock species (dcm) | 3.78 | 6.46 | .00 | 30.55 |
| Harvesting amount of livestock (kg) | 56.99 | 73.92 | .00 | 540.00 |
| Consuming amount of produced livestock (kg) | 6.25 | 7.33 | .00 | 32.00 |
| Selling amount of livestock species (kg) | 49.98 | 68.32 | .00 | 493.33 |
| Total earning by production (BDT) | 52898 | 34800 | 7450 | 224250 |
| **Dietary diversity score** | | | | |
| Household Dietary Diversity Score (HDDS) | 6.49 | 1.96 | 4.00 | 10.00 |
| **Socioeconomic characteristics** | | | | |
| Household Size | 4.54 | 1.17 | 3.00 | 7.00 |
| Family Monthly income (BDT) | 12,836.84 | 5,013.44 | 5,000 | 27,000 |

BDT: Bangladeshi taka (currency); M: Maund (1 Maund = 37.32 kg); dcm: Decimal; Results presented here are average value.

**Table 3.** Descriptive statistics of categorical variables (190 farm households).

| Categorical variables | N (%) |
|---|---|
| **Market access variables** | |
| Time to reach village market | |
| <1 h | 97 (51.1) |
| ≥1 h | 93 (48.9) |
| Time to reach district market | |
| <1.5 h | 80 (42.1) |
| ≥1.5 h | 110 (57.9) |
| **Agricultural technology usage variables** | |
| Irrigation process improved from last year | |
| Yes | 124 (65.3) |
| No | 66 (34.7) |
| Improved seed varieties used | |
| Yes | 169 (88.9) |
| No | 21 (11.1) |
| Intercropping | |
| Yes | 136 (71.6) |
| No | 54 (28.4) |

N: Total number of participants.

regression analysis is performed, and the Poisson regression coefficient (β) is presented. The relationship between HDDS and production diversity according to conditional market access and the agricultural variable is also calculated to explore how their association fares in particular conditions of these variables. All the analyses were conducted using SPSS software 25.0; 95% confidence interval values are provided, and $p < 0.05$ is considered a statistically significant predictor.

## 3. Results

### 3.1. Descriptive statistics

Tables 2 and 3 represents descriptive statistics of study variables and some basic farm characteristics. The household biodiversity score (production diversity) was 7.11, which means households produce 7.11 different crops and livestock on average. And the HDDS was 6.49, which means, on average, the household consumes 6.49 different varieties of foods (crops/livestock) during the reference day. The sample households are reported with an average farm size of 70.21 decimal.

More than half of the farm households required less than 1 h to reach the village market, while 42.1% of households needed less than one and a half hours to reach the district market (Table 3). In terms of agricultural technology adoption, 65 percent of farmers reported that they had used

**Table 4.** Association of HDDS with production diversity, market access, agricultural technology, and socioeconomic variables (Generalized Poisson Regression Analysis).

| Characteristics/Variables | Household dietary diversity score (HDDS)* | | | |
|---|---|---|---|---|
| | Bivariate regression analysis | | Multivariate regression analysis | |
| | Poisson regression coefficient (β) | 95% Wald confidence interval | Poisson regression coefficient (β) | 95% Wald confidence interval |
| **Production diversity:** | | | | |
| Biodiversity score | 0.085*** | 0.065, 0.104 | 0.084*** | 0.064, 0.107 |
| **Market access variables:** | | | | |
| Time to reach village market: | | | | |
| >1 h | -0.034 | -0.146, 0.78 | | |
| ≤1 h | 1 | | | |
| Time to reach district market: | | | | |
| ≤1 h 30 min | -0.125** | -0.239, -0.011 | -0.67 | -0.187, 0.054 |
| >1 h 30 min | 1 | | | |
| **Agricultural technology usage** | | | | |
| Improved seed varieties | | | | |
| Yes | 1 | -0.216, 0.145 | | |
| No | -0.036 | | | |
| Irrigation process improved | | | | |
| Yes | 1 | -0.241, -0.002 | -0.014 | -0.146, 0.0117 |
| No | -0.122** | | | |
| Intercropping | | | | |
| Yes | 1 | -0.226, 0.027 | | |
| No | -0.10 | | | |
| Farm size for the production of crops and livestock rearing | 0.002** | 0.001, 0.003 | 0.00 | -0.002, 0.001 |
| Total selling amounts of crops and livestock | 0.001** | 0.000, 0.002 | | |
| Total consumption amount of crops and livestock | 0.005** | 0.001, 0.008 | | |
| Household size (Total members of the HH) | -0.004 | -0.52, 0.044 | | |
| HH head's education status | | | | |
| Uneducated | 0.035 | -0.089, 0.159 | | |
| Educated | 1 | | | |
| Test statistics: Poisson log-linear model | Omnibus test: Likelihood ratio chi-square (df), p-value: 74.36 (4), $p < 0.001$, *$p < 0.1$, **<0.05, ***<0.01 | | | |
| Multiple regression condition | Total selling and consuming amounts have been found to have a high correlation with total firm size; hence, we did not include them to control. Moreover, household income was also considered for inclusion, but it has a very negligible effect on HDDS; therefore, excluded as well. Exp (B) = Exp (0.084) = 1.087. | | | |

* The Generalized Poisson Regression Estimator was used as the outcome variable had considerable under dispersion.

**Table 5.** Relationship between HDDS and Biodiversity score according to conditional market access and agricultural variable.

| | HDDS | | | |
|---|---|---|---|---|
| | Market access: Time required to reach district market | | Agricultural technology: Improved irrigation process | |
| Condition⟹ | <1.5 h<br>N = 80 | ≥1.5 h<br>N = 110 | Yes<br>N = 124 | No<br>N = 66 |
| Biodiversity score (B coefficient) | 0.079*** | 0.090*** | 0.080*** | 0.096*** |

The table provides regression coefficient when market access variable (time to reach district market changes) and agricultural technology usage (whether improved seed varieties used or not) changes; ***$p < 0.001$; These two variables were selected based on their significant association in bivariate analysis.

improved irrigation processes, 88.9 percent reported improved seed varieties, and 71.6 percent reported intercropping.

### *3.2. Association between farm production diversity and household dietary diversity*

The HDDS was positively and significantly related to agricultural production diversity, according to multivariate regression analysis (Table 4). Increasing farm production varieties by one group results in an increase of a 0 · 084 (β: 0.084, 95% CI: 0.065, 0.104; Exp (B) = 1.087) unit in the number of food groups consumed by the farm household. The bivariate analysis found varying degrees of association between market access, agricultural technology adoption, farm size, and total selling and consuming amounts. We discovered that total selling and consuming amounts correlated with total firm size; hence, we excluded them from the multivariate analysis as a control variable. Additionally, because household income had such a small effect on HDDS, it was omitted from the analysis. Even after controlling for all other variables, there was a significant association between farm production diversity and dietary diversity.

The association between HDDS and production diversity was examined in Table 5 in respect to several conditional changes in market access and agricultural technology use variables. When the travel time to the district market was reduced to 1.5 h, the effect of production diversity on the HDDS was reduced (β: 0.079). However, when the journey to the market takes longer (1.5 h), the effect of production diversity on HDDS increases (β: 0.090), showing that individuals rely more on production diversity when the journey is longer. When irrigation became more efficient, people became less reliant on production diversity.

## 4. Discussion

The study explored the nature of the relationship between household dietary diversity (HDD) and production diversity (crops and livestock) in response to different market access, agricultural technology usage, and socioeconomic variables. However, expectedly, this relationship is not straightforward and mired with different situations and accessibility of other factors, which has also been studied. This study demonstrated a significant association between production diversity and HDDS, albeit modest. These findings corroborate previous research demonstrating a considerable positive correlation between production diversity and HDDS (Bellon et al., 2016; Chinnadurai et al., 2016; Habtemariam et al., 2021; Kissoly et al., 2020; Luna-Gonzalez and Sorensen, 2018; M'Kaibi et al., 2017; Sibhatu and Qaim, 2018). Farm production diversity is also widely viewed as an important strategy for improving smallholders' food security (Kissoly et al., 2020); however, the empirical evidence is inconclusive from the context of smallholders, and the pathway of interactions are multifaceted. Our study contributes to the literature to affirm the influence of production diversity in enhancing dietary diversity at the household level.

Farmers tend to rely more on the goods they produce when the time to reach the district market is longer; this condition reverses when farmers have more access to the market. It could be due to the market's availability; farmers can purchase products from the market that they do not produce, resulting in the consumption of a diverse range of foods. Furthermore, transportation costs are a factor when the market is difficult to access. According to one study, market access can influence whether or not a product is consumed or sold. Market access also had a greater impact on dietary variety than diverse agricultural production, highlighting the importance of this variable (Sibhatu et al., 2015).

The study looked at how much better irrigation, seed varieties, and intercropping were used by farmers this year compared to the prior year. In the bivariate study, improved irrigation was found to significantly influence HDDS; no change in the irrigation system negatively affects the HDDS (β: -0.122; 95% CI: -0.241, -0.002). It was also clear that farmers who did not use any agricultural technology had a detrimental impact on the HDDS. Furthermore, changes in HDDS as a function of agricultural technology use imply that the more farmers used multiple technologies for production, the less they were reliant on production variety. It could be because of the financial rewards that come with increased production (Sibhatu et al., 2015). Similar findings were also reported in a study where solar-powered drip irrigation influenced to crop diversification and subsequent dietary diversity in the households in Northern Benin (Alaofè et al., 2016). Despite the fact that no agricultural technology variables were consistently predicted HDDS in bivariate analysis, the influence of improved irrigation on HDDS should not be overlooked. According to a study in Afghanistan that looked at the effects of irrigation on dietary diversity, improved irrigation facilities were positively connected with greater diverse food intake from local production. However, the study cautioned that irrigation facilities alone are insufficient to address food diversity among Afghanistan's smallholders (Kawsary et al., 2018). A panel data analysis in Malawi reveled the significant effect of improved seed varieties on dietary consumption (Bezu et al., 2014); however, our study failed to show any impact on that. Our analysis also points out that farmers' reliance on production diversity lessens when they were able to reach markets quickly and used improved irrigation. The explanation could be that when the market is more accessible, individuals are more likely to go and buy a variety of things. Farmers may be able to produce more as a result of enhanced irrigation, resulting in increased income and purchasing power, which may lead to more diverse food consumption. A research in Western Ethiopia that looked at the impact of market access on food intake found that having more market access promotes smallholder farmers to buy more besides their own product in order to improve their HDD (Usman and Callo-Concha, 2021); that resonates our findings explanation.

The study also looked at the total crop and livestock production over the previous 12 months and how much farmers consumed and sold on the market. However, total consumption and selling amounts were found to have collinearity with total land size in the multivariate analysis; thus, the total land size area was kept to minimize its effect. According to the bivariate analysis, farm size has an effect on HDD. Increased farm size may increase the chances of producing more crops, resulting in increased income and household consumption. According to one study, larger farms increase the variability of local food production, and farmers benefit from having larger farms because they generate more consistent income (Noack and Larsen, 2019). The other socioeconomic variables (HH head literacy and family) did not show a consistent significant influence on HDDS.

Because the study did not address individual food intake but rather the total food group consumption by households, the findings cannot be interpreted in terms of individual food consumption. Additionally, using single-round cross-sectional data to infer household nutrition assessment has drawbacks; it may not capture daily change and may not accurately reflect seasonal fluctuation (Shim et al., 2014). Since this study used cross-sectional survey data, it is difficult to discern causality (cause-effect relationships) between the variables. The study did not investigate the nutritional quality of nutrients consumed by households, their economic access to market goods, or the abundance of nutrient-dense foods in markets, all of which could have an effect on HDDS. This study makes no promise to be free of endogeneity (correlation between predictor variables and error term), which means that additional variables could affect the link. When working on agriculture-nutrition linkages in Bangladesh and other countries with similar circumstances, programs and policymakers might consider these findings. Bangladesh can benefit from putting more attention on diversifying its production due to its history of nutritional deficits, particularly among the underprivileged people. Another factor to consider is the construction of market opportunities, which will allow people to buy a range of goods in their neighborhood at reasonable prices. It also enables them to make money by selling their products, saving transportation costs, and eliminating middlemen's needs (Islam, 2020). Additionally, traditional agricultural techniques and procedures may not yield the desired results, and farmers in Bangladesh are commonly guilty of failing to utilize modern agricultural technology and practices in response to the country's climate susceptibility (Mondal, 2010). While the study findings cannot be considered to be indicative of all situations, environments, or seasons in Bangladesh, this does not negate it's importance, which has been duplicated in other nations with comparable socioeconomic conditions. As a result, concentrating efforts on agriculture can aid Bangladesh's efforts to eradicate hunger and malnutrition.

## 5. Conclusions

The influence and extent of diversified farm production on HDDS were investigated in this study for rural Bangladeshi smallholder households. After adjusting for the effect of market accessibility, agricultural technology use, and other factors, the findings indicated that more production diversification resulted in a degree of increased HDD. Less time to reach the district market and improved irrigation process also contributed to HDD. Smallholders were less reliant on diversification of produce when it took less time to reach markets and when irrigation techniques were improved. This implies that people's reliance on HDD varies according to their farm production and their market access and production technology. However, the implications of this evidence should be interpreted cautiously in light of smallholder producers' proclivity towards consumption and sale. Having said that, it emphasizes the significance of doing a more extensive investigation of these correlations, which may include a variety of various contexts, agricultural policy, and production orientation. Nonetheless, long-term, context-specific, nutrition-sensitive agriculture strategies can be implemented to produce a more diverse diet. Sufficient emphasis should be placed on developing surrounding marketplaces and acclimating farmers to the latest production techniques available.

## Declarations

### *Author contribution statement*

Md Ruhul Kabir; Oumma Halima; Nahian Rahman: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Susmita Ghosh; Md. Sayedul Islam: Analyzed and interpreted the data; Wrote the paper.

Habibur Rahman: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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### *Data availability statement*

Data will be made available on request.

### *Declaration of interests statement*

The authors declare no conflict of interest.

### *Additional information*

No additional information is available for this paper.

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