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Farm diversification and food and nutrition security in Bangladesh: empirical evidence from nationally representative household panel data

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Abstract

Existing literature suggests that farm production diversification has the potential to influence the diet diversity of farmers, but that the magnitude of the association is likely to vary by context and the underlying causal mechanisms are not well understood. This study analyzed the nexus between farm diversification and diet diversity using two round of nationally representative panel data from the Bangladesh Integrated Household Survey (BIHS), collected in 2011/12 and 2015. We used several indicators of dietary diversity including the Household Dietary Diversity Score (HDDS), Women's Dietary Diversity Score (WDDS), and the Food Variety Score (FVS). To measure farm diversification we used the total number of crop, vegetable and fruit species, the number of food crop species only, and the Margalef species richness index. We found robust evidence for a positive association between farm diversification and diet diversity, even when controlling for unobserved heterogeneity across households using the conditional fixed effect Poisson model in order to take advantage of the panel structure of the data. The magnitude of the estimated effect was small. Analysis of other factors indicates that market access, commercialization of farms, diversification of income towards off farm sources and women's empowerment also have positive and significant effects on household dietary diversity. These findings suggest that it may be necessary to couple efforts to increase farm diversity, market access, farm commercialization and income diversification with women's empowerment in order to improve dietary diversity in Bangladesh. Further research is needed to better understand these complex relationships including their ultimate associations with nutritional status.

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1 Introduction

In Bangladesh, significant progress has been made to reduce poverty and malnutrition over the past two decades, yet many indicators of food security and malnutrition remain high (Rahman 2010; Rahman and Salim 2013; Belton et al. 2014). In 2010, 33 million people were food insecure and by 2020 it is estimated that this number will increase to 37 million (USDA 2010). Nearly one-third of women in rural Bangladesh are undernourished, and 36% of under 5 children are stunted (Ahmed et al. 2012; Osmani et al. 2016). The nature and depth of malnutrition has important long-term implications for the country's economic and human development (Shively and Sununtnasuk 2015).

An extensive literature indicates that diversified diets are positively associated with better child nutrition outcomes (Kant et al. 1993; Hatloy et al. 1998; Tarini et al. 1999; Rose et al. 2002; Ruel and Menon 2002; Ruel 2003; Kant 2004; Arimond and Ruel 2004; Steyn et al. 2006; Moursi et al. 2008; Arimond et al. 2010; Rah et al. 2010). Low consumption of a number of foods including fruits, vegetables, nuts and seeds, and fish rank among the top causes of disability life years lost on a global scale (Forouzanfar et al. 2016). Diversification of agricultural production systems may improve dietary quality as well as having environmental benefits (Frison et al. 2006; Di Falco and Chavas 2009; Burlingame and Dernini 2012). However, many countries, particularly those in Asia, have focused largely on the production of few crops such as rice and wheat since the green revolution (Bamji 2007; Graham et al. 2007; Khoury et al. 2014).

There are multiple pathways through which farm diversity may lead to dietary diversity, illustrated through a number of recent agriculture-to-nutrition conceptual frameworks. These pathways include increased income, lowered food prices, more nutritious on-farm produce, food consumption, and women's empowerment (Gillespie et al. 2012; Haddad 2013; Meeker and Haddad 2013; Ruel et al. 2013a, b; Webb 2013; Kadiyala et al. 2014; Herforth and Harris 2014; Jones et al. 2014; Kanter et al. 2015; Romeo et al. 2016). A number of recent studies have analyzed empirically the association between farm diversification and dietary diversity in a number of developing countries (Romeo et al. 2016; Jones et al. 2014; Koppmair et al. 2016; Sibhatu et al. 2015; Dillon et al. 2015; Hirvonen and Hoddinott 2017; Kumar et al. 2015; Shively and Sununtnasuk 2015). One limitation of the current evidence base is that studies have largely focused on sub-Saharan Africa (Jones 2017) where smallholder farms are often subsistence-oriented and where the green revolution was not as successful (FAO 2014). It is plausible that the strength of associations vary by context, but more studies are needed from Asian settings to determine if this is true. A second limitation is that most of the existing studies have used household dietary diversity indicators (HDDS) as a dietary diversity measure, a measure that has been validated against caloric availability (Hoddinott and Yohannes 2002) but not a measure of nutrient adequacy (Kennedy et al. 2013). While HDDS may provide important information regarding the dietary options that may be available for individual household members (Romeo et al. 2016), intra-household food allocation is not always equitable (Villa et al. 2011) and it has been argued that more research is needed to examine individual rather than household level dietary diversity (Dillon et al. 2015). Most studies have also used cross-sectional data to analyze relationships, which may be subject to a variety of biases and which limits interpretability and attribution for policy purposes (Bhagowalia et al. 2012; Dillon et al. 2015; Hoddinott et al. 2015). Selection bias is a major concern of cross sectional studies, and may result in over or underestimation of the true association depending on the nature of the selection bias (Jones 2017). In cross sectional settings it is difficult or even impossible to account for household-specific effects and the unobservable which may be correlated with other included variables in the estimation. Other studies of the relationship between farm diversification and dietary diversity have used ordinary least squares and have not accounted for unobserved household-specific effects (Sibhatu et al. 2015; Koppmair et al. 2016), which may lead to biased and inconsistent estimates of parameters (Abdulai and CroleRees 2001). Therefore, the causal inference from these studies remains limited. Longitudinal designs can address some of these limitations (Abdulai and CroleRees 2001; Jones 2017). Lastly, most studies to date used a relatively small sample and no studies have used data from Bangladesh to examine the farm diversification and dietary diversification linkage though more research on this topic in country specific settings is recommended in the literature (Yosef et al. 2015).

We address these shortcomings by using a unique, nationally representative panel dataset collected in Bangladesh in two waves, in 2012 and 2015, to estimate the impact of farm diversification on women and household diet diversification. Use of panel data enables us to control for unobserved heterogeneity across farm households. In particular, we estimated household Poisson fixed-effects (FE) for the regressions with household dietary diversity, and individual Poisson FE for those with the woman's dietary diversity to derive the impacts of farm diversification on women's dietary diversity score (WDDS) and household dietary diversity score (HDDS).

2 Data, research methods and variables

2.1 Study context

In Bangladesh, rice is the main staple crop, providing two-thirds of consumed calories, and per capita rice consumption is the highest in the world (BBS 2010; Mottaleb et al. 2017;

BER 2016; Bhuiyan et al. 2002; Minten et al. 2013). Since the 1970s, Bangladesh has prioritized rice self-sufficiency through government promotion of green revolution technologies including improved seed, fertilizer, irrigation and liberalization of input agriculture markets (Ahmed 2004). This focus has led to rice self-sufficiency and rice now covers 81% of the total cropped area (BBS 2010; BER 2016). However, because of the focus on staple food production, the diet in Bangladesh is monotonous, lacking in diversity, and is low in certain micronutrients (Hossain et al. 2005; Belton et al. 2014). The recent national nutrition plan emphasized the importance of dietary diversity, raising an important question of whether farm production diversity is important to improve dietary diversity. The present research study seeks to answer this question by examining the relationship between farm diversification and dietary diversification using BIHS, unique panel data collected by IFPRI-Bangladesh.

2.2 Survey and sample description

To analyze the relationship between farm diversification and household and women dietary diversity, we have used the Bangladesh Integrated Household Survey (BIHS) two round panel data collected in 2011/12 and 2015, managed by the International Food Policy Research Institute (IFPRI). The BIHS sample is representative at national, divisional and Feed the Future (FTF) zone level of rural Bangladesh. BIHS used a stratified sampling procedure in two stages. The first round of sampling involved the selection of 375 primary sampling units (PSUs) from the seven divisions (strata) with probability proportional to the number of households in each stratum. In the second stage, households were selected proportionately from each PSU-using the sampling frame developed from the community series of the 2001 population census. BIHS is a nationally representative panel survey that includes detailed information on (1) plot-level agricultural production and practices, (2) dietary intake of individual household members, and (3) anthropometric measurements (height and weight) of all household members. The BIHS questionnaires included several modules as well as separate questionnaires for primary male and female decision makers in sampled households that offers an integrated data platform to answer a variety of research questions. Our study relied primarily on information concerning household and individual socio-economic and demographic characteristics, food consumption and household-level agricultural production and livestock holding. The survey covered an entire agricultural production year (Ahmed et al. 2013; Sraboni et al. 2014; Bell et al. 2015; Seymour 2017).

The first round of the BIHS had a sample size of 6503 rural households covering all agro ecological zones (AEZ), different income quintiles and different farming systems, including homestead/kitchen gardens[1] households from 325 primary sampling units. Within these households, 5934 women were surveyed and included in this study. The second wave had a sample size of 6715 households including the split and non-split household resurveyed from the same primary sampling unit. Similarly 6071 women were also surveyed from those household including the previous plus some new women, who were included. Sample attrition is very common in panel data but interestingly in this sample attrition was very low i.e. 1.26% per year (for detail about the BIHS sampling please see Ahmed et al. 2013; Sraboni et al. 2014; Bell et al. 2015; Seymour 2017). This may be due to the small temporal gap between the survey rounds (Table 1). The sample size was also slightly increased over time mainly due to split-up households. All samples were used for the regression analysis since an unbalanced panel is preferred for more efficient estimation than any balanced subset of it (Baltagi and Song 2006).

2.3 Empirical research methods

In this study, we are interested in understanding whether greater household farm diversity leads to greater household and women's dietary diversity in the absence of markets. Farm diversification may be an insurance mechanism and the costs (insurance premium) is the foregone profit from specialization. To examine whether farm diversification as the main variable of interest is associated with greater household and women's dietary diversity, we use the following reduced form regression equations:

$$DD_{it} = \beta X_{it} + \delta FD + \varepsilon_{it} \qquad (1)$$

where DD is the respective outcome variables (household and women dietary diversity), subscripts i and t denote household observation, and time (survey round), respectively. X is a vector of explanatory variables (other than farm diversification) that influences the outcome variables, and it includes household socio-economic, farm and contextual characteristics. FD is farm diversification measured by various indicators and the coefficient δ, measures the effect of farm diversification on diet diversification.

Our dependent variable, dietary diversity, is a count variable so the Poisson model is a natural starting point (Kouser and Qaim 2011; Hirvonen and Hoddinott 2017). The basic Poisson panel regression is given by $Prob(DD_{it} = dd_{it} \, x_{it}) = e^{-\lambda_{it}} \lambda_{it}^{dd_{it}} / dd_{it}!$, where dd_{it} are the dietary diversity indicators that vary across individual households i and over time t. The Poisson distribution is anticipated to have conditional mean λ_{it}, which hinges on a vector of exogenous variables (X_{it}). The most common specification of λ_{it} found in the literature is a

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[1] All the households who produce any food item even in their home/kitchen garden are included in the sample since home/kitchen gardens play an important role in consumption and nutrition in Bangladesh (Schreinemachers et al. 2015, 2016)

Table 1   Sample description

Items	Rounds (survey year)		Panel sample
	Round 1 (2011/12)	Round 2 (2015)	
Households	6503	6715	6040
Women	5934	6071	3816

Source: Authors' analyses of 2011/12 and 2015 BIHS panel data

log-linear model, which can be depicted as (Cameron and Trivedi 1998):

$$\ln \lambda_{it} = \beta X_{it} + \gamma V_i + C_i + \mu_t \qquad (2)$$

where X_{it} and V_i are vectors of time-variant and time-invariant exogenous variables, with β and γ as the respective vectors of parameters to be estimated. C_i and μ_t represent unobserved individual and time-specific effects, respectively. To examine the impact of farm diversification on women and household dietary diversity, we include different farm diversification indicators as part of the vector X_{it}. Other time-variant and time-invariant variables are included based on a review of the recent literature (e.g. Sibhatu et al. 2015; Koppmair et al. 2016). To capture developments over time and to control for time fixed effects, we also include year dummies for the 2015 survey round, using 2011/12 as the reference as a robustness check of the results. Equation (2) can be estimated with a random-effects panel estimator if we assume that the time invariant unobserved heterogeneity c_i is not correlated to any of the other covariates (strict exogeneity assumption).

Our main interest variable, farm diversification, is itself a decision variable and is influenced by many of the same factors that affect dietary diversity (Kumar et al. 2015; Dillon et al. 2015; Hirvonen and Hoddinott 2017; Jones 2017). If it is affected by (classical) measurement error. There will be downwards attenuation bias in our results, but since farm diversification is not randomly assigned, diversified farm households may be systematically different from non-diversified farm households and these differences might also have influenced our outcome variable. Unobserved characteristics of the farm households such as skills, capabilities, motivation, land quality, household common tradition of caring more (or less) about their household member's health (which are all likely to also affect dietary diversity) may influence the diversification decision through self-selection. If this is the case, the effect of farm diversification will be overestimated and vice versa. Other than these, there may be geographical selection because farm households that are more distant from the market face higher transaction costs of purchasing food items from the market, hence, diversify their farm for own consumption (Taylor and Adelman 2003), and location may itself also be correlated with dietary diversity.

To control for such selection biases, we have estimated the Poisson model in Eq. (2) with household fixed-effects (FE) for the regressions with household dietary diversity, and individual FE for those with the women's dietary diversity including the two way FE model by including year dummies as a robustness check. This allows for correlations between the individual effects and the explanatory variables, which can be differenced out in the estimation process. Models with household FE[2] focus on changes within households over time, controlling for time-invariant factors that might affect selection into farm diversification (Muriithi and Matz 2015). There are two estimation methods including unconditional maximum likelihood and conditional likelihood but both yield the same results for the β coefficients and associated covariance matrices (Cameron and Trivedi 1998). We use the conditional maximum likelihood method for the estimation of FE models. A random effects specification is used based on non-significant findings from the Hausman test. Findings from the Breusch-Pagan likelihood ratio test suggest that pooled specification is more appropriate for our data (Table 4), though we have reported both pooled and FE model results as we suspected that farm diversification is an endogenous variable as discussed above. To control for heteroscedasticity, all models are estimated with robust standard errors (SEs) (Greene 2012). By following Sibhatu et al. (2015), we estimated several FE models by extending model specifications step by step to test the robustness of our estimated results. FE models have recently been used to control for selection bias in different contexts (e.g., Crost et al. 2007; Jorgenson and Birkholz 2010; Kouser and Qaim 2011; Kathage and Qaim 2012; Muriithi and Matz 2015).

2.4 Key dependent and independent variables

2.4.1 Household and women dietary diversity

Dietary diversity is the primary outcome measure in this study. We employed two measures of dietary diversity: the dietary diversity score (DDS) and the food variety score (FVS) (Kant et al. 1993; Ruel 2003; Swindale and Bilinsky 2006; FAO 2013). The dietary diversity score (DDS), is a commonly used indicator that counts the number of food groups consumed over a certain recall period; usually 7 days or 24 h (Keding et al. 2012; Sibhatu et al. 2015). Most of the existing literature has used household dietary diversity scores (HDDs) using 7 day food consumption recall data to examine the relationship between farm diversity and dietary diversity (Jones et al. 2014; Snapp and Fisher 2015; Sibhatu et al. 2015). Few studies have used individual level DDS such as women and child DDS (Herforth 2010; Kumar et al. 2015; Shively and Sununtnasuk 2015; Koppmair et al. 2016; Hirvonen and

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[2] FE models also ameliorate the potential violation of the stable unit treatment value assumption (SUTVA) (Muriithi and Matz 2015).

Hoddinott 2017). In recent years, HDDS measures have, been frequently used as measures of household food access, and therefore of food security. A number of studies have showed a strong association between dietary diversity and household per capita consumption and daily caloric availability (Hatloy et al. 2000; Hoddinott and Yohannes 2002; Ruel 2003; Steyn et al. 2006; Carletto et al. 2013). In this study we have used HHDS measured by counting the number of food groups consumed by a household out of 12 (cereals; roots and tubers; pulses and legumes; milk and milk products; eggs; meat; fish and seafood; oils and fats; sugar and honey; fruits; vegetables; and a miscellaneous category) during the last 7 days (Swindale and Bilinsky 2006; FAO 2013; Kennedy et al. 2013; Sibhatu et al. 2015). It has been argued that these 12 food groups do not carry equal weights in terms of their contribution to nutritional adequacy, and for this reason, some studies have excluded the last three groups due to their lower contribution to micronutrient intake (Olney et al. 2009; Sibhatu et al. 2015). We treated HDDS both ways, as a 9 and 12 item scale, to check the sensitivity of our estimated results. Another limitation of HDDS is that, as a household indicator, it does not necessarily predict nutrient adequacy of individual level dietary intakes (Kennedy et al. 2013). Villa et al. (2011) clearly stated that intra-household dietary diversity allocation is asymmetric. Individual dietary diversity is a validated measure of the diet quality of an individual (Ruel et al. 2014). So we have also used women's dietary diversity score (WDDS) as a measure of women's dietary diversity by counting the number of food groups consumed by the women out of 9 food groups in the last 24 h prior to the survey (Arimond et al. 2010; FAO 2013).

The second measure of dietary diversity, food variety score (FVS) is defined as the number of different food items consumed during the recall period. This is an important indicator for nutritional assessments in a single environment and if the level of food group disaggregation in the data set is very high, which is true in our data sets (Sibhatu et al. 2015). Thus to further test the robustness of our results, we have also used FVS as a dietary diversity indicator by simply counting the number of food items consumed by the household during the last 7 days prior to the survey.

2.4.2 Farm diversification

The main explanatory variable in our analysis is farm diversification, measured using several indicators. We first measured farm diversification by counting the number of crop, vegetables and fruit species produced by the sample household on their farm (Sibhatu et al. 2015). This is a simple, unweighted count measure and recently has been used by a number of studies (Hawksworth 1995; Smale et al. 1998; Swindale and Bilinsky 2006; Herforth 2010; Remans et al. 2011; Jones et al. 2014; Powell et al. 2015; Sibhatu et al. 2015). We also use the

Margalef species richness index and only food crop production diversity score as alternative farm diversification measures to investigate whether these affect the results considerably. The Margalef index is mostly used in the biodiversity and ecology literature which accounts for the area cultivated with different crop species on the farm (Smale et al. 1998; Di Falco and Chavas 2009; Sibhatu et al. 2015). In our sample, some farming households also produce nonfood cash crops such as jute, cotton, tobacco, and flowers that do not directly contribute to dietary diversity. Focusing only on food crop diversity may be important from a nutrition point of view. To capture such effects we estimate the food crop diversity score. Food crop production diversity score is a simple and unweighted measure which counts only the number of food crop species produced by the sample household on their farm (Sibhatu et al. 2015). For comparison and to check the robustness of our results, we have shown results of models estimated with all these alternative measures of farm diversification. Use of multiple indicators for measuring diversity including farm and diet allow us to assess the consistency of the association between farm diversity and dietary diversity (Jones et al. 2014).

2.4.3 Other control variables

There are other factors that may influence diet diversity and underlie the relationship between farm diversification and diet diversification. We include several other variables, including access to market, gender, participation in off farm income activities, commercialization and other household and individual socioeconomic characteristics such as age, education, household size, farm size, sex of the household head, women's age and education. We have used all these covariates a priori based on existing theory (e.g. nonseparable household model, determinants of diet diversity) and review of related literature (Benjamin 1992; Von Braun 1995; Thorne-Lyman et al. 2009; Rashid et al. 2011; Gillespie et al. 2012; Pellegrini and Tasciotti 2014; Jones et al. 2014; Sibhatu et al. 2015; Shively and Sununtnasuk 2015; Kumar et al. 2015; Dillon et al. 2015; Jodlowski et al. 2016; Romeo et al. 2016; Koppmair et al. 2016; Carletto et al. 2017; Hirvonen and Hoddinott 2017).

3 Results and discussion

3.1 Descriptive statistics

To characterize descriptive statistics of both rounds of the panel, we first used parametric tests to compare the means in Tables 2 and 3. From Table 2 it is evident that household dietary diversity score (HDDS) is quite high compared to women's dietary diversity score (WDDS) in both the rounds. This indicates intra-household disparities in dietary diversity. HDDS significantly increases from the first round to second

Table 2 Descriptive statistics of outcome variables

Variable	Measurement and definition	Round 1 (2011/12)	Round 2 (2015)	Mean diff.
Household dietary diversity score (HDDS)	Number of food groups consumed by the household in the last 7 days	8.964 (1.814)	9.810 (1.631)	0.846***
Household dietary diversity score of healthy foods	Number of healthy food groups consumed by the household in the last 7 days	6.285 (1.579)	7.025 (1.440)	0.740***
Dietary diversity score only with respect to purchased foods	Number of food groups consumed by the household in the last 7 days only with respect to purchased foods	7.485 (2.028)	7.291 (2.170)	−0.194***
Food variety score (FVS)	Number of food items consumed by the household in the last 7 days	28.583 (8.641)	33.924 (9.742)	5.341***
Food variety score based on purchased foods only	Number of purchased food items consumed by the household in the last 7 days	19.838 (6.539)	21.978 (7.477)	2.140***
Women dietary diversity score (WDDS)	Number of food groups consumed by the women in the last 24 h	4.374 (1.150)	4.563 (1.170)	0.189***
Number of observations		6503 (5118)	6435 (6071)	

Source: Authors' analyses of 2011/12 and 2015 BIHS panel data. Mean values are shown with standard errors in parentheses. *, **, *** Indicates mean differences between the rounds are statistically significant at the 10%, 5%, and 1% level, respectively

round which is impressive given the daunting challenge of food and nutrition security in Bangladesh. Almost all the dietary diversity indicators increased over the years, except dietary diversity score, based on purchased foods only. This may indicate that households are diversifying their consumption from their own diversifying production. Similarly, Table 3 presents the key independent variables and other control variables used in this analysis. Farm diversity is very low in Bangladesh but has increased over the years very significantly. It is also evident that commercialization of the farm, measured by the share of produce sold in the market, also increased over the years. So it is difficult to determine whether commercialization or farm diversity is associated with dietary diversity since other factors may also directly or indirectly influence dietary diversity. These complexities are examined in more detail in the subsequent sections.

3.2 Association between farm diversification and household and women's dietary diversity

Table 4 shows results of pooled, random effects and fixed effects Poisson regression models in which household and women's dietary diversity are used as dependent variables and farm production diversity as an explanatory variable. Irrespective of model specifications, farm diversification is significantly positively associated with dietary diversity at the household level, but the magnitude of the farm diversity coefficients is relatively small. Specifically, producing one additional crop or vegetable or fruit species leads to a 1.9% increase in the household dietary diversity score. In the case of women, the association is positive but not significant in all model specifications and the magnitude is even much smaller than that of the household level. The links between farm diversity and diet diversity are mostly within-household over time because in all specifications the results are similar, whereas for the women regressions the effects are mostly

between households because results are significant in pooled and random effects but not with fixed effects.

The regression models in Table 4 also include a square term for farm diversification that is negative in all model specifications. This means that the effect of farm diversification on dietary diversity is not linear and it diminishes, perhaps due to the opportunity cost of commercialization becoming more relevant for households whose farm diversity is already very high. In order to test the potential bias due to variable measurement and to test the robustness of the results, models were estimated with alternative measures of farm diversification[3] including the food variety score and Margalef crop species richness index as a dependent variable instead of a simple count of number of crops or vegetable or fruit species. The results of alternative measures of farm diversification are consistent with the estimates with the simple count measure of farm diversity. Similar results were also found in other earlier studies (Pellegrini and Tasciotti 2014; Jones et al. 2014; Sibhatu et al. 2015; Koppmair et al. 2016; Romeo et al. 2016). The small, positive association between farm diversification and dietary diversity may be consistent across studies since most of the smallholder farmers in developing countries are subsistence in nature (World Bank 2007). However, it is also possible that the relationship may be more complicated given the importance of other factors such as markets, off farm income, gender and other socio-economic characteristics (e.g. Sibhatu et al. 2015; Koppmair et al. 2016). Farm diversification is also assumed to be endogenous, driven by market opportunities, off farm work, socio-economic and contextual characteristics. Taking into account these factors we further extended the regression models by including additional confounding factors step by step and these results are presented in the subsequent section.

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[3] To save space, results are not reported here but are available upon request.

Table 3 Description of explanatory variables used in the econometric analysis

Variable	Measurement and definition	Round 1 (2011/12)	Round 2 (2015)	Mean Diff.
Farm diversity	Number of crop species including vegetables and fruits produced by the household in the last year (number)	4.294 (3.886)	5.224 (3.389)	0.930***
Food crop production diversity	Number of food crop species produced by the household in the last year (number)	4.158 (3.783)	4.720 (3.552)	0.562***
Margalef species richness index	Weights by the area grown with different crops (index)	0.106 (0.240)	0.324 (0.052)	0.218***
Market distance	Distance from home to nearest market (km)	1.723 (1.691)	1.687 (1.860)	−0.036
Off-farm income	Household income from off farm sources in the last year (Taka)	47,329.170 (74,716.360)	67,138.700 (98,263.600)	19,809.530***
Market participation	Percentage of produce sold to the market (%)	13.721 (20.365)	21.805 (30.285)	8.084***
Livestock ownership	=1 if the household own livestock otherwise 0	0.820 (0.385)	0.825 (0.380)	0.005
Earning status of the adult women of the HH	=1 if adult women of the HH earned money in the last year	0.588 (0.492)	0.739 (0.439)	0.151***
Age of HH head	Age of HH head (year)	44.252 (13.948)	45.763 (13.837)	1.511***
Sex of the HH head	=1 if the household head is male	0.823 (0.382)	0.811 (0.391)	−0.012*
Education of HH head	Years of schooling of the HH head (year)	2.714 (1.265)	2.789 (1.254)	0.075***
Age of the women	Age of the women (year)	29.983 (9.689)	30.369 (9.771)	0.386**
Education of the women	Years of schooling of the women (year)	4.940 (4.935)	5.567 (5.739)	0.627***
Household (HH) size	Number of family members belongs to the HH (number)	4.196 (1.628)	4.958 (1.998)	0.762***
Farm size	Total land holding of the HH (decimal)	62.416 (122.4802)	83.548 (131.539)	21.132***
Number of observations		6503 (5118)	6435 (6071)	

Source: Authors' analyses of 2011/12 and 2015 BIHS panel data. Mean values are shown with standard errors in parentheses. *, **, *** Indicates mean differences between the rounds are statistically significant at the 10%, 5%, and 1% level, respectively

3.3 Role of access to market, farm commercialization, off farm income and gender in the underlying relationship between farm diversification and diet diversity

Table 5 shows how market, off farm income and gender affect the underlying relationship between farm diversification and diet diversity of households and women. We have used several indicators for market including access to markets measured by distance from the household to the nearest market where food can be sold or purchased, market participation measured by calculating the share of produce sold into the market by the household which also indicates the commercialization nature of the household. We have also included amount of off farm income by the household and women's empowerment status measured by earning status of the adult women of the

Table 4 Pooled, random and fixed-effects Poisson regression models results for household and women dietary diversity score

Explanatory variables	Pooled		Random effects		Fixed effects	
	HH	Women	HH	Women	HH	Women
Farm diversity	0.019*** (0.002)	0.009*** (0.003)	0.019*** (0.001)	0.009*** (0.002)	0.019*** (0.002)	0.004 0.003
Farm diversity squared	−0.001*** (1.08E-04)	−1.99E-04 (1.710E-04)	−0.001*** (8.34E-05)	−1.99E-04* (1.05E-04)	−0.001*** (1.16E-04)	−2.80E-05 (1.19E-04)
Constant	2.168*** (0.006)	1.460*** (0.011)	2.168*** 0.004196	1.460*** (0.006)	–	–
Log likelihood	−28,549.37	−20,473.47	28,549.37	−20,473.47	−10,990.88	−5538.34
Wald χ²	225.06***	22.81***	1.63E + 06***	981529***	204.7***	5.31*
Hausman /LR test			0.002	0.00	1.92	1.21
Number of observations	12,938	11,189	12,938	11,189	12,080	7632

Source: Authors' analyses of 2011/12 and 2015 BIHS panel data. The dependent variable is the household dietary diversity score (HDDS) including 12 food groups and women's diversity score (WDDS) including 9 food groups. Figures in parentheses are robust standard errors. *, **, *** Indicates significant at the 10%, 5%, and 1% level, respectively

Table 5 Farm diversification, market access, commercialization, off farm income, gender and dietary diversity score of household and women

Explanatory variables	Pooled		Fixed effects	
	HH	Women	HH	Women
Farm diversity	0.018*** (0.002)	0.009** (0.004)	0.017*** (0.002)	0.005 (0.004)
Farm diversity squared	−0.001*** (1.13E-04)	−1.58E-04 (1.80E-04)	−0.001*** (9.86E-05)	7.52E-05 (1.23E-04)
Market distance	−0.006** (0.003)	−0.011** (0.005)	−0.005** (0.002)	−0.005 0.004
[Farm diversity] x [Market distance]	2.151E-04 (4.672E-04)	0.001 (0.001)	3.19E-04 (3.079E-04)	0.001 0.001
Off-farm income	3.02E-07*** (5.08E-08)	1.90E-07** (8.37E-08)	2.03E-07*** (6.71E-08)	7.57E-08 (1.09E-07)
[Farm diversity] x [Off-farm income]	−9.95E-09 (9.08E-09)	−1.28E-10 (1.41E-08)	−2.65E-09 (8.53E-09)	−1.05E-08 (1.59E-08)
Market participation	3.06E-04 (2.08E-04)	3.60E-04 (2.21E-04)	4.88E-04*** (1.58E-04)	0.001*** (1.82E-04)
[Farm diversity] x [Market participation]	−1.26E-05 (3.20E-05)	−0.003 (0.002)	1.41E-05 (2.03E-05)	−0.003** (0.002)
Earning status of the adult women of the HH	0.001 (0.010)	−0.016 (0.017)	0.041*** (0.008)	0.051*** (0.015)
[Farm diversity] x [Earning status of the adult women of the HH]	0.001 (0.002)	0.001 (0.003)	−0.002 (0.001)	−0.003 (0.002)
Constant	2.157*** (0.010)	1.467*** (0.018)		
Log likelihood	−28,505.54	−20,455.88	−10,972.02	−5531.28
Wald χ^2	312.73***	57.99***	366.12***	66.25***
Number of observation	12,938	11,189	12,080	7632

Source: Authors' analyses of 2011/12 and 2015 BIHS panel data. The dependent variable is the household dietary diversity score (HDDS) including 12 food groups and women diversity score (WDDS) including 9 food groups. Figures in the parentheses are robust standard errors. *, **, *** Indicate significance at the 10%, 5%, and 1% level, respectively

household. Moreover, we have also included the interaction term of each of these variables with farm diversity into the regression models. The fixed effect model results suggest that households that are far away from the market have comparatively lower dietary diversity. Thus improving market access by reducing distances or expanding market infrastructures could enhance dietary diversity. The magnitude of the estimated coefficient for access to market is smaller than that of farm diversification. In particular, reducing distance to the market by 3.3 km and producing one additional crop or vegetable or fruit species will have the same effect on household dietary diversity as farm diversification. Another market indicator is market participation, which indicates the commercialization nature of the household. The estimated coefficient is significant and positive. It is also much smaller than the farm diversity coefficient (0.00049 < 0.017). These results suggests that both commercialization and farm diversification are important strategies for improving dietary diversity but, in comparison, farm diversification may still be a better strategy than commercialization.

The estimated coefficient of off-farm income is also positive and significant but much smaller than farm diversity and market participation coefficients. Off-farm income can increase the households' ability to purchase diversified food items from the market. Recent studies (e.g. Sibhatu et al. 2015; Koppmair et al. 2016) on this topic suggest that market

access, commercialization, and off farm income are even more important than farm diversification for improving dietary diversification. In our case, they are also important determinants of dietary diversity but not more than farm diversification. We also observed a positive and significant relationship between earning status of the adult woman of the household, our proxy for women's empowerment, and HDDS. Interestingly, this association is much greater than the impact from increasing farm diversification (0.041 > 0.017). Gender aspects, particularly women's empowerment, are considered important determinants of household food and nutrition security (ADB 2013). In Bangladesh, increases in women's empowerment are positively associated with household dietary diversity (Sraboni et al. 2014). Malapit and Quisumbing (2015) found certain dimensions of women's empowerment in agriculture are associated with nutrition in Ghana. Review evidence from south Asia also suggest women's empowerment is associated with child nutrition (Cunningham et al. 2015). Further, women's empowerment mitigates the negative effect of low production diversity on maternal and child nutrition in Nepal (Malapit et al. 2015).

As already stated the results of the impact of farm diversity and other confounding factors on dietary diversity at the women's level are also shown in Table 5. Fixed effect model results at the women's level suggest that association between farm diversification and women's dietary diversity is positive

but not statistically significant. Interestingly, the share of produce sold and women's earning status used as proxies for households' farm commercialization and women's empowerment are both statistically significant with positive coefficients. These suggest that households' farm commercialization and the earning status of adult women of the households are more important determinants of women's dietary diversity than farm diversification. The interaction coefficient between farm diversity and market participation is negative and significant which suggest that household farm commercialization reduces the importance of farm diversity for increasing women's dietary diversity. Thus, the effect of farm diversification on the household and individual level dietary diversification is not equal which is in line with the findings of Villa et al. (2011). However, Koppmair et al. (2016) showed that farm diversity impact on dietary diversity at the household and individual level were similar in Malawi.

3.4 Robustness check

By following Sibhatu et al. (2015) we checked the robustness of our results with several alternative measures in different situations. Firstly, we test the omitted variable bias by re-estimating the regression models, where we included socio-economic and demographic variables such as farm and household size, age, education, and gender of the household head, as well as women's age and education as additional explanatory variables (Zezza and Tasciotti 2010; Pellegrini and Tasciotti 2014). The re-estimated regression results show that some of these socio-economic and demographic factors are significant, but the sign, significance level and magnitude of the estimation coefficients for farm diversification, off farm income, access to market, share of sell and women's empowerment do not change much except share of sell coefficient at the women's level (Table 6). These results imply that our main results do not suffer from omitted variable bias. The results of the other variables are the expected ones: the age of the head of the household (a possible proxys for wisdom and experience) and household size are positively associated with household dietary diversity. Having livestock increases the chance of having a more diversified diet and even the magnitude of the coefficient is higher than farm diversification at the household level. Among the other variables women's age and farm size positively and significantly affect women's dietary diversity.

Secondly, as already stated, farm diversification is likely to be an endogenous variable that partly depends on unobserved variables. To test and control for such bias we re-estimated the regression models using a two-way FE model, including year dummies for the survey rounds using 2012 as the reference. The two-way FE estimation results show that time plays an important role, as the 2015 year dummy is highly significant at the household level but not at the women's level. The positive sign of the dummy coefficient indicates that the household dietary diversity

has increased over time. Re-estimated regressions results show that though magnitude of the coefficients is reduced, the direction and significance level of the estimation coefficients for farm diversification, off farm income, access to market and share of sell do not change much with the exception being women's empowerment coefficient at the household level (Table 7).

Thirdly, we tested the robustness of our main results by using four alternative measures of dietary diversity at the household level. These were dietary diversity based on healthy food groups only, dietary diversity based on food purchased from the market, food variety score (FVS), and FVS based on food purchased from the market. The main finding that increased farm diversification is likely to increase household dietary diversity also holds with these alternative specifications. Other findings also remained consistent, including associations among off farm income, share of sell and women's empowerment, with the exception of access to market which only retained a marginally significant association with dietary diversity when using a healthy food groups only specification (Tables 8 and 9). Finally, we tested the robustness of our main results by using alternative measure of farm diversification at the household and women's level. We have used two alternative measures of farm diversification, namely the Margalef species richness index and number of food crop species produced by the household. We re-estimated the regression models with these alternative measures of farm diversification (Tables 10 and 11). The findings are mostly in line with those discussed earlier suggesting little influence of the way that farm diversification is measured. Associations between farm diversification and dietary diversity at the household level remain positive and significant in all the cases but not significant at the women's level. Interestingly, when only including food crops, the impact of farm diversification on dietary diversity at the household level is still positive and significant but became smaller (Table 11) which implies that nonfood cash crops can also play an important role in improving household dietary diversity through the income pathway.

All the regression results with alternative measures in different situations and specifications yield positive and significant associations between farm diversification and dietary diversity at the household level but not at the women's level, providing robust confirmation of a positive link between farm diversification and household dietary diversity. The magnitude of the coefficient is small but still higher than other significant coefficients which also underlines the important role of farm diversification on dietary diversity in a dominant rice producing and consuming economy like Bangladesh. Moreover, this effect increased over the years. Thus it is the households that saw the most improvement in farm diversity

and improvement in other things such as off-farm income which had the greatest increase in diet diversity.

4 Conclusions

Improving food and nutrition security is one of Bangladesh's most pressing policy priorities. It is often hypothesized that higher farm diversification may lead to better food and nutrition outcomes including improved dietary diversity. In a number of policy documents (e.g. 5 Year Plans, Country Investment Plan, National Agricultural Policy, second Bangladesh National Plan of Action for Nutrition etc.), the Government of Bangladesh (GoB) has emphasized the need to diversify agricultural production. The GoB has enacted a number of initiatives including the Crop Diversification Programme (CDP) to encourage and support agricultural diversification in Bangladesh. Other studies also recommend that crop diversification should be a desired strategy for agricultural growth in Bangladesh (Rahman 2009). But what are the food and nutrition security implications of such a diversification strategy? Empirical studies on impact evaluation of farm diversification on food and nutrition are very limited. Recent studies on the link between farm diversification and dietary diversity (e.g., Jones et al. 2014; Dillon et al. 2015; Sibhatu et al. 2015; Koppmair et al. 2016) have reported mixed results and make requests for further research. In particular, some of these studies indicated that farm diversity is not always the most efficient way to increase dietary diversity: other factors such as market access may be even more important than farm diversification in improving dietary diversity.

However, to our knowledge, this is an important contribution to a slim body of literature examining whether farm diversification, in the context of Bangladesh, influences dietary diversity, an important indicator of food and nutrition security. Using nationally representative panel data and exploiting the possibilities associated with the structure of the data, this study aimed to estimate the causal effects of farm production diversification on different indicators of household and women's diet diversity in Bangladesh. Starting from a naïve pooled Poisson estimation that assumed farm diversification to be exogenous, we moved on to controlling for the unobserved heterogeneity across households through the estimation of fixed-effects econometric models, thereby adding to the existing literature that mainly relies on cross-sectional data. To the best of our knowledge this is the first study using panel data and panel econometric procedures on this topic in Bangladesh or elsewhere, however, a limitation is that the study cannot control time-variant unobservables.

Our results suggest that farm diversification has statistically significant and positive impact on dietary diversity at the household level while its square term is also significant but has a negative sign. These indicate that the relationship between farm diversification and household dietary diversity is not linear and follows an "inverted U" shape. However, we did not observe a significant association between farm diversification and women's dietary diversity. Our results also showed that household market access, farm commercialization and off-farm income have positive effects on household dietary diversity but these effects are still smaller than farm diversification. In addition, our results also revealed that women's income is also positively associated with household dietary diversity and the effects are greater than increased farm diversity. These results were similar even after controlling for household socio-economic factors. The association between farm diversification and women's dietary diversity was positive, but not significant, yet both farm commercialization and women's empowerment had statistically significant and positive relationships with women's dietary diversity. These findings suggest that farm commercialization and earning status of the adult women of the households are more important determinants of women's dietary diversity than farm diversification. Moreover, household farm commercialization reduces the role of farm diversity for women's dietary diversity. Our results are robust to alternative regression model specifications and also to alternative measures of farm diversification and dietary diversity.

In conclusion, agricultural diversification can be an important predictor of household dietary diversity and therefore diet quality. Agricultural programmes and policies aiming to improve food and nutrition security should promote diversity in agricultural production, rather than only increasing total quantity produced of selected staple crops, as has been the traditional direction in Bangladesh, where large-scale input and output support programs have mostly focused on rice production, with little incentive for farmers to diversify production. Furthermore, policies or interventions should also promote market access through improved infrastructure, women's empowerment, diversification of income towards off farm sources and farm commercialization along with promoting further farm diversification to address the food and nutrition security challenge in Bangladesh.

Finally, as farm diversification efforts in Bangladesh are based on assuming much larger impacts on household dietary diversity, more research is needed to improve the pathways through which farm diversification influences dimensions of food and nutrition security,[4] in addition to the one investigated here. Moreover these pathways may have spillover impacts on the environment and biodiversity (Babu and Mthindi 1994; Remans et al. 2011). We

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[4] Including obesity because increase in diversified food consumption may lead to negative effects if it is concentrated in households that already consume a large amount of calories (Pellegrini and Tasciotti 2014).

used both household level and individual level DDS as they tell us different things: HDDS/FVS is informative about food security and WDDS about nutrient adequacy among women. Future research can further dig into individual level DDS (e.g. Children's DDS) using recent indicators. Our data is based on two points in time but dietary diversity varies in time, for example according to agricultural seasons. High frequency data may solve this seasonality aspect of dietary diversity.

Compliance with ethical standards

Annex A

Table 6 Robustness of the results with other confounding factors

Explanatory variables	Pooled		Fixed effects	
	HH	Women	HH	Women
Farm diversity	0.015*** (0.003)	0.005 (0.005)	0.014*** (0.002)	−0.001 (0.005)
Farm diversity squared	−3.917E-04*** (1.165E-04)	−1.060E-04 (1.849E-04)	−3.018E-04*** (8.710E-05)	1.256E-04 (1.254E-04)
Market distance	−0.006** (0.003)	−0.011** (0.005)	−0.005** (0.002)	−0.005 (0.004)
[Farm diversity] × [Market distance]	2.511E-04 (4.679E-04)	0.001 (0.001)	2.568E-04 (2.933E-04)	0.001 (0.001)
Off-farm income	2.650E-07*** (5.270E-08)	1.200E-07 (8.660E-08)	1.340E-07*** (4.670E-08)	−6.220E-09 (7.860E-08)
[Farm diversity] × [Off-farm income]	−1.330E-08 (9.160E-09)	−7.880E-10 (1.430E-08)	−4.650E-09 (6.750E-09)	−7.820E-09 (1.490E-08)
Market participation	1.671E-04 (2.118E-04)	2.381E-04 (2.271E-04)	4.611E-04*** (1.562E-04)	4.879E-04 (2.014E-04)
[Farm diversity] × [Market participation]	−7.720E-06 3.210E-05)	−0.003 (0.002)	−2.320E-05 2.020E-05)	0.001 (0.002)
Earning status of the adult women of the HH	0.002 (0.011)	−0.007 (0.018)	0.028*** (0.008)	0.042*** (0.015)
[Farm diversity] × [Earning status of the adult women of the HH]	0.001 (0.002)	−3.859E-04 (0.003)	−0.001 (0.001)	−0.003 (0.002)
Livestock ownership	0.016 (0.013)	−0.017 (0.023)	0.025** (0.011)	−0.015 (0.023)
[Farm diversity] × [Livestock ownership]	−0.003 (0.003)	0.001 (0.005)	−0.003 (0.002)	0.002 (0.005)
Age of HH head/women	2.220E-04 (2.215E-04)	0.001*** (0.001)	0.002*** (4.285E-04)	0.013*** (0.002)
Sex of the HH head	−0.025*** (0.008)	–	–	–
Education of HH head/women	0.029*** (0.002)	0.005*** (0.001)	–	–
Household (HH) size	0.013*** (0.002)	0.014*** (0.002)	0.040*** (0.003)	0.006 (0.006)
Farm size	1.660E-04*** (4.180E-05)	1.228E-04 (6.270E-05)	2.320E-05 (3.780E-05)	1.971E-04** (9.570E-05)
Farm size squared	−8.620E-08** (3.600E-08)	−5.700E-08 (5.470E-08)	−9.220E-09 (2.430E-08)	−5.680E-08 (6.830E-08)
Constant	2.028*** (0.018)	1.345 (0.031)	–	–
Log likelihood	−28,372.85	−20,413.148	−10,940.16	−5524.69
Wald χ^2	578.12***	143.45***	665.64***	127.9***
Number of observation	12,938	11,189	12,080	7632

Source: Authors' analyses of 2011/12 and 2015 BIHS panel data. The dependent variable is the household dietary diversity score (HDDS) including 12 food groups and women diversity score (WDDS) including 9 food groups. Figures in the parentheses are robust standard errors. *, **, *** Indicates significant at the 10%, 5%, and 1% level, respectively

Table 7 Robustness of the results in two way fixed effect estimation

Explanatory variables	Pooled		Fixed	
	HH	Women	HH	Women
Farm diversity	0.011*** (0.003)	0.005 (0.005)	0.005** (0.002)	−0.002 (0.005)
Farm diversity squared	−2.180E-04* (1.154E-04)	−1.190E-04 (1.852E-04)	1.630E-05 (6.710E-05)	1.276E-04 (1.252E-04)
Market distance	−0.005* (0.003)	−0.011** (0.005)	−0.004** (0.002)	−0.005 (0.004)
[Farm diversity] × [Market distance]	1.866E-04 (4.677E-04)	0.001 (0.001)	2.326E-04 (2.860E-04)	0.001 (0.001)
Off-farm income	2.280E-07*** (5.380E-08)	1.070E-07 (8.690E-08)	6.440E-08* (3.800E-08)	−5.110E-09 (7.890E-08)
[Farm diversity] × [Off-farm income]	−1.200E-08 (9.250E-09)	4.190E-10 (1.430E-08)	−3.520E-10 (6.280E-09)	−7.930E-09 (1.490E-08)
Market participation	2.123E-04 (2.115E-04)	6.700E-05 (2.356E-04)	3.918E-04*** (1.505E-04)	4.685E-04** (2.015E-04)
[Farm diversity] × [Market participation]	−4.990E-05 (3.230E-05)	−0.002 (0.002)	−7.690E-05*** (1.990E-05)	0.001 (0.002)
Earning status of the adult women of the HH	−0.009 (0.011)	−0.011 (0.018)	0.007 (0.007)	0.042*** (0.015)
[Farm diversity] × [Earning status of the adult women of the HH]	0.001 (0.002)	−0.001 (0.003)	−0.001 (0.001)	−0.003 (0.002)
Livestock ownership	0.022* (0.013)	−0.012 (0.023)	0.030*** (0.010)	−0.015 (0.023)
[Farm diversity] × [Livestock ownership]	−0.002 (0.003)	0.001 (0.005)	−4.646E-04 (0.002)	0.002 (0.005)
Age of HH head/women	1.408E-04 (2.216E-04)	0.001*** (0.001)	−4.830E-05 (4.010E-04)	−0.015 (0.019)
Sex of the HH head	−0.015* (0.008)	–	–	–
Education of HH head/women	0.028*** (0.002)	0.005*** (0.001)	–	–
Household (HH) size	0.010*** (0.002)	0.013** (0.002)	0.011*** (0.003)	0.006 (0.006)
Farm size	1.702E-04*** (4.180E-05)	1.345E-04 (6.290E-05)	−6.820E-05* (3.750E-05)	1.960E-04** (9.560E-05)
Farm size squared	−8.410E-08** (3.590E-08)	−6.260E-08 (5.480E-08)	3.840E-08 (2.490E-08)	−5.650E-08 (6.830E-08)
	0.068*** (0.006)	0.027*** (0.010)	0.080*** (0.004)	0.084 (0.057)
Constant	2.020*** (0.018)	1.342*** (0.031)	–	–
Log likelihood	−28,313.24	−151.07	−10,891.08	−5524.43
Wald χ²	697.33***	20,409.34***	1214.48***	129.43***
Number of observation	12,938	11,189	12,080	7632

Source: Authors' analyses of 2011/12 and 2015 BIHS panel data. The dependent variable is the household dietary diversity score (HDDS) including 12 food groups and women diversity score (WDDS) including 9 food groups. Figures in the parentheses are robust standard errors. *, **, *** Indicates significant at the 10%, 5%, and 1% level, respectively

Table 8 Robustness of the results with alternative measure of household dietary diversity

Explanatory variables	Dietary diversity score based on purchased foods		Dietary diversity of healthy foods	
	Pooled	Fixed effects	Pooled	Fixed effects
Farm diversity	0.007** (0.003)	0.006* (0.003)	0.018*** (0.004)	0.017*** (0.003)
Farm diversity squared	−5.860E-05 (1.348E-04)	1.870E-04 (1.194E-04)	−4.849E-04*** (1.389E-04)	−3.349E-04*** (1.052E-04)
Market distance	−0.010*** (0.003)	−0.004 (0.003)	−0.007** (0.003)	−0.005* (0.003)
[Farm diversity] × [Market distance]	−1.470E-05 (0.001)	1.665E-04 (4.990E-04)	3.220E-04 (0.001)	2.263E-04 (3.746E-04)
Off-farm income	3.570E-07*** (5.340E-08)	1.540E-07*** (5.680E-08)	3.200E-07*** (6.050E-08)	1.710E-07*** (5.810E-08)
[Farm diversity] × [Off-farm income]	−6.980E-09 (9.940E-09)	−1.310E-08 (1.040E-08)	−1.490E-08 (1.060E-08)	−7.180E-09 (8.360E-09)
Market participation	−1.379E-04 (2.433E-04)	0.001*** (2.302E-04)	2.476E-04 (2.516E-04)	0.001*** (1.923E-04)
[Farm diversity] × [Market participation]	−1.689E-04*** (3.820E-05)	−1.937E-04*** (3.460E-05)	−1.450E-05 (3.800E-05)	−3.500E-05 (2.520E-05)
Earning status of the adult women of the HH	−0.030*** (0.012)	0.017 (0.011)	−3.542E-04 (0.013)	0.031*** (0.009)
[Farm diversity] × [Earning status of the adult women of the HH]	−0.001 (0.002)	−0.006*** (0.002)	0.002 (0.002)	−0.001 (0.001)
Livestock ownership	−0.023 (0.014)	0.012 (0.014)	0.021 (0.015)	0.035*** (0.013)
[Farm diversity] × [Livestock ownership]	−0.005 (0.003)	0.001 (0.003)	−0.003 (0.003)	−0.004 (0.003)
Age of HH head	−3.792E-04 (2.498E-04)	−2.776E-04 (0.001)	1.742E-04 (2.633E-04)	0.002*** (0.001)
Sex of the HH head	−0.002 (0.009)	–	−0.030*** (0.010)	–
Education of HH head	0.041*** (0.003)	–	0.034*** (0.003)	–
Household (HH) size	0.016*** (0.002)	0.007** (0.004)	0.015*** (0.0020)	0.050*** (0.003)
Farm size	−8.580E-05* (4.780E-05)	−3.500E-04*** (7.120E-05)	1.726E-04*** (4.950E-05)	9.680E-06 (4.790E-05)
Farm size squared	5.230E-08 (3.940E-08)	1.690E-07** (7.930E-08)	−8.660E-08** (4.260E-08)	1.180E-08 (2.810E-08)
Constant	1.887*** (0.020)	–	1.652*** (0.022)	–
Log likelihood	−28,393.47	−10,652.14	−26,332.16	−9974.80
Wald χ^2	786.3	130.77***	569.63***	637.04***
Number of observation	12,938	12,080	12,938	12,080

Source: Authors' analyses of 2011/12 and 2015 BIHS panel data. The dependent variable is the household dietary diversity score (HDDS) including 12 food groups based on purchased foods only and household dietary diversity score (HDDS) including 9 healthy food groups only (excluding sweets and sugars; oils and fats; and spices, condiments, and beverages). Figures in the parentheses are robust standard errors. *, **, *** Indicates significant at the 10%, 5%, and 1% level, respectively

Table 9 Table 8 Robustness of the results with household food variety score: an alternative measure of household dietary diversity

Explanatory variables	Food variety score based on all food items		Food variety score based on purchased food items only	
	Pooled	Fixed effects	Pooled	Fixed Effects
Farm diversity	0.026*** (0.002)	0.029*** (0.004)	0.020*** (0.002)	0.022*** (0.004)
Farm diversity squared	−0.001*** (6.560E-05)	−0.001*** (2.076E-04)	−0.001*** (8.530E-05)	−0.001*** (1.506E-04)
Market distance	−0.010*** (0.002)	−0.002 (0.003)	−0.015*** (0.002)	−0.002 (0.003)
[Farm diversity] × [Market distance]	6.060E-05 (2.580E-04)	−9.060E-05 (4.594E-04)	−1.436E-04 (3.301E-04)	6.090E-05 (0.001)
Off-farm income	4.210E-07*** (2.530E-08)	3.750E-07*** (1.200E-07)	4.600E-07*** (2.860E-08)	3.100E-07*** (1.180E-07)
[Farm diversity] × [Off-farm income]	−7.700E-09* (4.560E-09)	−1.860E-08 (1.460E-08)	1.270E-09 (5.430E-09)	−7.150E-09 (1.420E-08)
Market participation	1.077E-04 (1.165E-04)	0.001*** (2.399E-04)	−4.232E-04*** (1.454E-04)	6.264E-04*** (2.422E-04)
[Farm diversity] × [Market participation]	−3.110E-05* (1.740E-05)	−2.970E-05 (3.330E-05)	−1.237E-04*** (2.240E-05)	−8.830E-05** (3.570E-05)
Earning status of the adult women of the HH	0.031*** (0.006)	0.068*** (0.012)	−0.004 (0.007)	0.050*** (0.012)
[Farm diversity] × [Earning status of the adult women of the HH]	0.003*** (0.001)	0.001 (0.002)	0.002* (0.001)	−0.003 (0.002)
Livestock ownership	−0.001 (0.007)	0.024 (0.016)	−0.021*** (0.008)	0.005 (0.017)
[Farm diversity] × [Livestock ownership]	−0.004** (0.002)	−0.004 (0.004)	−0.008**** (0.002)	−0.002 (0.004)
Age of HH head	−3.430E-05 (1.218E-04)	0.004*** (0.001)	1.142E-04 (1.487E-04)	0.002*** (0.0010
Sex of the HH head	0.025*** (0.004)	–	0.024*** (0.005)	–
Education of HH head	0.042*** (0.001)	–	0.056*** (0.002)	–
Household (HH) size	0.030*** (0.001)	0.080*** (0.004)	0.028*** (0.001)	0.057*** (0.004)
Farm size	3.611E-04*** (2.260E-05)	1.253E-04* (6.720E-05)	2.030E-04*** (2.800E-05)	4.090E-06 (7.740E-05)
Farm size squared	−1.850E-07*** (1.980E-08)	−6.520E-08 (5.990E-08)	−9.690E-08*** (2.400E-08)	−1.750E-09 (7.600E-08)
Constant	3.025*** (0.010)		2.712*** (0.012)	–
Log likelihood	−48,938.93	−18,550.99	−44,791.23	−16,186.14
Wald χ²	7360.96***	1150.96***	4300.69***	469.52***
Number of observation	12,938	12,080	12,938	12,080

Source: Authors' analyses of 2011/12 and 2015 BIHS panel data. The dependent variable is the household food variety score (FVS) including all food items and household food variety score (FVS) based on purchased food items only. Figures in the parentheses are robust standard errors. *, **, *** Indicates significant at the 10%, 5%, and 1% level, respectively

Table 10 Robustness of the results with alternative measure of farm diversification: Margalef species richness index

Explanatory variables	Pooled		Fixed Effects	
	HH	Women	HH	Women
Margalef species richness index	0.018** (0.007)	−0.009 (0.012)	0.013** (0.006)	−0.015 (0.012)
Margalef species richness index squared	−0.001** (0.001)	−1.569E-04 (0.001)	−0.001 (0.001)	−5.100E-05 (0.001)
Market distance	−0.004*** (0.002)	−0.006** (0.003)	−0.003*** (0.001)	−0.002 (0.002)
[Margalef species richness index] × [Market distance]	−1.577E-04 (0.002)	0.003 (0.003)	−0.002 (0.001)	0.001 (0.002)
Off-farm income	2.000E-07*** (3.040E-08)	1.060E-07*** (4.260E-08)	1.170E-07*** (2.890E-08)	−5.650E-08 (3.890E-08)
[Margalef species richness index] × [Off-farm income]	−3.130E-08 (3.280E-08)	4.780E-08 (4.850E-08)	−1.920E-08 (2.100E-08)	5.000E-08 (4.840E-08)
Market participation	2.497E-04** (1.227E-04)	−1.270E-06 (1.969E-04)	3.435E-04*** (9.880E-05)	4.468E-04** (1.847E-04)
[Margalef species richness index] × [Market participation]	1.397E-04 (1.321E-04)	2.918E-04 (2.232E-04)	−1.030E-05 (9.100E-05)	2.851E-04 (1.856E-04)
Earning status of the adult women of the HH	0.007 (0.007)	−0.011 (0.011)	0.025*** (0.005)	0.026*** (0.010)
[Margalef species richness index] × [Earning status of the adult women of the HH]	0.009 (0.005)	0.005 (0.009)	0.008** (0.004)	−0.004 (0.008)
Livestock ownership	0.015* (0.008)	−0.006 (0.014)	0.017** (0.007)	−0.007 (0.013)
[Margalef species richness index] × [Livestock ownership]	−0.010 (0.007)	−0.006 (0.012)	−0.004 (0.006)	0.008 (0.011)
Age of HH head	4.273E-04** (2.191E-04)	0.002*** (0.001)	0.002*** (4.263E-04)	0.012*** (0.002)
Sex of the HH head	−0.023*** (0.008)	–	–	–
Education of HH head	0.031*** (0.002)	0.005*** (0.001)	–	–
Household (HH) size	0.013*** (0.002)	0.014*** (0.002)	0.043*** (0.003)	0.006** (0.006)
Farm size	2.472E-04*** (4.020E-05)	1.502E-04*** (5.880E-05)	5.540E-05 (3.950E-05)	2.083E-04 (9.590E-05)
Farm size squared	−1.340E-07*** (3.610E-08)	−6.940E-08 (5.340E-08)	−2.560E-08 (2.350E-08)	−6.310E-08 (6.940E-08)
Constant	2.047*** (0.016)	1.354*** (0.025)	–	–
Log likelihood	−28,394.04	−20,416.25	−10,945.48	−5524.90
Wald χ^2	535.72***	137.25***	607.79	123.44***
Number of observation	12,938	11,189	12,080	7632

Source: Authors' analyses of 2011/12 and 2015 BIHS panel data. The dependent variable is the household dietary diversity score (HDDS) including 12 food groups and women diversity score (WDDS) including 9 food groups. Figures in the parentheses are robust standard errors. *, **, *** Indicates significant at the 10%, 5%, and 1% level, respectively

Table 11 Robustness of the results with alternative measure of farm diversification: Food crop production diversity

Explanatory variables	Pooled		Fixed Effects	
	HH	Women	HH	Women
Food crop production diversity	0.012*** (0.003)	0.003 (0.005)	0.008*** (0.002)	−0.003 (0.005)
Food crop production diversity squared	−3.136E-04*** (1.197E-04)	−1.390E-04 (1.838E-04)	−1.704E-04** (7.590E-05)	1.705E-04 (1.351E-04)
Market distance	−0.005** (0.003)	−0.010** (0.004)	−0.005** (0.002)	−0.004 (0.004)
[Food crop production diversity] × [Market distance]	2.072E-04 (4.693E-04)	0.001 (0.001)	2.586E-04 (2.981E-04)	0.001 (0.001)
Off-farm income	2.550E-07*** (4.780E-08)	1.110E-07 (7.680E-08)	1.360E-07*** (4.640E-08)	−2.290E-08 (6.700E-08)
[Food crop production diversity] × [Off-farm income]	−1.220E-08 (8.860E-09)	1.430E-09 (1.350E-08)	−5.060E-09 (6.950E-09)	−4.900E-09 (1.370E-08)
Market participation	9.860E-05 (2.055E-04)	−1.379E-04 (3.328E-04)	3.298E-04** (1.530E-04)	2.916E-04 (2.979E-04)
[Food crop production diversity] × [Market participation]	8.950E-06 (3.230E-05)	3.340E-05 (5.150E-05)	7.360E-08 (2.050E-05)	4.500E-05 (4.410E-05)
Earning status of the adult women of the HH	0.005 (0.010)	−0.006 (0.017)	0.032*** (0.007)	0.042*** (0.015)
[Food crop production diversity] × [Earning status of the adult women of the HH]	0.001 (0.002)	−0.001 (0.003)	−0.001 (0.001)	−0.004 (0.002)
Livestock ownership	0.012 (0.012)	−0.013 (0.021)	0.018* (0.010)	−0.014 (0.022)
[Food crop production diversity] × [Livestock ownership]	−0.002 (0.003)	1.813E-04 (0.005)	−0.001 (0.002)	0.002 (0.005)
Age of HH head	2.718E-04 (2.213E-04)	0.002*** (0.001)	0.002*** (0.000)	0.012*** (0.002)
Sex of the HH head	−0.025*** (0.008)			
Education of HH head	0.029*** (0.002)	0.005*** (0.001)		
Household (HH) size	0.013*** (0.002)	0.014*** (0.002)	0.042*** (0.003)	0.006 (0.006)
Farm size	1.681E-04*** (4.210E-05)	1.088E-04* (6.240E-05)	3.290E-05 (3.790E-05)	2.075E-04** (9.560E-05)
Farm size squared	−8.840E-08** (3.620E-08)	−4.820E-08 (5.440E-08)	−1.530E-08 (2.360E-08)	−6.180E-08 (6.900E-08)
Constant	2.035*** (0.018)	1.350*** (0.029)		
Log likelihood	−28,381.18	−20,415.278	−10,944.54	−5524.648
Wald χ²	561.45***	139.19***	620.57***	127.99
Number of observation	12,938	11,189	12,080	7632

Source: Authors' analyses of 2011/12 and 2015 BIHS panel data. The dependent variable is the household dietary diversity score (HDDS) including 12 food groups and women diversity score (WDDS) including 9 food groups. Figures in the parentheses are robust standard errors. *, **, *** Indicates significant at the 10%, 5%, and 1% level, respectively

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