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# Diversified agriculture leads to diversified diets: panel data evidence from Bangladesh

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This study used a panel data model to examine the relationship between agricultural diversification and dietary diversity of farm households across three waves of nationally representative Bangladesh Integrated Household Survey data (BIHS- 2011-12, 2015, and 2018). Prior research measured diversification in terms of crop cultivation and livestock rearing. However, this study takes a different approach to measuring agricultural diversification by combining the three major sectors—crop, fish, and livestock production—at the farm household level to evaluate the impact of such agricultural diversification on the diversification of diets in households. The panel data allows us to establish that agricultural production diversification has a significantly positive effect on the dietary diversity of farm households. Moreover, other important factors that impact agricultural diversification to improve dietary diversity, like women's employment, market access, engagement with non-farm income sources, and access to information also have a strong association in improving the dietary status, food and nutritional security of households. Participation in the market helps farming households to become more commercially oriented but negatively affects the dietary diversification of the households. However, participation in non-farming activities was reported to have a significant positive influence on dietary diversity, though not as much as agricultural diversification. From the perspective of policy that requires nutrition into consideration, the findings suggest to focus on providing support for diversified farming systems can directly increase the nutritionally enriched dietary intake, increasing the employability of women. Promoting market participation through modern infrastructural facilities should be prioritized to improve the current scenarios.

KEYWORDS

**agricultural diversification, household, dietary diversity, Bangladesh, panel evidence**

## 1. Introduction

Human beings have a basic right to adequate food and nutrition. Without a sustainable food system that facilitates healthy and sufficient food options and ensures food security for all, this right cannot be attained. Worldwide, there are around 815 million people who are seriously undernourished; the majority of these individuals reside in low- and middle-income nations

(FAO, IFAD, UNICEF, WFP, and WHO, 2017). Though having a deficit quantity of food is an indicatory factor to malnutrition or under nutrition, only the quantity of food is not enough to ensure good health (Kennedy et al., 2010; Bellows et al., 2020). Therefore, consuming a diverse range of foods is very important to prevent micronutrient deficiencies.

Agricultural diversification is a process associated with growth of an economy, which is distinguished by a gradual transition from subsistence crops to a demand-driven diversified production system, by transferring farm resources to non-farm activities or from low-value to high-value agriculture in a more diversified and parallel way (Hayami and Otsuka, 1994; Vyas, 1996; Joshi, 2004; Delgado and Siamwalla, 2018) and precipitated by fast pace of technological change and developed rural infrastructure in agricultural production (Rosegrant and Hazell, 1999; Saikia and Gogoi, 2017). Diversified agricultural production and diverse diets have a positive but variable relationship (Pellegrini and Tasciotti, 2014; Azzarri et al., 2015; Snapp and Fisher, 2015; Romeo et al., 2016; Jones, 2017; Koppmair et al., 2017; Saaka et al., 2017; Sibhatu and Qaim, 2018a; Lovo and Veronesi, 2019). Diversifying food production can increase the diversity of foods available, although this effect can diminish over time (Parvathi, 2018).

Agriculture has the potential to improve nutrition, which is emphasized by the SDG-2, highlighting that the increment in the farm productivity of small-scale food producers through production diversification can improve household food security and nutrition in several logical ways (Islam et al., 2018; Ruel et al., 2018; Habtemariam et al., 2021). The first advantage of diversifying food production is that it improves dietary quality and healthiness by bringing different types of foods more readily available to consumers (Ruel et al., 2018; Habtemariam et al., 2021). The second pathway offers improved and sustained food availability by lowering the risks resulting from negative events such as extreme weather and climate crises. Thirdly, the economic consequence of producing a variety of commodities is having profitable and more stable earnings, which households can utilize to purchase a variety of food items during periods of price volatility, thereby decreasing market risks (Habtemariam et al., 2021).

However, increased agricultural income may not be sufficient to sustain high dietary diversification. The contribution of agricultural income to the share of calories in different food groups implies considerable changes in diet composition rather than a direct impact on diet diversification (Andrew et al., 2015).

Agricultural diversification, food diversification, and nutritional consequences are all interconnected in intricate and multidimensional ways. Several studies (Pellegrini and Tasciotti, 2014; Andrew et al., 2015; Chinnadurai et al., 2016; Mulmi et al., 2017; Uddin, 2017; Adjimoti et al., 2018; Lovo and Veronesi, 2019; Singh et al., 2020; Khandoker et al., 2022) only focused either on crop diversification or farm diversification (crops and livestock), and been unable to incorporate the non-crop foods, like- fish, and livestock products. Whereas, for assuring nutritional benefits, farm profitability, and to clearly capture the impact of agricultural diversification the cultivation of non-crop foods are essential (IFPRI-BIDS-INFS, 1998) conducted a study on micronutrient deficiencies and the possibility of nutritional improvement through diversified agricultural production methods. Results showed that diversified food production methods could influence micronutrient deficiencies. At the same time, diversified fish production and vegetable gardening offered a potential to increase household incomes. Different measures of agricultural production diversification have been linked to increases in household diet diversification and intake of nutritious foods such as legumes, vegetables, fruits, meat and fish (Kennedy et al., 2010; Rani et al., 2010). In Bangladesh, the majority of household diets rely on carbohydrate – rich staples, with few animal protein and limited vegetables-fruits (Ruel, 2003; Murshid et al., 2008). Islam et al. (2018) used data from two rounds (2012 and 2015) of the BIHS in order to determine the dependency between farm diversification and dietary diversity. Despite of substantial positive correlation between these variables, the estimated effect magnitude was found to be relatively low. However, the other characteristics examined demonstrated that market access, farm commercialization, income diversification toward sources other than agriculture. Ahmed and Tauseef (2018) also used the BIHS data from 2012 and 2015 to identify the determinants influencing dietary diversity by using two measures: the World Food Program's Food Consumption Score (FCS) and the Household Dietary Diversity Score (HDDS), emphasizing that higher levels of education for the household's male head and spouse promote agricultural diversification. Additionally, households that are found to raise a greater number of non-rice food crops, milk cows, and engage in fishery production have a more diverse diet for consumption. Presenting relevant statistical information on how farm diversification affects food security in Bangladesh, (Rehan et al., 2017) discovered that enhanced food security results from increased diversification, particularly in terms of food consumption diversity. Women's involvement in agricultural production activities was shown to be a significant factor that encouraged diet diversity in Bangladesh.

Diversity in terms of agricultural commodity production and consumption has become a key pathway for achieving food security and nutritional status in developing countries. It is argued that increasing agricultural diversity toward higher-yielding vegetable, condiment, spice, fruit, and plantation types is necessary for ensuring the sustainability of agriculture-based societies, speeding up economic growth, and alleviating rural poverty (Bigsten and Tengstam, 2011; Michler and Josephson, 2017; Birthal et al., 2020; Singh et al., 2020).

However, the literature on the relationship between dietary diversity and agricultural diversification of farm households is limited in Bangladesh, and there are several dimensions and methods that can be used to understand the current scenario for further justification. With the benefit of using a rich panel dataset of 3 years of the IFPRI BIHS, this study examines the nexus between agricultural diversification and dietary diversity of farm households and among different income groups to elicit new knowledge and provide practical policy insights.

The remainder of the paper is organized as follows: Section 2 presents the methodology followed by the results and discussions in section 3. Finally, the paper ends with brief conclusion.

## 2. Methodology

### 2.1. Data

Data from three waves of the Bangladesh Integrated Household Survey (BIHS) in 2012, 2015 and 2018 were used to conduct this study. This household survey was conducted by Data Analysis and Technical Assistance Limited under the supervision of

IFPRI. We collected and used these datasets in accordance with the IFPRI's data usage guidelines, terms and conditions. In accordance with the established rules and regulations, we obtained the required authorizations to access and make use of the data.

The BIHS survey represents the following levels: (i) nationally representative of rural Bangladesh, (ii) representative of rural areas of each of the seven administrative divisions of the country: Barisal, Chittagong, Dhaka, Khulna, Rajshahi, Rangpur, and Sylhet; and (iii) representative of the Feed the Future Zone of Influence in south-western Bangladesh (Ahmed et al., 2013). The total BIHS sample size is 6,503 households in 325 primary sampling units (i.e., villages). Among the 6,503 households, 4,423, 4,619 and 4,886 households are "Nationally Representative (representative of Rural Bangladesh)" respectively in 2012, 2015 and 2018 at the division level, and the households outside of these areas are classified as being in the "Feed the Future Zone (FTF)" (Ahmed et al., 2013). The FTF is a whole-of-government initiative led by USAID in the south and southwest regions of the country that have also been considered in this study.

Households that have never been involved in the agricultural production system such as crop production, livestock rearing, and fisheries cultivation have not been included in this study, as agricultural diversification in the case of these households cannot be measured. To achieve a balanced panel dataset with the common households who have participated these surveys in all three waves we have excluded the households which have split up during the time period of 2012–2018. Hence, our sample size is smaller than that of the original BIHS data, which is a balanced panel of total 12,279 individuals in each round from the 4,093 group of farm-households with complete survey information (Table 1).

The BIHS survey instruments included household, agricultural, livestock and fisheries, food consumption and nutritional status, and community questionnaires. The data includes plot-level agricultural production, household harvest, and household variables such as assets, income, and consumption covering 299 food items in the week before the survey. We analyzed our research interests using this data set's extensive information.

## 2.2. Measurement of agricultural diversification and dietary diversity

The primary outcome variables are agricultural production diversity and household dietary diversity. In order to investigate the reliability of the association between farm agricultural production diversity and household dietary diversity, we applied different indicators.

### 2.2.1. Agricultural diversification

The first explanatory variable of this study is the Production Diversification Score (PDS), which is calculated by adding up all the food crops, fish and livestock products each household produces (Chegere and Stage, 2020). This simple count has been adopted in recent years by a number of studies since it allows for the inclusion of both crop and animal species produced by the farms in the results (Harper and Hawksworth, 1995; Herforth, 2010; Remans et al., 2011; Jones et al., 2014; Sibhatu et al., 2015; Koppmair et al., 2017; Sibhatu and Qaim, 2018a; Muthini et al., 2020). Previous studies (Sharma, 2005; Bhattacharyya, 2008; Rahman, 2008; Jha et al., 2009; Islam and Rahman, 2012; Anwer et al., 2019) have been found employing the Index of maximum proportion, Herfindahl Index, Simpson Index, Ogive Index, Entropy Index, Modified Entropy Index, and Composite Entropy Index, to assess diversification, mostly crop diversification, with the distribution of land as a single indicator. While considering poultry, fisheries, dairy, and other similar production, the distribution of land area used by these indices becomes questionable as a measure of diversity. For instance, poultry and dairy can be raised even if farmers do not have access to crop land.

The PDS is calculated by excluding the number of non-food crops from the total value of crop, fish and livestock counted. As the PDS does not take into account how much area is devoted to cultivating a crop. Rather, the PDS is constructed in a manner very similar to the Household Food Variety Score (HFVS) which is constructed by including each type of food consumed from the household's own cultivation array (Chegere and Stage, 2020). As a result, if self-production of various food products is a significant source of variation in the types of food consumed, the PDS and the HFVS are also assumed to be directly linked.

Another explanatory variable used is the Agricultural Diversification Score (ADS). Based on the 12 food categories utilized in the HDDS, the ADS calculates the total number of food categories obtained from the production, assuming that a dependency between the ADS and the HDDS exists (Chegere and Stage, 2020). Each produced food group contributes one point to the ADS. The nutritional values of the items within a specific food group tend to be quite similar, so the addition of food items from a single food group might not improve overall nutrition very much (Sibhatu and Qaim, 2018b). As a result, the ADS is better able to reflect the variety of crops grown.

### 2.2.2. Dietary diversity

Dietary diversity, according to the FAO (2013), is a proxy for nutrient adequacy of the diet of individuals since it is a qualitative measure of food consumption that reflects household access to a diverse range of foods. Dietary diversity scores, as specified by the FAO recommendations, are based on a simple count of the number of different food groups consumed by a family or an individual in the previous 24 h.

In measuring dietary diversity, HDDS is predicated by the number of food groups available for consumption for the family during the time under consideration (FAO, 2007). The HDDS is based on a score from 0 to 12 for each of the following 12 food groups: cereals; roots and tubers; vegetables; leafy vegetables; fruits; meat and poultry; eggs; fish and seafood; pulses and nuts; milk and milk products; oil and fats; and sugar and honey. Each food group counts toward the household score if a food item from the group is consumed by anyone in the household in the previous 7-day recall period (FAO, 2007). The HDDS is supposed to be a reflection of a family's economic means and their capacity to buy a variety of healthy foods. Increases in both socioeconomic status and food security in the household have been linked to dietary diversification (Hatløy et al., 2000; Hoddinott and Yohannes, 2002).

Another measure of dietary diversity, the HFVS is calculated as the sum of all food items eaten within the recall time frame, usually a week earlier than the survey because of the availability of a wider range of food group differentiation (Sibhatu et al., 2015; Sibhatu and Qaim, 2018b; Ecker and Kennedy, 2019). Thus, we have also

considered HFVS as an indication of dietary diversity in order to further verify the reliability of our results.

## 2.3. Econometrics model

Three waves of BIHS survey data for households of rural Bangladesh were used to analyze the impact of the independent variables on the dependent variable, dietary diversity (DDi), which is a count variable and is not normally distributed. So, the Poisson model is the appropriate model for our study (Hirvonen and Hoddinott, 2017). We have analyzed a set of balanced panel data and to determine the impact of independent variables on the dependent variable, we have used a Fixed Effects model. The findings from the Hausman test and Likelihood Ratio test allowed to imply the fixed effects specification. To analyze the relationship between agricultural production diversity and dietary diversity this study has used the following regression model:

$$DD_i = \beta_0 + \beta_1 AD_i + \beta_2 MA_i + \beta_3 X_i + u_i$$

Where, $DD_i$ = Dietary Diversity of household i (HDDS or HFVS).

Household Dietary Diversity Score (HDDS): Number of food groups consumed by the household in the last 7 days.

Household Food Variety Score (HFVS): Number of different food items consumed by the household in the last 7 days.

AD = Agricultural Diversification of household i (PDS or ADS).

Production Diversification Score (PDS): Number of the different food crops, fish and livestock products produced by a household.

Agricultural Diversification Score (ADS): Number of different food groups produced, according to the 12 groups used in the HDDS.

$MA_i$ = Vector of market access indicator of household i (i.e., nearest market distance, market participation rate, and income from non-farm activities).

$X_i$ = Vector of other household characteristics (i.g. gender of the household head, age of both household head and spouse, education of household head, household size, share of child and older members in the family etc.)

μi = error term.

The estimates of the Poisson distribution's coefficients can be interpreted as having a degree of semi-elasticity. Therefore, a change (positive or negative) in the estimate for $\beta 1$ implies a change in production diversification which will result in a modification in the dietary diversification of farm households (see Table 4).

# 3. Results and discussion

## 3.1. Descriptive statistics

The primary outcome variables of our study are the HDDS and HFVS, both represents the precise conception of dietary status of the households. To understand the level of dependency of food consumption on own production we further calculated the following scores from the food purchasing data. Moreover, in order to maximize the analysis's capability for making reliable predictions, we are using multiple measures.

TABLE 1 Extracted sample description.

| Items | Wave 1 (2012) | Wave 2 (2015) | Wave 3 (2018) | Total | Panel (Balanced) |
|---|---|---|---|---|---|
| Number of households in BIHS main dataset | 6,503 | 6,437 | 5,605 | 18,545 | 4,093 |
| Number of selected farm households | 4,499 | 4,617 | 4,892 | 14,008 | |

Source: Author's Calculation, BIHS.

This study first use parametric tests to find out the difference of outcome variables in order to represent descriptive statistics across three waves of the panel. From Table 2, it is evident that HDDS keeps growing considerably from the first to the second wave and then from second to third wave. Another key indicator of dietary diversity given in the table is HFVS, which confirms that the number of different food items consumed also increases over the years from 2012–2018. All these changes in outcome variables were found to be highly significant.

The degree of agricultural production diversity is measured by two key independent variables. We investigated the consistency of the link between agricultural diversification and dietary diversity using a variety of explanatory variables (Jones et al., 2014).

From Table 3 we found several changes in explanatory variables over the years. The explanatory variable PDS slightly decreased from the first wave to the second wave, but again increased from the second to third wave and the overall change from 2012 to 2018 was positively significant. The other explanatory variable calculated based on food crops, fish and livestock, ADS, indicates that diversification in agriculture increased in each wave and the changes were highly significant. Market participation increased in each wave, but the changes were insignificant. Again, the income from both farm and non-farm sources increased significantly in each waves. The earning status of women in the households significantly increased over time which is indicating higher women's employment.

## 3.2. Econometric analyses

In this study, panel data Poisson regression models have been used to analyze the impact of agricultural diversification on the dietary diversity of farm households. The PDS and ADS were used as explanatory variables, and the HFVS and HDDS were used as outcome variables to assess the diversification. Since the PDS and HFVS are built in a similar manner, there should be a correlation between them. Likewise, the ADS and HDDS should be closely linked, since the production of more food items or foods from diverse groups simultaneously increases the total range of food items or food groups available for consumption (Chegere and Stage, 2020).

Moreover, considering different perspectives of diversification, this study has used four different measures of dietary diversity at the household level to examine the robustness of the primary findings. Household dietary diversity based on all food groups (HDDS), dietary

TABLE 2 Descriptive statistics of outcome variables.

| Outcome variables | Mean and Standard Deviation (SD) | | | | Mean diff. (2012 vs. 2015) | Mean diff. (2015 vs. 2018) | Mean diff. (2012 vs. 2018) |
|---|---|---|---|---|---|---|---|
| | Pooled | 2012 | 2015 | 2018 | | | |
| Household dietary diversity score (HDDS) | 10.219 (1.521) | 9.673 (1.598) | 10.415 (1.420) | 10.569 (1.382) | 0.742*** (22.82) | 0.154*** (4.74) | 0.895*** (27.56) |
| Household dietary diversity score on purchased food (PF_HDDS) | 8.754 (1.950) | 8.257 (1.932) | 8.846 (1.911) | 9.160 (1.898) | 0.589*** (13.92) | 0.314*** (7.42) | 0.903*** (21.34) |
| Household food variety score (HFVS) | 33.831 (10.143) | 29.016 (8.427) | 34.500 (9.732) | 37.978 (10.105) | 5.484*** (26.25) | 3.478*** (42.91) | 8.962*** (16.65) |
| Household food variety score on purchased food (PF_HFVS) | 28.380 (9.386) | 24.577 (27.770) | 28.341 (9.126) | 32.222 (9.562) | 3.763*** (19.23) | 3.882*** (19.84) | 7.645*** (39.07) |
| Number of observations (HH group) | 12,279 | 4,093 | 4,093 | 4,093 | - | - | - |

Source: BIHS 2012, 2015, and 2018; *t*-values are in the parentheses; *** & ** indicate significance at 1% & 5%, respectively.

diversity based solely on food groups purchased from the market (PF_HDDS), HFVS, and household food variety score based only on food items purchased from the market (PF_HFVS) were the variables.

The aim of this study is to capture the impact of agricultural diversification (i.e., the combination of crops, livestock and fisheries) on household dietary diversity. It is possible that this diversity in production is interrelated to other excluded components that could skew the estimation process. Considering the relevance of other covariates such as market access, non-farm income, gender and other socio-economic features (Sibhatu et al., 2015; Koppmair et al., 2017; Islam et al., 2018), the links could be more complex. To test for such bias, this study checked the robustness of the regression models, and the following tables show the regression analysis results of the main explanatory variables of PDS and ADS including the farm and household size, as well as age, education, and gender of the household head, education of women, share of children in household, and access to information as additional explanatory variables influencing dietary diversity.

FVS for both overall and purchased based food items is the number of food items consumed by the household. Table 4 features the outcomes of Poisson regression models with pooled and fixed effects. Regardless of underlying assumptions, PDS is found to be strongly correlated ($p < 0.01$) with household's FVS, which means that producing one additional food crop, vegetable, or fruit, cultivating fish, or rearing livestock species results in a 0.6% increase in the HFVS. On the other hand, the PF_HFVS (third column) shows that for the pooled model, PDS has an inverse association with the PF_HFVS, meaning that producing one additional food item significantly ($p < 0.01$) decreases the food items purchased from the market by 0.2%, whereas in the case of the fixed effect model, increasing production diversification does not decrease the PF_HFVS of the household.

Farm size has a significant positive impact on achieving diet diversification through increasing the production diversification of farm households. The coefficient for farm size is small but significant ($p < 0.01$), indicating that larger farms contribute to a higher food variety within the household's diet, even when considering fixed effects. In pooled data, we found that increasing farm income contributed to increasing household food variety, but the association became insignificant and inverse under the fixed effect condition, as farm income may be higher when smallholder farm households used to sell their produce in the market for cash by lowering their own consumption. However, the role of market distance and market participation has a significant influence on the relationship between the production diversity and food diversity of farm households. The coefficient for market distance indicates a statistically significant ($p < 0.1$) negative relationship between proximity to markets and food variety. The results under the fixed-effect condition reveal that those living further from the marketplace have less access to a wide variety of foods and that the estimated market access coefficient is lower than the PDS. Market participation is another useful indicator of the commercialization of the household. The market participation coefficient reveals a statistically significant ($p < 0.1$) and adverse correlation between market participation and food variety score, whether the food is produced or purchased. The coefficient of this indicator has been found to be substantially negative and much smaller than the coefficient of PDS because selling farm produce in the market can seriously reduce the variety of foods remaining for consumption by farm households.

Moreover, factors such as the household's total non-farm income and the involvement of women in the workforce were also considered. An increase in income from non-farm sources consistently contributes to increasing FVS ($p < 0.01$), meaning that non-farm income can support a household to buy various foods from the market, but the magnitudes are smaller than those of the PDS. On the other hand, the coefficient of non-farm income is much smaller than the production diversification coefficient but significantly larger than the coefficient of farm income, which indicates that increasing farm income may not necessarily increase the food variety in the consumption basket and that non-farm income sources may not contribute more to increasing diet diversity than producing diversified agricultural foods on farm for smallholder households.

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TABLE 3 Descriptive statistics of explanatory variables.

| Explanatory Variables | Mean and Standard Deviation (SD) | | | | Mean diff. (2012 vs. 2015) | Mean diff. (2015 vs. 2018) | Mean diff. (2012 vs. 2018) |
|---|---|---|---|---|---|---|---|
| | Pooled | 2012 | 2015 | 2018 | | | |
| PDS | 8.049 (5.183) | 7.923 (5.586) | 7.546 (4.80) | 8.677 (5.068) | −0.377 (−3.31) | 1.131*** (9.92) | 0.754*** (6.61) |
| ADS | 3.806 (1.864) | 3.629 (1.909) | 3.757 (1.816) | 4.032 (1.843) | 0.128*** (3.13) | 0.275*** (6.69) | 0.403*** (9.82) |
| Farm size (decimal) | 62.645 (110.485) | 63.885 (110.857) | 64.603 (123.102) | 59.447 (95.750) | 0.719 (0.29) | −5.156* (−2.11) | −4.437 (−1.82) |
| Market distance (Km) | 1.783 (2.654) | 1.744 (1.681) | 1.709 (1.859) | 1.897 (3.852) | −0.035 (−0.60) | 0.188*** (3.21) | 0.153** (2.60) |
| Market participation (% of value of the produce sold) | 24.248 (27.241) | 23.729 (26.502) | 24.488 (28.031) | 24.527 (27.167) | 0.759 (1.26) | 0.039 (0.07) | 0.798 (1.33) |
| Farm income (Tk) | 35,548 (67,701) | (27,115) (49,548) | (34,643) (66,095) | (44,887) (82,280) | 7,528*** (5.06) | 10,244*** (6.88) | 17,772*** (11.94) |
| Non-farm income (Tk) | 62,801 (96,504) | 41,595 (59,215) | 61,601 (101,969) | 85,208 (114,395) | 20,005*** (9.54) | 23,607*** (11.26) | 43,613*** (20.80) |
| Sex of HH head (dummy; 1 = Male) | 0.816 (0.387) | 0.831 (0.375) | 0.818 (0.386) | 0.800 (0.400) | −0.013 (−1.54) | −0.0178* (−2.08) | −0.031*** (−3.63) |
| Age of household head (years) | 46.065 (13.355) | 43.999 (13.542) | 46.149 (13.291) | 48.048 (12.919) | 2.150*** (7.34) | 1.899*** (6.48) | 4.049*** (13.82) |
| Education of household head (years) | 3.600 (4.115) | 3.476 (4.090) | 3.599 (4.083) | 3.725 (4.168) | 0.123 (1.35) | 0.127 (1.39) | 0.250** (2.75) |
| Earning status of adult women (dummy; 1 = Yes) | 0.768 (0.422) | 0.645 (0.478) | 0.780 (0.415) | 0.879 (0.326) | 0.134*** (14.76) | 0.099*** (10.91) | 0.233*** (25.67) |
| Education of adult women (years) | 3.391 (3.616) | 3.227 (3.580) | 3.365 (3.574) | 3.580 (3.683) | 0.139 (1.73) | 0.214** (2.69) | 0.353*** (4.42) |
| Household size (number) | 4.777 (1.823) | 4.178 (1.505) | 4.772 (1.720) | 5.381 (2.007) | 0.594*** (15.30) | 0.608*** (15.67) | 1.202*** (30.97) |
| Child share in household size (%) | 35.079 (20.845) | 38.973 (21.525) | 35.529 (20.417) | 30.736 (19.730) | −3.444*** (−7.57) | −4.793*** (−10.54) | −8.237*** (−18.11) |
| Elder member share in household size (%) | 14.493 (20.180) | 6.090 (14.862) | 13.908 (18.840) | 23.481 (22.231) | 7.818*** (18.73) | 9.574*** (22.93) | 17.391*** (41.66) |
| Access to information (dummy; 1 = Yes) | 0.886 (0.318) | 0.797 (0.402) | 0.900 (0.300) | 0.960 (0.195) | 0.103*** (15.01) | 0.060*** (8.78) | 0.163*** (23.79) |
| Number of observations (HH group) | 12,279 | 4,093 | 4,093 | 4,093 | - | - | - |

*t*-values are in the parentheses; *** and ** indicate significance at 1 and 5%, respectively.

Thus, households with higher non-farm income have a higher dependency on purchased food items for variation in food consumption. This study also found a positive and significant ($p < 0.01$) relationship between the earning status of women and the food diversity status of farm households. Households with female members who are engaged in earning from farm and non-farm sources have higher dietary diversification. This indicates that women's employment has a significant impact on improving diet and nutritional status.

Other variables indicate that the gender of the head of the household and household size are positively associated with household diet diversity. The impact of household head's education and especially women's education on dietary diversity is also found to be positive. Households with more children and elderly members have less food diversity. Additionally, ownership of informative devices, which is the proxy measure of access to information, like television, radio, mobile phones, etc., which provide access to information, had a strong correlation and a significant ($p < 0.01$) influence on the dietary diversification of households.

The key finding that higher PDS is associated with higher HFVS is robust across all of the different specifications. The overall results suggest that production diversification, the earning status of adult women, and access to information sources are important factors for improving the food variety scores of farm households, and agricultural production diversification has more influence than non-farm income.

Table 5 shows the results from regression analysis of the alternative measures of agricultural diversification. At the level of individual farm households, ADS and HDDS have been observed with a positive and significant relationship. The results show that for every one unit increase in the ADS, the HDDS significantly ($p < 0.01$) went up by 0.8%, irrespective of the model specifications. In the case of dietary diversity based on purchased food, one unit increase in the ADS decreased the purchased food groups by 1.2%, indicating that higher agricultural diversification can lessen the dependency on purchased food. Though there is no evidence of a significant relationship between ADS and PF_HDDS after accounting for fixed effects. Both models found that the larger the farm size of the household, the less dependent it was on purchased food items. Again, higher market distance

TABLE 4 Regression analysis of PDS on HFVS and PF_HFVS (fixed-effect Poisson model).

| Variables | HFVS | | PF_HFVS | |
|---|---|---|---|---|
| | Pooled | Fixed effects | Pooled | Fixed effects |
| PDS | 0.006*** (4.933e-04) | 0.006*** (0.001) | −0.002*** (0.001) | 0.003*** (0.001) |
| Farm size | 4.73e-05** (2.24e-05) | 1.433e-04*** (3.52e-05) | −4.29e-05 (3.03e-05) | 8.00e-05* (4.10e-05) |
| Market distance | −0.004* (0.002) | −0.002* (0.001) | −0.006* (0.003) | −0.001 (0.001) |
| Market participation | −1.857e-04* (9.56e-05) | −1.977e-04* (1.176e-04) | −0.001*** (1.102e-04) | −1.058e-03 (8.063e-04) |
| Farm income | 1.07e-07*** (3.96e-08) | −2.78e-08 (4.62e-08) | 5.32e-08 (4.83e-08) | −4.40e-08 (5.13e-08) |
| Non-farm income | 2.46e-07*** (4.60e-08) | 9.73e-08*** (3.55e-08) | 3.41e-07*** (6.58e-08) | 1.20e-07*** (3.80e-08) |
| Sex of HH head (1 = Male) | 0.012* (0.007) | 0.037*** (0.012) | 0.025*** (0.008) | 0.057*** (0.013) |
| Age of HH head | 0.001*** (2.139e-04) | 2.999e-04 (4.745e-04) | 0.001*** (2.410e-04) | (0.001) (5.161e-04) |
| Education of HH head | 0.007*** (0.001) | 0.002 (0.002) | 0.008*** (0.001) | 0.002 (0.002) |
| Earning status of adult women (1 = Yes) | 0.030*** (0.006) | 0.061*** (0.006) | 0.006 (0.006) | 0.044*** (0.007) |
| Education of adult women | 0.011*** (0.001) | 0.003* (0.002) | 0.012*** (0.001) | 0.003 (0.002) |
| Household size | 0.031*** (0.002) | 0.029*** (0.003) | 0.036*** (0.002) | 0.032*** (0.004) |
| Share of children | −4.562e-04*** (1.476e-04) | −1.088e-04 (2.204e-04) | −4.946e-04*** (1.681e-04) | −1.772e-04 (2.376e-04) |
| Share of elders | −1.303e-03*** (1.598e-04) | −0.002*** (2.247e-04) | −0.002*** (1.842e-04) | −0.002*** (2.458e-04) |
| Access to information (1 = Yes) | 0.119*** (0.008) | 0.031*** (0.009) | 0.155*** (0.009) | 0.037*** (0.010) |
| Year 2015 (dummy 1) | 0.139*** (0.006) | 0.155*** (0.006) | 0.102*** (0.007) | 0.126*** (0.006) |
| Year 2018 (dummy 2) | 0.197*** (0.007) | 0.229*** (0.008) | 0.199*** (0.008) | 0.237*** (0.009) |
| Constant | 2.968*** (0.016) | – | 2.840*** (0.019) | – |
| Log likelihood | −45396.471 | −25297.673 | −45344.017 | −24576.449 |
| Wald $\chi 2$ | 5417.17 | 3828.77 | 4260.56 | 3226.02 |
| Observations | 12,279 | 12,279 | 12,279 | 12,279 |
| Number of HH | – | 4,093 | – | 4,093 |

Robust standard errors are in the parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

decreases the food group variation in both cases. An increase in the percentage value of the produce sold in the market can reduce the consumption of different food groups. However, the higher income from both farm and non-farm sources increases the household consumption of diversified food groups, but the magnitudes are smaller than the ADS.

It has been shown that households led by male members have less dietary diversity than those headed by female members; however, the diversity of the diet of farm households improves with increasing educational status and age, which is also an indicator of the experience of the head. Additionally, education is thought of as an indicator of awareness for women, and it was observed that the earning status of women has also a favorable and significant association with the HDDS. Dietary diversity of farm households increased substantially as household size increased, however, when the dependency ratio of children and elderly members grew, there was a subsequent decline in the dietary diversity of the households. The availability of information, on the other hand, suggests that diversified agricultural production can provide a wider variety of food groups to choose from, which, as a consequence, can improve the nutritional quality of farm households.

The regression findings of this study utilizing a variety of measures provide validation of a significant association between agricultural diversification and dietary diversification of farm households in Bangladesh. Among the various control variables, the age of the household head, the education of the head, the education of women, and access to information services were found to have consistent and meaningful outcomes. In both fixed-effect analyses time is considered as a variable by including the three wave dummies considering 2012 as the base year. Both the 2015- and 2018-year dummies are extremely significant at the individual household level, emphasizing the role of time. An upward trend in the dummy coefficient suggests that dietary diversification has improved through time, and that agricultural diversification has contributed to this trend by increasing the variety of foods available to farming households.

## 3.3. Discussion

Rice cultivation has traditionally accounted for 75 percent of Bangladesh's gross cropped area (BBS, 2018). The government has taken steps to encourage farmers to diversify away from rice monoculture and into other agricultural practices. Thus, in the context of Bangladeshi agriculture, shifting away from rice production and engaging in unconventional non-rice crop cultivation and/or non-crop agriculture such as livestock, poultry, and fisheries is referred to as agricultural diversification. On the other hand, household consumption patterns in Bangladesh, as well as in other South and Southeast Asian countries, are heavily reliant on cereals, as

TABLE 5 Regression analysis of ADS on HDDS and PF_HDDS (fixed-effect Poisson model).

| Variables | HDDS | | PF_HDDS | |
|---|---|---|---|---|
| | Pooled | Fixed effects | Pooled | Fixed effects |
| ADS | 0.008*** (0.001) | 0.008*** (0.001) | −0.012*** (0.001) | 2.082e-04 (0.001) |
| Farm size | 4.43e-06 (1.16e-05) | 6.21e-05*** (1.91e-05) | −1.073e-04*** (2.38e-05) | −1.38e-05 (3.63e-05) |
| Market distance | −0.001 (0.001) | −0.001* (0.001) | −0.004 (0.002) | −4.443e-04 (0.001) |
| Market participation | −2.75e-05 (5.15e-05) | −4.16e-05 (6.65e-05) | −2.673e-04*** (7.64e-05) | −1.471e-04 (9.70e-05) |
| Farm income | 7.12e-08*** (1.82e-08) | 3.26e-09 (2.26e-08) | −5.56e−10 (3.24e-08) | -1.36e-10 (3.72e-08) |
| Non-farm income | 5.97e-08*** (1.16e-08) | 2.24e-08 (1.38e-08) | 1.62e-07*** (2.76e-08) | 4.93e-08** (1.92e-08) |
| Sex of HH head (1 = Male) | −0.022*** (0.004) | −1.282e-04 (0.007) | −0.024*** (0.006) | 0.015 (0.009) |
| Age of HH head | 0.001*** (1.165e-04) | 2.121e-04 (3.006e-04) | 0.001*** (1.740e-04) | −3.400e-04 (3.951e-04) |
| Education of HH head | 0.004*** (3.603e-04) | 0.001 (0.001) | 0.006*** (0.001) | 0.001 (0.001) |
| Earning status of adult women (1 = Yes) | 0.002 (0.003) | 0.011*** (0.004) | −0.019*** (0.005) | 0.002 (0.005) |
| Education of adult women | 0.005*** (4.423e-04) | 0.002** (0.001) | 0.008*** (0.001) | 0.002 (0.002) |
| HH size | 0.010*** (0.001) | 0.009*** (0.002) | 0.019*** (0.001) | 0.014*** (0.003) |
| Share of children | −2.021e-04** (7.95e-05) | −2.178e-04* (1.274e-04) | −3.884e-04*** (1.194e-04) | −3.733e-04** (1.791e-04) |
| Share of elders | −4.994e-04*** (9.36e-05) | −0.001*** (1.428e-04) | −0.001*** (1.366e-04) | −0.001*** (2.014e-04) |
| Access to information (1 = Yes) | 0.063*** (0.005) | 0.024*** (0.006) | 0.103*** (0.007) | 0.028*** (0.008) |
| Year 2015 (dummy 1) | 0.058*** (0.003) | 0.067*** (0.003) | 0.049*** (0.005) | 0.064*** (0.005) |
| Year 2018 (dummy 2) | 0.059*** (0.004) | 0.076*** (0.005) | 0.069*** (0.005) | 0.096*** (0.007) |
| Constant | 2.105*** (0.009) | – | 1.967*** (0.014) | – |
| Log likelihood | −26813.491 | −15478.132 | −26948.516 | −15286.191 |
| Wald $\chi 2$ | 2685.33 | 1334.13 | 2551.76 | 894.24 |
| Observations | 12,279 | 12,279 | 12,279 | 12,279 |
| Number of HH | - | 4,093 | - | 4,093 |

Robust standard errors are in the parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

food consumption diversity in these regions is not yet widespread. The goal of dietary diversification is to alter people's food consumption habits so that they consume a wider variety of foods, thereby enhancing their nutritional value and, ultimately, their food security. Thus, it is assumed here that agricultural households can improve their dietary diversity by implementing agricultural diversification strategies.

In this study, we have analyzed the role of agricultural diversification on dietary diversity in smallholder farm households in Bangladesh, and the results of this study support the idea that agricultural production diversification is linked to dietary diversity of rural farm households. Our findings are consistent with those from earlier studies, despite the fact that we used different data and indicators of dietary diversity (Jones et al., 2014; Pellegrini and Tasciotti, 2014; Sraboni et al., 2014; Sibhatu et al., 2015; Snapp and Fisher, 2015; Romeo et al., 2016; Sibhatu and Qaim, 2017; Jones, 2017; Koppmair et al., 2017; Islam et al., 2018 ; Parvathi, 2018; Chegere and Stage, 2020). Yet this study also reveals a few new insights. Previous studies measured farm diversity using a simple species count, which we also employed to calculate the production diversity score. However, the agricultural diversification score, defined as the number of food groups produced, was also used in the primary specifications. The impact on dietary diversity is greater when comparing the number of food groups produced to the species count alone. This makes sense in a subsistence-based system like Bangladesh, where the farm family itself uses the majority of the farm's output. When households engage in more diverse agricultural activities, such as cultivating different crops, raising various livestock, and participating in fisheries, it contributes to a greater variety of food consumed within the household (Troell et al., 2014; Andrew et al., 2015). For example, a farm that produces a variety of grains, vegetables, fruits, and livestock would have a higher agricultural diversification score compared to a farm that produces only one or two crops. In turn, this higher diversity could translate to better nutritional outcomes for the household consuming the food produced on the farm.

While diversification may be beneficial for small-scale subsistence farmers, it may not be as advantageous for larger, commercially oriented farms (Sibhatu and Qaim, 2017). A previous study utilizing data from more commercially oriented farmers in Indonesia, Kenya, and Uganda demonstrated that increasing the variety of foods a farm produces may reduce cash profits and eliminate the advantages of specialization in more commercialized settings with greater market access (Sibhatu et al., 2015). This suggests that the relationship between farm diversification and commercialization may vary depending on the context and market conditions. Therefore, it is important to consider market access and the goals of a farm when deciding whether to diversify its production. Considering this fact, this study used two ways to show how important the market was:

market access, which was shown by how far away the household was from the nearest market, and market participation, which was used to predict how commercialized the farm was by figuring out how much of the value of produce was sold in the market (Islam et al., 2018). Numerous studies have emphasized the significance of markets in enhancing dietary quality (Sibhatu et al., 2015; Snapp and Fisher, 2015; Hirvonen and Hoddinott, 2017; Koppmair et al., 2017; Sibhatu and Qaim, 2017). This study found that households which are located closer to markets tend to have a higher variety of foods in their diet, possibly due to easier access to a diverse range of food products. Most smallholders rely on subsistence agriculture, but they still frequently purchase more than half of their food from the market (Jones, 2017; Sibhatu and Qaim, 2017). In such condition, increasing the accessibility of markets by shortening distance or constructing new marketplaces might improve the dietary diversity of rural households. On the other side, households with lower levels of market participation, perhaps relying more on subsistence farming or self-sufficiency, tend to have a higher variety of foods in their diet. This suggests the relationship between the extent of market participation and the diversity of diet in a household. It also highlights the importance of understanding local food systems and the ways in which they may impact dietary patterns. In favorable market conditions, a number of studies found a positive correlation between production diversity and the level of commercialization and cash profits (Pellegrini and Tasciotti, 2014; Jones, 2017; Sibhatu and Qaim, 2018a). So, farm diversification that targets the market, rather than subsistence farming, will have a greater favorable impact on household nutrition.

Additionally, recent researches (Sibhatu et al., 2015; Koppmair et al., 2017) suggest that increasing dietary diversity is even more dependent on non-farm income than it is on-farm diversification. Considering the importance of non-farm income as a part of income diversification strategy in rural areas, we also included this determinant in our models. Results supported that non-farm income can consistently contribute to greater food variety consumption, suggesting that this type of income can help households afford to buy a wider variety of foods. For instance, in rural areas of developing countries, non-farm income generated from small businesses or off-farm employment can enable households to purchase diverse food items such as fruits, vegetables, and animal products that are not locally produced (Babatunde and Qaim, 2010; Rahman and Mishra, 2020). This can improve the nutritional status of individuals and reduce the risk of malnutrition.

In the context of Bangladesh, empowering household women has a favorable contribution to achieving more nutritious and better diet diversity (Sraboni et al., 2014). Evidence from Ghana and Nepal also suggests that women's employment in agriculture is associated with better nutrition status and can also mitigate the limited impact of low production diversity within farm households (Malapit et al., 2015). Our findings supported the fact that women's earning status, used as a proxy for women's empowerment, also has a favorable and significant association with the dietary diversity of rural farm households. This suggests that improving women's earning potential and overall empowerment can lead to improved nutrition and food security for their families. Moreover, it highlights the importance of addressing gender inequalities in rural areas and promoting women's economic and social empowerment as a means to improve overall household well-being. Finally, the analysis has shown that access to information sources can improve the dietary diversity status of rural households. For example, access to agricultural extension services and radio programs led to increased knowledge about nutrition and improved dietary diversity among rural households in Malawi (Ragasa et al., 2022). Overall, our study justified that dietary diversity in farm households are more strongly influenced by diversification of agricultural production, the economic status of adult women, and access to information sources than by non-farm income. These findings can have policy implications in developing countries where subsistence-based agricultural practices are followed and diversification strategies along with market interventions for commercialization are promoted for sustainable agriculture.

## 3.4. Limitations and scopes

However, there are some limitations in our study which may pave the way for further research. One limitation is, we have used the secondary data which only covers panel data from the years 2012, 2015, and 2018. These data may not be representative of the current entire population or provide a complete understanding of the phenomenon being studied. So, future research could expand on the time frame to better understand the current situation. Another limitation can be stated that agricultural diversification is likely to be an endogenous variable that partly depends on unobserved variables. While fixed effects models can control for time-invariant unobserved heterogeneity, they may not completely eliminate endogeneity concerns. But in case of panel data analysis, including fixed effects can minimize the potential bias arising from omitted variables and time-invariant confounders, and thus strengthen the internal validity of results. Employing robust standard errors is another methodological choice we made to enhance the reliability of our results as robust standard errors are account for heteroscedasticity and clustered observations. Though these techniques may not fully address endogeneity and selection bias, together these methodological choices contribute to the overall rigor of our study by minimizing potential biases and increasing the validity of our statistical inference. Future research could explore alternative econometric approaches, such as instrumental variable regression or difference-in-differences, to comprehensively resolve these concerns.

# 4. Conclusions and policy recommendations

For developing nations to speed up their economic growth and sustainable development, decrease poverty, and increase food security, agriculture is recognized as a potent solution and an important instrument. By gradually shifting away from low-value subsistence crops (especially staple foods) and toward high-value commodities with a better potential for profitability, agricultural diversification can be a strategy. Better food and nutrition outcomes may result from more agricultural diversification because of the increased variety of foods accessible. The recent policy documents of the government have stressed the importance of increasing agricultural diversification in Bangladesh. Therefore, this study has prioritized to assess the

relationships between agricultural diversification and dietary diversity among farm households, as well as the factors that affect this correlation over the time. The findings from the analysis confirm previous research results, although previous research had only measured diversification in terms of crop cultivation and livestock rearing. This study follows a different perspective of measuring agricultural diversification by combining the three major sectors of crop, fish, and livestock production at the farm household level, to assess the impact of such agricultural diversification on the dietary diversity of farm households in Bangladesh. The balanced panel data allows us to highlight that agricultural diversification has a positive significant impact on the diet diversification of farm households. Moreover, women's earning status within farm households has a strong association in improving the dietary status, food, and nutritional security as well. Participation in non-farm activities was found to have a significant impact on dietary diversity but not more than agricultural diversification. The analysis suggests that market facilities need to be improved to achieve higher diversity in production and consumption of farm households.

From a socioeconomic perspective this study has found that education of the household head and women has a significant effect on dietary diversity, by creating awareness among people which helps to take the right decisions for household food security and nutrition. Supporting this result, another interesting insight is that access to information facilities has significant impact on assuring higher household dietary diversity because authentic knowledge can be disseminated en masse to people through appropriate media channels, helping shape their perception, attitude, and practices related to nutrition and diet choices.

So, from the perspective of policy that requires nutrition into consideration, our findings support the following: (a) encourage women's employability and diversification of income; (b) provide support for diversified farming systems including high value crop diversification of both food crops and non-food crops so that the food crops can directly increase the nutritionally enriched dietary intake, and the non-crops can maximize the cash income of the farm that may also indirectly improve the dietary diversification among the farm households; (c) support livestock ownership; and (d) promote market access through improved infrastructure.

In Bangladesh, agricultural diversification is already being promoted based on the assumption that this process can improve household dietary diversity. This study provides support for that approach; however, additional research is required in order to specify the mechanisms through which agricultural production diversification can effectively and efficiently optimize the dietary diversity of farm households to ensure sound health.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

Ethical review and approval was not required for the study on human participants because data were used directly from IFPRI. Written informed consent from the participants was taken by the IFPRI during data collection.

## Author contributions

TM, TJ, AK, and MA: conceptualization. MA, AK, and IB: methodology. TM, IB, and MA: formal analysis and data curation. MA and IB: investigation and supervision. TM and IB: writing—original draft preparation. JW, KC, AK, TJ, and MA: writing—review and editing. MA and AK: funding acquisition. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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