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RESEARCH

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# Leveraging farm production diversity for dietary diversity: evidence from national level panel data

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## Abstract

Dietary diversity is the key to improved health and nutrition. Farm production diversity has the potential of enhancing dietary diversity but this interrelationship varies and is ambiguous in many societies. To examine the effect of farm production diversity on household dietary diversity using nationally representative panel data of Bangladesh we have used Bangladesh Integrated Household Survey (BIHS) data collected by International Food Policy Research Institute (IFPRI) in 2011/12, 2015 and 2018/19. Total sample size is 11,720. For assessing dietary diversity we have used different indicators namely household dietary diversity score (HDDS) and food variety score (FVS). We have also used multiple methods for measuring farm production diversity including production diversity score, crop diversity score and Simpson diversification index. Poisson regression model has been used. Results revealed a strong positive association among farm production diversity, income and dietary diversity though the extent of the association is small. The variables such as market orientation, access to market, age and education are also found to influence on household dietary diversity. Our results propose that for increasing dietary diversity efforts should be taken to increase farm production diversity combined with diverse income and market access.

**Keywords:** Household dietary diversity score, Farm production diversity, Income, Panel data, Bangladesh

## Introduction

The commitment of achieving Sustainable Development Goal of eliminating hunger (SDG-2) has posed a challenge linking agriculture and nutrition through promoting sustainable agriculture (Allen and Brauw 2018). Over the past few decades, agricultural productivity along with global food production made a contribution to reduce hunger (Godecke et al. 2012) but malnutrition or hidden hunger remain extensive, notably in Asia and Sub-Saharan Africa region (Sibhatu and Qaim 2018a). Although the nutritional status of many developing countries has been upgraded over the years South Asian countries lag behind other regions. This region is the home of around 50% of world's hungry population (Pandey et al. 2016). Aside from the high level of food insecurity, about 23% of the populations of South Asia lack proper calorie consumption (WDI

2014). South Asian countries mainly depend on agriculture for employment and livelihoods (Deb 2014). Bangladesh, a developing and overpopulated nation in South Asia, has achieved commendable growth in reducing poverty and hunger over the last two decades, but several indices of nutrition remain a matter of concern (Belton et al. 2014; Rahman 2010; Rahman and Salim 2013). In rural Bangladesh, one-third of women are malnourished and 36% of children under five are stunted (Ahmed et al. 2012; Osmani et al. 2016). Moreover, the country continues to struggle with micronutrient deficiencies such as zinc, iron, iodine and vitamin A due to inadequate diets that are dominated by rice and lack diversification (Ahmed et al. 2013). Research indicates that the food habit of Bangladeshi people is inadequately diversified and this emerged as a major barrier in acquiring a standard nutritional status. Dietary diversity is a proxy method of nutrient adequacy of an individual's diet (Kennedy et al. 2011). It can be defined as different types of foods available across and within food groups that can ensure adequate intake of vital nutrients for optimal health (WHO/FAO 1996; Ruel 2002). It is linked to adequate vitamin and micronutrient intake and better child nutrition outcomes (Fongar et al. 2019; Kennedy et al. 2007; Muthini et al. 2020; Steyn et al. 2006).

Dietary diversity is determined by different factors including agricultural biodiversity and farm production diversity (Jones et al. 2014; Oyarzun et al. 2013), production technology, historical consumption habits, household income (Doan 2014; Drescher et al. 2009) and cultural traits at the regional level. Although dietary diversity is a crucial indicator of nutrition, but for low-income people consumption of nutritious food is quite difficult (FAO 2013; Chegere and Stage 2020). For households engaged in subsistence agriculture, farm production diversity would be a promising approach for achieving nutritional security and therefore nutritionists have given emphasis to harnessing the linkages between farm diversity and diversity in household diets (Malapit et al. 2015). For small landholders, agricultural diversification plays a vital role in dietary diversity as it improves the consumption of own-produced food, as well as purchased food on account of increased income from the selling of farm produce (Chegere and Stage 2020; Herrero et al. 2010; IFAD and UNEP 2013).

Various trails are indicating how agriculture can affect the nutritional outcomes which include increased farm production and consumption of food, increased income, reduction of food prices and women empowerment (Kadiyala et al. 2014; Kanter et al. 2015). Research related to agriculture-nutrition linkages has recently gained increased attention and several studies have been conducted on-farm diversity and nutrition. Different studies used varied methods of assessing the link between production diversity and dietary diversity with varied outcomes. Some studies showed a positive association between farm diversity and household dietary diversity (Chegere and Stage 2020; Jones 2017; Pellegrini and Tasciotti 2014; Saaka et al. 2017). Chinnadurai et al. (2016) showed a positive relationship between household dietary diversity and crop diversity, whereas the association was found negative in case of diversity of vegetable production and dietary diversity. Likewise, Sibhatu and Qaim (2018b) found a mixed result indicating that farm production diversity was positively related to dietary diversity when measured with simple species count, whereas did not find any significant relation with dietary diversity when production diversity was measured in terms of the number of food crops. Production diversity also interrelates with other factors such as household income, market access and commercialization of households. While rising income has proven to be an important indicator of dietary diversity (Dillon et al. 2014; Singh et al. 2020), small effort has been taken to see how dietary diversity and nutrition are affected by diversifying income of the household (Benfica and Kilic 2016). Also in developing countries, farmers are gradually diversifying their sources of income which makes the relationship is critical to understand (Davis et al. 2014, 2017; Winters et al. 2010).

Our present research adds to the literature in various aspects. The current evidence revealed that the association between them is complex and situation-specific (Muthini et al. 2020; Sibhatu et al. 2015). In this strand of literature, one of the drawbacks is that most of the studies were conducted in the African region, where smallholder farmers were mainly subsistence in nature and the green revolution was not very effective (Jones 2017; FAO 2014). Hence, more research is required in the Asian region to determine the association. The intensity of associations may vary by context, but further research from Asian settings is essential to confirm this. Moreover, most of the studies used cross-sectional data and one of the main problems of cross-sectional studies is selection bias which violating the true association (Jones 2017). Panel data is needed not only to reduce omitted variable bias but also to increase the accuracy of the estimation procedure (Tae et al. 2007). Also, many studies used small sample sizes and simple econometric methods for assessing the relationship which makes it difficult to draw firm conclusions especially in the policy context. Our research has not only used the large, nationally representative, unique panel data but also used panel econometric procedures. In addition, we have also used alternative measures for measuring both dietary diversity and agricultural production diversity. Hence, it is necessary to address the above shortcomings and gain a deeper knowledge of the relationship between farm production diversity and dietary diversity of households. The present study seeks to answer the research question of whether farm production diversity has any effect on household dietary diversity. Therefore this study's objective is to examine the effect of farm production diversity and dietary diversity using the complete set of (3 rounds) large, unique and nationally representative panel data in Bangladesh.

## Materials and methods

### Conceptual framework

The question of whether a farm produces its food or buys from the market has a significant contribution to its nutrition. The paradigm shows the interplay among farm production diversity, income and dietary diversity. The relationships among these three factors are endogenous implying that they affect each other and the interconnection is ambiguous (Fig. 1). Farm diversity is a direct strategy to promote food diversity in subsistence farm households. In subsistence farming, production decisions are influenced by consumption decisions and vice versa. This means that households must produce what they want to consume and also they have to diversify their diet based on their products only. In the case of commercial farming, households focus on specialization to increase income which has a significant contribution to the diet. Higher agricultural diversity may give farmers greater access to produce diverse food and livestock animal in their farm and more chances to cultivate other crops (i.e., plantation, cash crops) which may also have a contribution on nutrition through improved revenue. Some exogenous

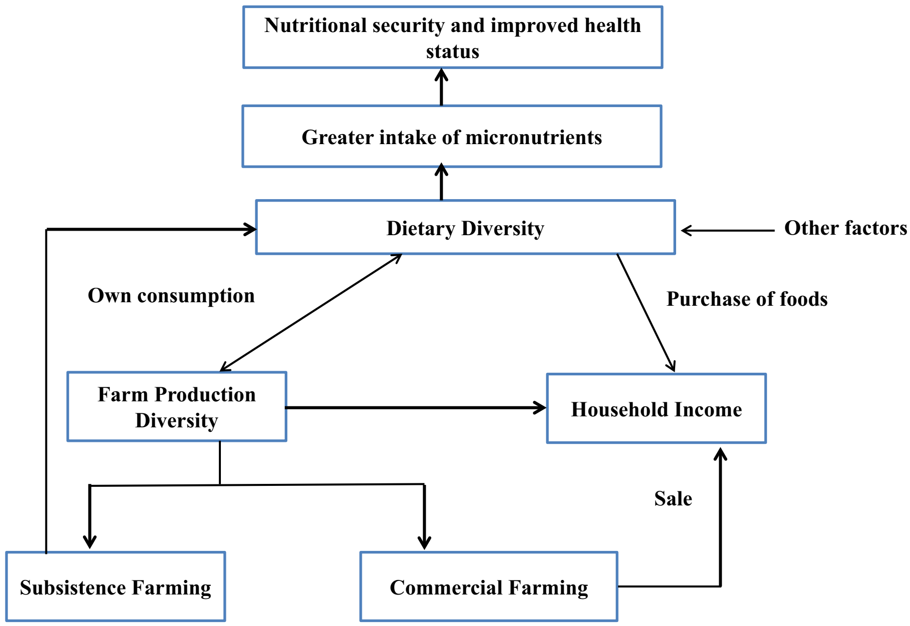


**Fig. 1** Conceptual framework displaying the associations among farm production diversity, income and dietary diversity (Authors' construction based on Bellon et al. 2016)

factors such as socioeconomic and demographic characteristics, market infrastructure, population density, climate variability etc. may have an impact on dietary diversity. A diverse diet is interconnected with higher micronutrient intakes and improved health status.

## Data

The study is conducted using three rounds panel data of Bangladesh Integrated Household Survey (BIHS) collected in 2011/12, 2015 and 2018/19. BIHS is a large, exclusive and nationally representative panel dataset in Bangladesh which is managed by the International Food Policy Research Institute (IFPRI). It is a household survey statistically representative at the national and seven administrative divisional levels of rural Bangladesh namely Chittagong, Barisal, Dhaka, Khulna, Rajshahi, Rangpur, and Sylhet. BIHS followed a two-stage stratified sampling technique: firstly, by selecting 325 primary sampling units (PSUs) and secondly, by selecting households from the PSUs. The BIHS survey collected detailed data on plot-level agricultural production, dietary intake of individual household members, and anthropometric measurements of all household members (Mequanint et al. 2019). The survey questionnaire included several modules for household members addressing a variety of research questions and covering the whole agricultural production year. Information regarding household food consumption patterns, agricultural production, socio-economic characteristics of the individual and household, agricultural and productive asset, livestock holding and participation of the social safety net program has been considered for analysis.

BIHS collected a sample of total of 6500 rural households covering whole agro-ecological zones (AEZ) of Bangladesh. Among 6500 households, 4423, 4619 and 4886 households were national representatives in 2011/12, 2015 and 2018/19, respectively (representative of rural Bangladesh) and the remaining households fall under a different stratum referred to as the "Feed the Future Zone (FTF)". FTF households have not been used in our study. Besides, we have limited our research to households which are engaged in any of the agricultural production systems (i.e., growing crops, raising livestock/poultry/fisheries, etc.). Therefore, we have used a smaller sample size than the original BIHS data. Of these data, some of the observations are dropped due to probable errors in the demographic and food consumption data. So the final estimation consists of 11,720 samples using 3 round data (Table 1). A slight change in sample size is observed over the year which is mainly due to split-up households.

## Estimation strategy

Our main outcome variable is household dietary diversity score (HDDS) which is a count variable that takes the value between 1 and 12 (or between 1 and 9 when includes 9 food groups). We have used Poisson regression with a maximum-likelihood estimation technique. For measuring the association among farm production diversity, income, and dietary diversity we have used the given model:

$$\mathrm{DD}_{it} = \alpha_0 + \alpha_1 \mathrm{PD}_{it} + \alpha_2 \mathrm{HI}_{it} + \gamma_{it} \quad (1)$$

where $\mathrm{DD}_{it}$ is dietary diversity. $\mathrm{PD}_{it}$ is farm production diversity and $\mathrm{HI}_{it}$ is annual household income at time $t$. $\gamma_{it}$ is the random error term, and subscripts $i$ and $t$ indicate observations and time, respectively. $\alpha_0$, $\alpha_1$ and $\alpha_2$ are coefficients to be estimated.

Equation (1) indicates that our model has two explanatory variables, i.e., farm production diversity and income. In addition to farm diversity and income there may be other factors, i.e., market orientation, market distance, farm size, participation in social safety net programs and socioeconomic characteristics that affect dietary diversity. So we have included these factors in our extended model and the model takes the following form:

$$\mathrm{DD}_{it} = \alpha_0 + \alpha_1 \mathrm{PD}_{it} + \alpha_2 \mathrm{HI}_{it} + \alpha_3 \mathrm{MA}_{it} + \alpha_4 \mathrm{MO}_{it} + \alpha_5 \mathrm{SSN}_{it} + \alpha_6 \mathrm{HS}_{it} + \gamma_{it} \quad (2)$$

where $\mathrm{MA}_{it}$ is a vector of variables covering market access, $\mathrm{MO}_{it}$ indicates market orientation, $\mathrm{SSN}_{it}$ is participation in social safety net programs and $\mathrm{HS}_{it}$ household demographic and socioeconomic characteristics.

All the analyses including data coding, merging and reshaping have been done using STATA version 16.1 software.

## Measurement of key variables

### *Dietary diversity*

In this study, our primary outcome variable is dietary diversity. It is a crucial element of balanced diet since higher dietary diversity ensures a higher intake of nutrients (Kennedy et al. 2007; Steyn et al. 2006). Food variety score and dietary diversity score (DDS)

**Table 1** Description of the sample

| Item | Round-1 (2011–12) | Round-2 (2015) | Round-3 (2018–19) | Panel |
|---|---|---|---|---|
| Households | 3896 | 4004 | 3820 | 11,720 |

are two commonly used measures for determining dietary diversity (FAO 2011). Food variety score (FVS) simply counts the number of food items consumed by the household during the recall period (Drewnowski et al. 1997). Although the food variety score is a suitable measure for assessing nutritional status it is less preferable for cross-country analysis due to differences in dietary habits across countries (FAO 2011; Pellegrini and Tasciotti 2014). In this setting, dietary diversity score is preferred to food variety score. In our study, we have measured dietary diversity using both FVS and HDDS.

Household dietary diversity score which is widely accepted measure records the number of food groups eaten by the households over a recall period (Keding et al. 2012; Sibhatu et al. 2015). Although there is no international standard for the number of food groups required to calculate HDDS, FAO proposed of using 12 food groups (FAO 2011). These are Cereals; White tubers and roots; Legumes, nuts and seeds; Vegetables; Fruits; Fish and other seafood; Meat; Eggs; Milk and milk products; Oils and fats; Sweets; and Spices, condiments and beverages (Table 2). Each food group adds one score point toward the HDDS if a food item from that group is consumed by any member of the household in the given period. Thus, HDDS ranges from 0 to 12. For assessing HDDS studies used both 24-h period (e.g. Koppmair et al. 2016; M'Kaibi et al. 2017) and a 7-day recall period (e.g. Chegere and Stage 2020; Jones et al. 2014; Jones 2017; Sibhatu and Qaim 2017). Special days like festival, holidays and fasting is practiced in every community and for this seven-day recall period which captures the daily variation in diets, could be more appropriate than the 24-h (Sariyev et al. 2021). In this study, we have constructed HDDS using a 7-day recall period. Studies indicate that the last three food group's (viz Oils and fats; Sweets; and Spices, condiments and beverages) contribution to dietary diversity is ambiguous and for this we have calculated HDDS both using 12 food groups and 9 food groups. The food variety score (FVS) is our second DD assessment tool, which we created by calculating the amount of various food items ingested by the household during 7-day recall period. The main difference between HDDS and FVS is that HDDS restricts to different food

**Table 2** Food groups included in household dietary diversity score. *Source*: Combined from Kennedy and Ballard (2010)

| Household dietary diversity score (HDDS) | Household dietary diversity score using healthy food groups (HDDS9) |
|---|---|
| 1. Cereals | 1. Cereals |
| 2. White tubers and roots | 2. White tubers and roots |
| 3. Vegetables | 3. Vegetables |
| 4. Fruits | 4. Fruits |
| 5. Meat | 5. Meat |
| 6. Eggs | 6. Eggs |
| 7. Fish and other seafood | 7. Fish and other seafood |
| 8. Legumes, nuts and seeds | 8. Legumes, nuts and seeds |
| 9. Milk and milk products | 9. Milk and milk products |
| 10. Oils and fats | |
| 11. Sweets | |
| 12. Spices, condiments and beverages | |

groups (not food items) whereas FVS counts each and every food items consumed by the household.

### Farm production diversity

Our key independent variable is farm production diversity which can be defined as the variation of crop and animal species produced in a farm (Sibhatu 2016). It seems like a prospective approach for enhancing food and nutritional benefit of smallholders and enhancing their access to the variety of foodstuffs (Burlingame and Dernini 2012; Fanzo et al. 2013). The empirical literature suggests different indicators for measuring farm production diversity. We have used multiple methods for measuring farm production diversity so that we can compare the outcomes and test the reliability of the relationship. These methods are production diversity score, crop diversity score and Simpson diversification index. Farm production diversity score is a simple count of the number of food crops, vegetables, fruits and animal species of the households (Koppmair et al. 2017; Muthini et al. 2020; Sibhatu and Qaim 2018b).

Some of the households also grow non-food cash crops like cotton, jute, tobacco, flowers and other minor crops. Although these crops do not directly contribute to dietary diversity but increase the farm income so we have included them in our study. So our second measure is the crop diversity score where we have included all the crops (viz. cash crops, food crops etc.) produced by the household.

Another widely used indicator of farm diversity is Simpson Diversity Index (SID). SID is superior to other methods in the way that it not only captures crop richness but also the crop evenness (Chegere and Stage 2020; Lovo and Veronesi 2019). SID is calculated as:

$$\text{SID} = 1 - \sum_{i}^{n} S_i^2$$

where $n$ = the total number of crops, $S_i$ = area proportion of the $i$th crop in the total cropped area.

Thus, $S_i$ denotes the proportion of the area of the $i$th crop to the total cropped area. SID ranges from zero to one with zero representing no agricultural diversification and one indicating complete diversification. For evaluating the association between farm production diversity and dietary diversity we have used multiple indicators for both outcome variable and main explanatory variable because these allow for a more thorough and accurate result.

### Control variables

The relationship between dietary diversity and production diversification may be influenced by socio-economic and demographic characteristics. For this, based on the thorough literature review we have included these factors as control variables in our regression (Annim and Frempong 2018; Babatunde and Qaim 2010; Carletto et al. 2017; Chegere and Stage 2020; Hirvonen and Hoddinott 2017; Jones et al. 2014; Koppmair et al. 2016; Kumar et al. 2015; Muthini et al. 2020; Pellegrini and Tasciotti 2014; Romeo et al. 2016; Sariyev et al. 2021; Sibhatu et al. 2015; Singh et al. 2020; Thorne-Lyman et al. 2009). For assessing whether income has any effect on dietary diversity we have included the annual income of the households as the independent variable. For getting annual income we have calculated farm and off-farm income. We have taken other variables like market orientation, access to the market, participation in social safety net programs, etc. Individual socioeconomic characteristics such as age, sex and education of the household head, farm size, household size and status of the household's agricultural asset have also been included. Figure 2 at a glance shows the different explanatory variables and outcome variables used for analyzing the relationship between dietary diversity and farm production diversity:

#### Robustness check

For conducting the robustness check to corroborate the stability of the major findings we have utilized different estimating methods and measures of important variables. The following techniques have been used:

Firstly, several factors may affect household dietary diversity other than farm production diversity. Besides, some omitted variables may be interrelated to farm production diversity, thereby biasing the estimated results. For testing omitted variable bias, we have re-estimated regression models by adding household socioeconomic characteristics.

Secondly, to test whether there are some unobserved variables like a special event which occurred from first to the third round or not we have estimated the two-way FE regression model. In this model, we have included year dummy and used 2011–12 as the reference period, 2016 as period 1 and 2018–19 as period 2.

Lastly, as a robustness check we have used different methods both outcome variables and explanatory variables. For measuring dietary diversity we have used HDDS based on 9 food groups and FVS. On the other hand, we have utilized alternate methods of production diversity such as the Simpson Index of diversity and crop diversity score and estimated the regression model for each of these methods with outcome variable dietary diversity (HDDS, HDDS using 9 food groups and FVS).

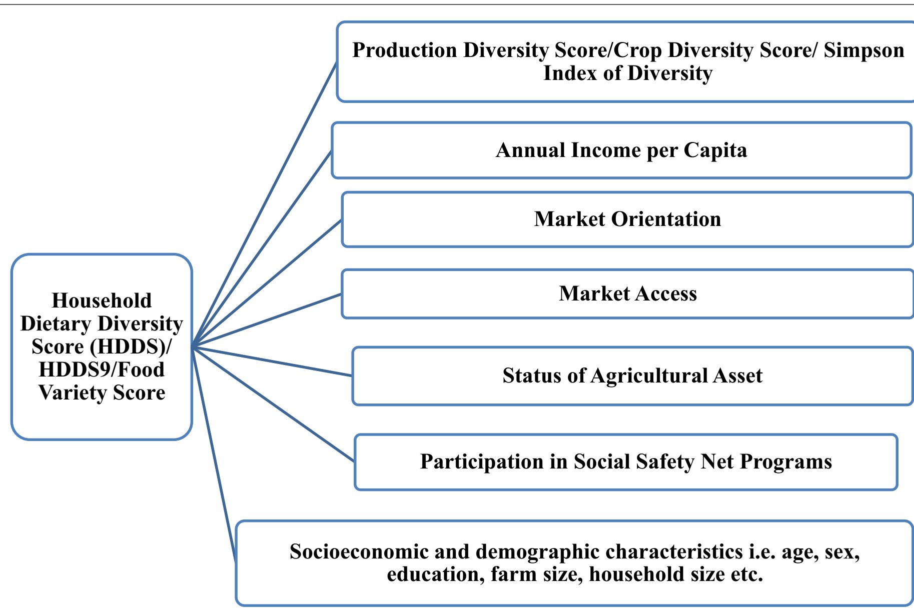


**Fig. 2** Framework showing outcome and independent variables used in the regression

# Results

## Descriptive statistics

Descriptive statistics of the variables are shown in Table 3. Households are consumed more than 9 different food groups out of 12 food groups in 7 days. The average HDDS is 9.50 which indicate that the average household has consumed 9.50 food groups out of 12 food groups during the recall period. The average number of food groups eaten by the households is almost constant, especially in the last 2 rounds. HDDS in case of both 12 food groups and 9 food groups has been improved from the first round to the third round. The average HDDS based on healthy food groups (9 food groups) is 7.47. Households consume on an average 32 items in a 7-day recall period. A significant rise is also observed in the case of FVS from the first round to the third. The values of both dietary diversity and FVS are found to be almost constant in the 2nd and 3rd rounds.

Household dietary diversity score (HDDS) and production diversity score (PDS) across 7 administrative divisions in Bangladesh are depicted in Fig. 3. The box plot shows HDDS score is almost the same and not the greater variation is found in the HDDS across divisions. Households consume on an average 9 food groups across divisions. However, variation is found in PDS across divisions. Highest PDS is found in Barisal division (6.2) and the lowest is in Chittagong divisions (4.2).

Kernel density distribution of the production diversity score shows that households are producing around five different crops or animal products in the given 12-month period (Fig. 4) The right-skewed distribution curve shows that the average value of farm production diversity is greater than the mode and most of the of household's production diversity is below the average. Households produce on an average 5 different crop species in a year. The value of Simpson index of crop diversification is 0.31. All the indicators of farm production diversity indicate that farm diversity is low in Bangladesh but has increased over time.

The value of market orientation is only 17% indicating that most of the agricultural households experienced subsistence farming and the annual per capita income is comparatively low which is approximately Tk. 1, 38,000 (approximately USD 1665 as at the time of writing). The average distance from home to the nearest market is 1.17 km. The socio-economic characteristics show that around 80% of households are male-headed. The average years of schooling of the household head are very low (only 3 years). The average household size is consisting of 4 people. The average farm size is 75.84 decimal and around 45% of households participate in the different social safety net programs.

## Association between dietary diversity and farm production diversity

Table 4 exhibits the results of Poisson regression using pooled, fixed effects and random effects where we have used household dietary diversity score as dependent variable and production diversity score and annual per capita income as explanatory variables. Farm production diversity is positively significantly related to household dietary diversity but the extent of this association is very small. The result of pooled specification indicates that DDS would be increased by 0.7% at the household level if one food group is produced. There is a significant positive association between annual income and HDDS which means that income could improve households' capability to purchase a wider range of foodstuff and thereby increase dietary diversity.

**Table 3** Description of the variables used in the econometric analysis

| Variable | Measurement and definition | Round-1 | Round-2 | Round-3 | Total |
|---|---|---|---|---|---|
| *Outcome variable* | | | | | |
| HDDS | Number of food groups consumed by the household in the last 7 days | 8.90 (1.47) | 9.60 (1.31) | 9.86 (1.27) | 9.50 (1.41) |
| HDDS9 | Household dietary diversity score based on nine food groups | 6.66 (1.59) | 7.78 (1.21) | 7.97 (1.21) | 7.47 (1.36) |
| FVS | Number of food items consumed by the household in the last 7 days | 26.46 (8.20) | 32.90 (9.55) | 35.95 (9.88) | 31.78 (10.04) |
| *Main explanatory variables* | | | | | |
| Production diversity score | Count of food crop and animal species grown by the household | 4.78 (3.18) | 5.06 (3.43) | 5.37 (3.49) | 5.07 (3.38) |
| Crop diversity score | Number of crop species grown by the household | 5.18 (4.05) | 5.03 (3.80) | 5.37 (3.78) | 5.17 (3.88) |
| SID | Simpson's Index of Crop Diversification | 0.24 (0.29) | 0.31 (0.21) | 0.38 (0.19) | 0.31 (0.24) |
| Income of household | Household annual income in the last year (Taka) | 129,418 (300,469) | 137,829 (301,840) | 146,682 (348,842) | 137,918 (317,542) |
| Market orientation | Percentage of produce sold to the market (%) | 10.16 (15.93) | 19.73 (20.28) | 22.41 (20.28) | 17.42 (20.27) |
| Market access | Distance from home to the nearest market (km) | 1.31 (1.20) | 1.19 (1.31) | 1.02 (2.07) | 1.17 (1.57) |
| *Control variables* | | | | | |
| Age of HH head | Age of the HH head (years) | 43.95 (13.71) | 45.82 (13.56) | 47.38 (12.97) | 45.71 (13.499) |
| Sex of HH head | = 1 if the household head is male | 0.83 (0.38) | 0.79 (0.40) | 0.78 (0.41) | 0.80 (0.39) |
| Education of HH head | Years of schooling of the HH head (year) | 3.18 (3.88) | 3.28 (3.86) | 3.47 (3.94) | 3.13 (3.89) |
| Household size | Number of HH members (number) | 4.22 (1.58) | 3.73 (1.48) | 4.37 (1.83) | 4.10 (1.66) |
| Farm size | Total land holding of the HH (decimal) | 81.04 (108.66) | 77.61 (121.05) | 68 (88.08) | 75.84 (107.029) |
| Participation in SSN program | = 1 if HH participate any social safety net program | 0.44 (0.50) | 0.42 (0.49) | 0.47 (0.50) | 0.44 (0.49) |
| Agricultural asset value | Current value of agricultural assets (Taka) | 5098 (33,698) | 4754 (30,116) | 4880 (33,770) | 4909 (32,540) |

Authors' analyses using 3 rounds of BIHS panel data. Mean values are shown with standard deviation in parentheses

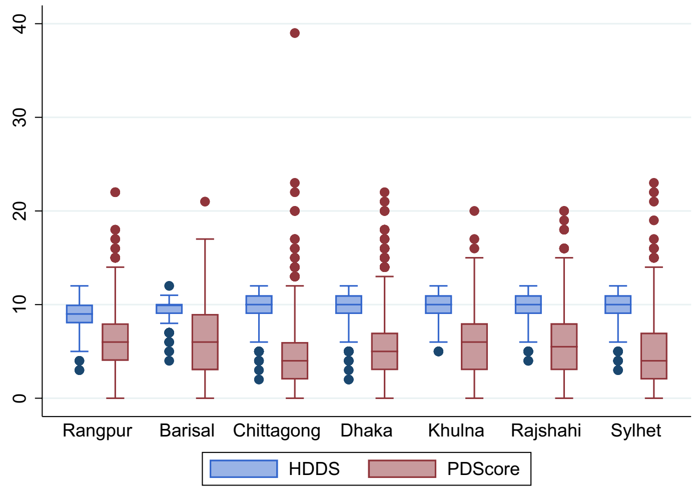


**Fig. 3** Division wise household dietary diversity score and production diversity score in Bangladesh

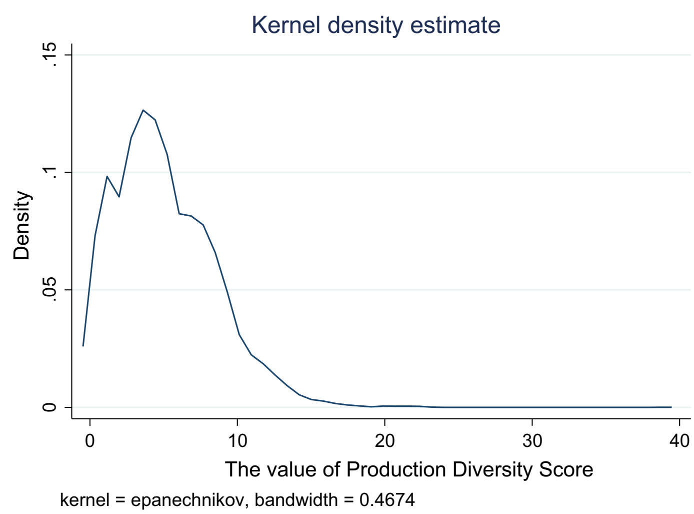


**Fig. 4** Kernel density of production diversity score in Bangladesh

**Table 4** Results of pooled, fixed-effect and random effects Poisson regression model

| Explanatory variables | Dependent variable: HDDS | | |
|---|---|---|---|
| | **Pooled** | **Fixed effects** | **Random effects** |
| Farm production diversity measured through PDS | 0.007*** (0.0009) | 0.008*** (0.0016) | 0.007*** (0.0008) |
| Annual income | 4.122E−08*** (9.57E−09) | 2.16E−08** (1.26E−08) | 4.69E−08*** (8.94E−09) |
| Constant | 2.20*** (0.006) | – | 2.29*** (0.005) |
| Log likelihood | – | − 13,939.09 | − 25,753.83 |
| Wald $\chi^2$ | 90.40*** | 27.89*** | 108.08*** |
| LR test | | | 0.12 |
| Number of observations | 11,720 | 11,720 | 11,720 |

Authors' analyses using 3 rounds of BIHS panel data

***, and ** indicate significance at the 1% and 5%, levels, respectively; figures in the parentheses indicate standard errors

To examine whether market has any effect on the association between diet diversity of households and farm production diversity we have extended the model by using this factor (Table 5). Because of the significance of market orientation, we have extended the model by adding an interaction term namely market orientation which is recorded by the average percentage of agricultural output sold. For assessing whether distance from home to nearest market has any effect on dietary diversity we have included the variable as market access. Given that households having within walking distance of markets can diversify their eating habits by buying goods from markets, it is reasonable to expect stronger linkages between farm production diversity and household dietary diversity further away from markets. The variable market access is found negative and significant showing that households in more remote areas have less dietary diversity. Simultaneously, the effects of farm diversity on household dietary diversity are still strong. When the estimates are compared, it appears that reducing the walking time to the district market by 1 h would have a greater positive impact on household dietary diversity than growing one more food crop to the farm. Our results noticeably show that market access is important for increasing the dietary diversity of farm households. The variable namely market orientation is found positive and significant suggests that increasing the commercialization may be a better strategy for improving nutrition than encouraging more diverse subsistence agriculture.

The relationship between dietary variety and production diversity also depends on household and socio-economic factors. The extended model of the association among production diversity, income and dietary diversity showed that farm production diversity and annual income have a significant positive association with dietary diversity irrespective of model specifications (Table 6). We have calculated alternative measures of farm diversity (i.e., SI and CDS) and found a significant positive association with dietary diversity. This is common in subsistence farming where the farm household consumes a large portion of the farm's output. The variable market access suggests that dietary diversity can be enhanced by reducing the distance from the market or improving infrastructure.

For testing omitted variable bias, we re-estimated the model using socio-economic variables and found that some of the socioeconomic variables such as age and education of household head and household size including production diversity are positively

**Table 5** Relationship among production diversity, income, market orientation and market access

| Explanatory variables | Pooled | Fixed effect |
|---|---|---|
| Farm production diversity (PDS) | 0.007 (0.002)*** | 0.010*** (0.003) |
| Farm production diversity squared | − 1.9E−05 (1.5E−04) | − 9.5E−05 (2.2E−04) |
| Annual income | 5.991E−08*** (1.81E−08) | 4.07E−08** (2.27e−08) |
| [Farm production diversity] × [Annual income] | − 3.71E−09 (2.59E−09) | −3.94E−09 (3.91E−09) |
| Market orientation | 0.001*** (3.1E−04) | 0.001*** (0.0004) |
| [Farm production diversity] × [Market orientation] | − 6.65E−05 (4.58E−05) | − 8.25E−05 (6.25E−05) |
| Market distance | − 0.014 (0.006)*** | − 0.015** (0.008) |
| [Farm production diversity] × [Market distance] | 9.6E−04 (7.6E−04) | 0.001 (0.001) |
| Constant | 2.21*** (0.012) | – |
| Wald $\chi^2$ | 128.65 | 59.81 |
| Number of observations | 11,720 | 11,720 |

Authors' analyses using 3 rounds of BIHS panel data. The dependent variable is HDDS

***, and ** indicate significance at the 1% and 5%, levels, respectively; figures in the parentheses indicate standard errors

**Table 6** Association among farm production diversity, income and other confounding factors

| Explanatory variables | PDS | | SID | | CDS | |
|---|---|---|---|---|---|---|
| | **Pooled** | **Fixed effect** | **Pooled** | **Fixed effect** | **Pooled** | **Fixed effect** |
| Farm production diversity | 0.005*** (0.001) | 0.007*** (0.002) | 0.006*** (0.014) | 0.095*** (0.021) | 0.005*** (0.001) | 0.006*** (0.002) |
| Annual income | 2.59E−08*** (9.98E−09) | 1.84E−08 (1.69E−08) | 2.62E−08*** (9.97E−09) | 1.59E−08 (1.69E−08) | 2.36E−08*** (1.00E−09) | 1.81E−08 (1.69E−08) |
| Market orientation | 7.13E−04*** (1.57E−05) | 8.5E−04*** (2.23E−04) | 6.30E−04*** (1.6E−04) | 7.18E−04*** (2.2E−04) | 7.04E−04*** (1.5E−04) | 9.13E−04*** (2.2E−04) |
| Market access | 0.006*** (0.002) | − 0.006** (0.003) | − 0.006*** (0.002) | − 0.006** (0.0031) | − 0.006*** (0.002) | − 0.006** (0.0031) |
| Age of HH | 0.0002*** (0.0003) | 0.002*** (0.0006) | 0.002 (0.0002) | 0.002*** (0.0006) | 8.49E−05 (0.0002) | 0.002*** (0.0007) |
| Sex of HH | − 0.001 (0.009) | − 0.008 (0.017) | − 0.001 (0.009) | − 0.004 (0.166) | − 4.52E−04 (0.008) | − 0.006 (0.16) |
| Education of HH head | 0.007*** (0.001) | 0.008*** (0.003) | 0.007*** (0.0009) | 0.008*** (0.003) | 0.006*** (0.0008) | 0.008*** (0.003) |
| HH size | 0.014*** (0.002) | 0.009*** (0.004) | 0.014*** (0.002) | 0.008** (0.003) | 0.014*** (0.002) | 0.009** (0.003) |
| Farm size | 4.77E−05 (3.89E−05) | 1.57E−05 (6.6 E−05) | − 1.31E−05 (6.6E−05) | − 1.31E−05 (6.6E−05) | 4.66E−05 (3.84E−05) | − 3.8E−06 (6.5E−05) |
| Participation in social SSN program | 0.015*** (0.006) | 0.002 (0.009) | 0.014*** (0.006) | 0.003 (0.008) | 0.014*** (0.006) | 0.002 (0.009) |
| Agricultural asset value | 7.20E−08 (9.29E−08) | 2.25E−08 (1.7E−07) | − 6.54E−09 (9.29E−07) | − 9.63E−09 (1.70E−07) | − 6.66E−08 (9.30E−08) | − 2.45E−08 (1.1–07) |
| Constant | 2.12 (0.017) | – | 2.14 (0.016) | – | 2.13 (0.015) | – |
| Wald $\chi^2$ | 250.89 | 75.73 | 246.60 | 81.32 | 265.80 | 79.53 |
| Number of observations | 11,720 | 11,720 | 11,720 | 11,720 | 11,720 | 11,720 |

Authors' analyses using 3 rounds of BIHS panel data. The dependent variable is HDDS

***, and ** indicate significance at the 1% and 5%, levels, respectively; figures in the parentheses are standard errors

significantly associated with HDDS in this newly estimated model. This indicates that our primary findings are free from omitted variable bias (Table 6). A positive significant association with age indicates that the households having older heads have revealed higher dietary diversity. The variable education has a significant and positive effect indicating that educated people are more conscious about nutritionally-balanced diets and diversified baskets. Education not only enhances the knowledge of health and nutrition, but it also helps to manage the diversified food at an affordable cost. Household size is positively significantly associated with HDDS indicating higher dietary diversity with more members in the households.

Bangladesh Government is conducting different social safety net programs for upgrading the socio-economic status especially for the rural and disadvantaged group such as Stipend for Primary Students, School Feeding Program, Stipend for Dropout Students, Stipend for Secondary and Higher Secondary or Female Student etc. For assessing whether this SSN program has any effect on dietary diversity we have added this variable. We have found a positive significant relation with dietary diversity in the pooled model.

## Discussion

One of the crucial outcomes of this study is that farm production diversity is positively significantly associated with household dietary diversity irrespective of the model specifications and methods used. The extent of the association is relatively smaller and is relevant to previous studies. Most of the earlier studies found the extent of the relationship between 0.05 and 0.20. (Bellon et al. 2016; Koppmair et al. 2017; Sariyev et al. 2021; Sibhatu and Qaim 2018a, b) although Jones et al. (2014) and Chegere and stage (2020) found higher impact using OLS approach. Also this small association is persistent in developing countries like Bangladesh where the majority of farmers are smallholder and subsistent (World Bank 2007). Studies showed that the relationship between farm diversity and dietary diversity depends on the methods used for measuring both. The relationship is positive when both crop and livestock species are taken into account, however, if only crop count is utilized, the relationship become negative (Jones et al. 2014). Sibhatu and Qaim (2018b) showed that in certain cases, other variables such as market access and off-farm income had greater impacts on dietary diversity than farm diversity. However, in our study we have found other factors are also important but not as farm diversity. The variable namely annual income is positively associated with dietary diversity which indicates that increasing income can increase household's ability to purchase diversified food. This result is also consistent with previous studies (Babatunde and Qaim 2010; Singh et al. 2020). The estimated coefficient of market orientation is positive for dietary diversity but the extent of association is smaller than the farm production diversity (0.010 > 0.001). These findings show that although both production diversity and commercialization are crucial tools for increasing dietary diversity but production diversification may be a better approach than commercialization in the long run. However, Koppmair et al. (2016), found that access to markets for buying food and selling farm produce along with modern technology more important for dietary diversity than farm diversity. The variable market distance is negatively associated with dietary diversity which is persistent with previous studies (Muthini et al. 2020; Sibhatu and Qaim 2018b). To know more about the underlying relationship, i.e., whether the relationship is linear or not we have used the interaction term of production diversity squared and estimated the model. A significant positive interaction term ($PD^2$) implies that increased farm production variety is connected with greater dietary diversity, whereas a negatively significant $PD^2$ suggests that as farm production diversity grows, the magnitude of the association declines (Sibhatu and Qaim 2018b). This study has not found any significant association with dietary diversity after using the interaction term production diversity squared although the sign is negative. Insignificant coefficients do not imply that there is no association or that the interaction component should be deleted but depend on the values of interrelating factors (Ai and Norton 2003; Brambor et al. 2006; Sariyev et al. 2021). It's also likely that production diversity has a significant marginal impact on a range of other parameters that interact with production diversity measures (Sariyev et al. 2021).

We have estimated two way fixed effect regression model to test and control the unobserved bias and found that year dummy is positively significant which indicates that time plays a crucial role and dietary diversity has increased over the years (Table 7).

Finally, all of the regression results using multiple indicators in various situations and specifications show that farm diversity have positive significant relationship with dietary diversity at the household level (Tables 8, 9). The extent of the association is small but it is nevertheless greater than other coefficients which are significant, indicating the importance of farm diversity on dietary diversity in a rice dominating country.

## Conclusions

Dietary diversity is the most commonly used and essential indicator of food and nutrition. At the macro level, this necessitates agricultural diversification. In recent years, nutrition-sensitive agricultural research has gained considerable attention for improving nutritional status and one example of such program is farm diversification. So far different studies have found diverse outcomes. Policy makers are interested to know the exact relationship between farm diversity and dietary diversity. Our study examines the association between farm production diversity and household dietary diversity using a nationally representative and complete (3 rounds) panel dataset of Bangladesh. For doing this we have used alternate measures for assessing both farm diversity and dietary diversity. We have initiated our analysis with the pooled Poisson regression which assumed that production diversity is exogenous and finally move to the fixed effect model. Our results indicate that both household dietary diversity and farm production diversity increases over the years although production diversity is comparatively low in Bangladesh. Our results provide robust evidence that production diversity is positively significantly associated with dietary diversity although the magnitude is lower. We have also found a positive significant association between income and dietary diversity. Market orientation, access to the market and participation in social safety net programs has also impact on household dietary diversity but the magnitude is lower than production diversity. In Bangladesh as rice is the staple crop, traditionally different government and non-government large-scale support programs have mainly focused on rice cultivation to maintain food security of its growing population, with limited incentive have given to farmers for diversifying production. But in recent years, Government of Bangladesh (GoB) has underlined the necessity of agricultural diversification in different policy papers like National agricultural policy, Country Investment Plan and Five Year Plan. Agriculture nutrition linkages sometimes appear to be too complicated to pursue. In this case our study will help in shaping the agenda of agricultural development strategy that is essential for improving nutrition among farm households. Therefore, from a policy perspective our results suggest that as farm production diversity is an important indicator of household dietary diversity and nutrition agricultural policies and programs should focus on production diversity rather than solely increasing the production of selected staple crops. Furthermore, an attempt can also be taken to encourage income diversification and market access for addressing the nutrition security of SDGs of Bangladesh. One of the potential limitations of this study is that our data is based on three points of time, but dietary diversity of farm households changes throughout the time especially within the years, such as with agricultural seasons. More research using high frequency data is needed to solve the problem of seasonality component of dietary diversity. In addition, we have analyzed effect of farm production diversity on household dietary diversity but not individual dietary diversity. Hence, more research is needed to better understand the intra household dietary diversity especially for women and children.

## Appendix

See Tables 7, 8 and 9.

**Table 7** Two way fixed effect model for the robustness check

| Explanatory variables | Dependent variable: HDDS | |
|---|---|---|
| | Pooled | Fixed effect |
| Farm production diversity | 0.004*** (0.001) | 0.004*** (0.002) |
| Annual income | 2.47E−08*** (9.99E−09) | 1.04E−08 (1.69E−08) |
| Market orientation | 5.55E−05 (1.6E−04) | 5.5E77−05 (2.37E−04) |
| Market access | − 0.003* (0.002) | − 0.003 (0.003) |
| Age of HH | 0.0002 (0.0003) | − 0.0002 (0.0007) |
| Sex of HH | − 0.009 (0.009) | 0.023 (0.017) |
| Education of HH head | 0.007*** (0.0009) | 0.002 (0.003) |
| HH size | 0.014*** (0.002) | 0.010*** (0.004) |
| Farm size | − 1.33E−05 (3.88E−05) | − 6.1E−05 (6.66E−05) |
| Participation in social SSN program | 0.157*** (0.006) | 0.002 (0.009) |
| Agricultural asset value | 8.39E−08 (9.32E−08) | 1.55E−08 (1.70E−07) |
| *Year* | | |
| 2015–16 | 0.078*** (0.007) | 0.079*** (0.008) |
| 2018–19 | 0.088*** (0.007) | 0.092*** (0.009) |
| Constant | 2.10*** (0.017) | – |
| Wald $\chi^2$ | 431.60 | 202.19 |
| Number of observations | 11,720 | 11,720 |

Authors' analyses using 3 rounds of BIHS panel data

***, ** and * indicate significance at the 1% 5% and 10% levels, respectively; figures in the parentheses are standard errors

**Table 8** Extended model of the association between alternative measure of dietary diversity and farm production diversity

| Explanatory variables | Dependent variable: food variety score | |
|---|---|---|
| | Pooled | Fixed Effect |
| Farm production diversity measured through PDS | 0.011*** (0.0006) | 0.018*** (0.001) |
| Annual income | 3.51E−08*** (5.22E−09) | 3.89E−08*** (8.97E−09) |
| Market orientation | 0.002*** (8.36E−05)) | 0.003*** (0.0001) |
| Market access | − 0.016** (0.001) | − 0.014*** (0.002) |
| Age of HH | 0.001 (0.001) | 0.006 (0.004) |
| Sex of HH | − 0.0013 (0.005) | − 0.05*** (0.009) |
| Education of HH head | 0.016*** (0.0005) | 0.02*** (0.002) |
| HH size | 0.045*** (0.001) | 0.034 (0.02) |
| Farm size | − 1.45E−04 (2.11E−04) | − 5.22E−05 (3.62E−05) |
| Participation in social SSN program | 0.035*** (0.003) | 0.006 (0.005) |
| Agricultural asset value | 1.95E−07 (4.62E−07) | 5.06E−08 (8.79E−08) |
| Constant | 3.09*** (0.009) | 2.12*** (0.016) |
| Wald $\chi^2$ | 5639.66 | 2314.39 |
| Number of observations | 11,720 | 11,720 |

Authors' analyses using 3 rounds of BIHS panel data

***, and ** indicate significance at the 1% and 5%, levels, respectively; figures in the parentheses are standard errors

**Table 9** Extended model of the association between HHDS (using healthy food groups) and farm production diversity

| Explanatory variables | Dependent variable: HHDS based on 9 food groups | | | | | |
|---|---|---|---|---|---|---|
| | Pooled | | | Fixed effect | | |
| | PDS | SID | CDS | PDS | SID | CDS |
| Farm production diversity | 0.006*** (0.001) | 0.09*** (0.015) | 0.006*** (0.001) | 0.009*** (0.002) | 0.146*** (0.023) | 0.007*** (0.002) |
| Annual income | 3.03E−08*** (1.10E−08) | 3.01E−08*** (1.11E−08) | 2.81E−08*** (1.11E−09) | 2.48E−08*** (1.91E−08) | 2.11E−08 (1.91E−08) | 2.41E−08 (1.91E−08) |
| Market orientation | 0.001*** (0.0002) | 0.001*** (0.0002) | 0.0009*** (0.0003) | 0.002*** (0.0003) | 0.0014*** (0.0002) | 0.0017*** (0.0003) |
| Market access | − 0.008** (0.003) | − 0.008*** (0.002) | − 0.013*** (0.0002) | − 0.008** (0.004) | − 0.008*** (0.003) | − 0.008* (0.003) |
| Age of HH | 0.0004 (0.0003) | 0.0005* (0.0003) | 3.54E−04 (2.78E−04) | 0.0004 (0.0007) | 0.004*** (0.0007) | 0.004*** (0.0007) |
| Sex of HH | − 0.024** (0.001) | − 0.024** (0.009) | − 0.022** (0.001) | − 0.051 (0.019) | − 0.044** (0.019) | − 0.05* (0.018) |
| Education of HH head | 0.014*** (0.002) | 0.009*** (0.001) | 0.008*** (0.001) | 0.015*** (0.003) | 0.014*** (0.003) | 0.015*** (0.003) |
| HH size | 0.014*** (0.002) | 0.014*** (0.002) | 0.014** (0.002) | 0.005*** (0.004) | 0.004*** (0.004) | 0.006 (0.004) |
| Farm size | 8.9E−05* (4.4E−05) | − 6.26E−05 (4.35E−05) | − 7.76E−06* (4.29E−05) | − 5.41E−05 (7.52E−05) | − 5.64E−05 (7.5E−05) | − 2.99E−05 (7.47E−05) |
| Participation in social SSN program | 0.022*** (0.007) | 0.021** (0.007) | 0.021*** (0.008) | 0.002*** (0.009) | − 0.003 (0.009) | 0.003 (0.009) |
| Agricultural asset value | 8.94E−08 (1.02E−08) | 7.78E−08 (1.02E−07) | 8.50E−08 (1.07E−07) | 2.37E−08 (1.91E−08) | − 2.24E−08 (1.91E−07) | − 2.07E−08 (1.92E−07) |
| Constant | 1.89*** (0.017) | 1.88*** (0.018) | 1.87*** (0.017) | | | |
| Wald $\chi^2$ | 321.04 | 324.95 | 326.85 | 160.20 | 174.08 | 154.33 |
| Number of observations | 11,720 | 11,720 | 11,720 | 11,720 | 11,720 | 11,720 |

Authors' analyses using 3 rounds of BIHS panel data

***, ** and * indicate significance at the 1% 5% and 10% levels, respectively; figures in the parentheses are standard errors


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#### Author contributions
SK is involved in conceptualization, methodology, data extraction, data merging and reshaping, analysis the data and writing the original draft. AS is involved in conceptualization, methodology, supervision and editing the manuscript. SKS is involved in conceptualization and editing the manuscript. All authors read and approved the final manuscript.


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#### Availability of data and materials
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## Declarations

#### Ethics approval and consent to participate
This manuscript does not reported any experimental research or research on humans.

#### Competing interests
The authors declare no competing interests.

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