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IMPLICATIONS OF DIVERSIFIED AGRICULTURE PRODUCTION ON THE ECONOMIC AND NUTRITIONAL STATUS OF FARMING HOUSEHOLDS

(FINAL REPORT)

Food and Agriculture Organization of the United Nations

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FINAL REPORT

Implications of diversified agriculture production on the economic and nutritional status of farming households

The study conducted by:

Bureau of Socio-economic Research and Training (BSERT), Faculty of Agricultural Economics and Rural Sociology, Bangladesh Agricultural University (BAU), Mymensingh-2202

Principal Investigator:	**Dr. Abu Hayat Md. Saiful Islam** Professor, Department of Agricultural Economics Bangladesh Agricultural University, Mymensingh
Co-Investigator (s):	**Dr. Md. Akhtarul Alam** Professor, Department of Agricultural and Applied Statistics Bangladesh Agricultural University, Mymensingh
	Dr. Ganesh Thapa Consultant Barhadashi-7, Rukchanbari, Jhapa, Nepal

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Executive Summary

Agricultural diversification consists of developing a larger number of crop- or enterprise-mix to generate higher value and income. It therefore represents an important strategy to overcome the challenges faced in many developing countries to manage risk, to adapt to heterogeneous production conditions and to increase income generating opportunities by entering new markets. Generally, diversification is considered as a function of commercialization and development in addition to being a function of enhanced income and sustainability. Diversified food production has been recognized as a way to improve nutrition and health. On the other hand, agricultural commercialization increases employment opportunities and income, and market is a key factor in the commercialization process. Therefore, understanding the nexus between agricultural diversification and commercialization, from one side, and farm households' income, dietary diversity and nutrition, on the other, is a key topic in the scientific and policy debates, particularly in the developing countries that are mainly dominated by rural agricultural households with persistent food insecurity and poor nutrition outcomes.

Few empirical studies, assessing the linkages between agricultural diversification, commercialization and farming households' income, intra-household dietary diversity and nutrition and present context specific results. While some studies found a positive association, others revealed a negative relationship or no relationship at all. Therefore, the relationship is ambiguous and still the question is highly pertinent to answer whether, and to what extent diversification and commercialization lead to improved nutrition and income. Moreover, most of these studies including other studies in Bangladesh are at the aggregate level, which makes it difficult to conclude on the explicit link between agricultural diversification, commercialization, and farm households' income, intra-household dietary diversity and nutrition. In addition, how this link varies by agroecological zones, farm nature (e.g. subsistence vs commercial) and types (e.g. small, medium and large), and seasons (e.g. lean and lost harvest) remains uncertain. Which dimension of agricultural diversification (including fisheries, poultry and livestock, and non-food crops) and commercialization improves farm households' income and nutritional status? What are the determinants of agricultural diversification? What are the other factors including market

access that influences this linkage? To answer these questions of high policy relevance, it requires additional research particularly in the Bangladeshi context.

The objectives of the study are: (i) to assess and unpack the linkages between agricultural diversification (including fisheries, poultry and livestock, and non-food crops), commercialization and farm households' income; and (2) to identify, assess and analyze the linkages between agricultural diversification, commercialization and farming households' dietary diversity and nutritional status.

The present study used a wide range of secondary data - including the IFPRI Bangladesh Integrated Household Surveys (BIHS, 2011/12 and 2015) and BBS Household Expenditure Surveys (HIES 2000, 2005, 2010, 2016)- to assess the impact of diversified agriculture production and commercialization on economic and nutritional status of farming households and to identify determinants of crop diversification.

It is evident from BIHS data that household dietary diversity score (HDDS) is quite high compare to women dietary diversity score (WDDS) in both the rounds. This indicates the intrahousehold disparities in dietary diversity. HDDS is significantly increases from the first round to second round which is impressive given the daunting challenge of food and nutrition security in Bangladesh. Almost all the dietary diversity indicators are increasing 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. It is also evident that between the rounds all the household food and nutrition indicators are improving. All other indicators including per capita food expenditure, protein, vitamin A&C, iron and zinc intake is increasing over the round. Results indicate that women and child dietary diversity over the round is increasing and stunting also decreasing. However, underweight and wasting is slightly increasing.

From HIES data set results show that HH dietary diversity score has increased from 0.68 to 0.74 between 2010 and 2016. On average, the consumption of calorie and protein have decreased while consumption of micro-nutrient (zinc) and vitamin has increased between 2010 and 2016. Household dietary diversity and food expenditure are also discussed at farm size, subsistence vs. commercial HHs and the agro-ecological zones. It is evident that the large farm have better HH

dietary diversity. In 2016, the FSC is highest for the large farms and lowest for the marginal farms. Irrespective of farm size, the expenditure shares of cereals decreased while the share of fruits, vegetables and meat increased between 2000 and 2016.

Findings show that the commercial HHs have better dietary diversity in comparison to subsistence HHs. While the expenditure share of cereals is higher for subsistence HHs, the share is lower for commercial HHs indicating the higher share of food expenditure towards non-cereals and better diet quality for the commercial HHs. It is also evident that the best performing agro-ecological zones in terms of dietary diversity are Middle Meghna River Floodplain and Chittagong Coastal Plain & St. Martin's Coral Island and worst performing agro-ecological zone is Old Himalayan Piedmont Plain and Tista Floodplain.

The overall findings indicate that household income, expenditure, food and nutrition security indicators are significantly improving in Bangladesh. We assessed the linkage between agricultural diversification and commercialization with the status of intra household dietary diversity, household income and child nutrition. Results are encouraging and show that higher farm production diversity and commercialization are positively associated with household income, nutrition and reduce child stunting. The linkage between agricultural diversification and farming household income is significantly positive. The direction between agricultural commercialization index and farming household income is positive indicating that increasing agricultural commercialization have positive effect on increasing household income. The linkage between agricultural commercialization and dietary diversity and nutrition consumption is positive. Within agricultural commercialization, crop commercialization have positive effect on women dietary diversity and reduce child stunting. Agricultural diversification and commercialization are also analyzed based on the agro-ecological zones in Bangladesh in 2016. The three agro-ecological zones with the lowest SI are Sylhet Basin and Surma-Kusiyara, Floodplain Eastern Hills and Middle Meghna River Floodplain. Similarly, the three agro-ecological zones with the highest SI are Ganges Tidal Floodplain, Grater Dhaka, and Chittagong Coastal Plain & St. Martin's Coral Island. The top three agroecological zones in fisheries commercialization are Grater Dhaka, Eastern Hills and Ganges Tidal Floodplain while the lowest are Sylhet Basin and Surma-Kusiyara Floodplain, Old Himalayan Piedmont Plain and Tista Floodplain, and Karatoya Floodplain and Atrai Basin. The three agroecological zones with

the lowest crop commercialization index are Lower Meghna River and Estuarine Floodplain, Ganges Tidal Floodplain Sylhet Basin and Surma-Kusiyara Floodplain.

The study also identified factors influencing diversification and commercialization: results show that access to information via access to mobile phone, smaller and marginal farm size and commercialized household positively affect farm diversification. Similarly, access to machine, information via access to mobile phone, having migrant members and larger farm size positively and significantly associated with higher crop commercialization while share cropping, working in urban areas and older aged household head negatively associated with crop commercialization. A male headed HH have lower agricultural diversification in comparison to female headed households. HHs with medium or smaller of marginal farm size have higher livestock commercialization index while HH with marginal and small farm size have lower fisheries commercialization index in comparison to HH with larger farm size.

The study underscore the importance of diversified agriculture production and commercialization towards improving household income, dietary diversity and better nutrient consumption. Findings of this study have significant policy implications for agricultural diversification and commercialization which are very much important for agricultural development in Bangladesh. The results give policy makers an indication whether to encourage, discourage or simply guide the existing trend of farm production diversity and commercialization given its income and nutrition impacts. If there were no positive association, policy makers would think about alternative option for investment. Therefore, given the positive association between higher farm production diversity and commercialization and household income, nutrition consumption, it is expected that there would be significant efforts on the part of governments, non-government, national and international organizations to promote agricultural diversification and commercialization with investment in research, extension, infrastructure particularly market network infrastructure and research and extension and market institutional development. Further, results would also strengthen the arguments to remove the barriers that hinder farmers from agricultural diversification and commercialization.

Furthermore, policy and programs that increase agricultural productivity should also be supported, to enable smallholders to release land for diversification and to produce a marketable

surplus. This may include the development and spread of improved agricultural technologies including high yielding varieties, as well as increase access to extension and credit facilities which may facilitate information and liquidity constraints that often hinder technology adoption by smallholders in the developing country like Bangladesh. However, agricultural diversification and commercialization alone may not be sufficient to sustainably increase income and improving food and nutrition security of the smallholders. Thus, future policy and programs focusing on improving farm diversification and commercialization should also focus on complementary interventions such as income diversification towards off farm income and women empowerment to sustainably increase income and food security in Bangladesh. As we have seen agricultural diversification and commercialization increases income and this will obviously increase demand for basic goods and services thus enhancing market access is a key strategy to make smallholder agriculture more nutrition-sensitive.

Our study also identified what influence diversification and commercialization that have implications for policy in Bangladesh. Results show that peer effect via living in higher agricultural diversified areas i.e. clustering of diversification due to spillover effects, access to information via access to mobile phone, smaller and marginal farm size and commercialized household positively affect farm diversification. Similarly, access to machine, information via access to mobile phone, having migrant members and larger farm size positively and significantly associated with higher crop commercialization while share cropping, working in urban areas and older aged household head are negatively associated with crop commercialization.

These results have important policy implications for agricultural diversification and commercialization which are essential for agricultural and rural development in Bangladesh. Therefore, policy and programs aiming for agricultural diversification and commercialization should aim for those interventions which encourage agricultural diversification and commercialization. Particularly to facilitate agricultural diversification and commercialization in Bangladesh, policy and programs should focus on: i) strengthening research and extension to develop and disseminate productivity, income and nutrition enhancing and climate adaptive agricultural technologies; ii) investment in access to information including climate, technology

and market information, iii) invest in rural infrastructure including market infrastructure as it can complement agricultural diversification and commercialization by accessing market for diversified and commercialized products, accessing improved input and output production, postharvest and processing technologies; and iv) investment in mechanization along the agricultural value chains including production, postharvest and processing given the scarcity of labour and post-harvest losses and food safety concerns. As our results shows that access to machine and information are important determinants and, hence, such access needs to be facilitated among smallholders in Bangladesh to reap the full benefits from diversification and commercialization. There has been some effort by the Ministry of Agriculture through various projects where farmers can access to machine particularly labour saving machine including tillage, harvesting, threshing, transplanting and drying machines. Government including public–private partnership based mechanization has potential to promote diversification and commercialization and, ultimately, improving food security, nutrition, poverty alleviation and achieving SDG goals in Bangladesh. Further research on agricultural diversification and commercialization to find out the optimum patterns of agricultural diversity and commercialization so that Bangladesh can ensure food security, nutrition and incomes by using scarce resources to achieve the SDG goals.

Abbreviations

ADCI	Agricultural Diversification and Commercialization Indices
AEZ	Agro-ecological Zones
BBS	Bangladesh Bureau of Statistics
BIHS	Bangladesh Integrated Household Survey
CDDS	Child Dietary Diversity Score
DD	Dietary Diversity
FAO	Food and Agriculture Organization
FCS	Food Consumption Score
FVS	Food Variety Score
HAZ	Height for Age
HDDS	Household Dietary Diversity Score
HH	Household
HIES	Household Income and Expenditure Survey
IFPRI	International Food Policy Research Institute
IV	Instrumental Variable
MAD	Minimum Acceptable Diet
MDDW	Minimum Dietary Diversity of Women
NAP	National Agricultural Policy
OLS	Ordinary Least Squares
SI	Simpson Index
WAZ	Weight for Age
WDDS	Women Dietary Diversity Score
WHZ	Weight for Height
2SLS	Two Stage Least Square

Contents

List of tables

List of figures

1. Introduction

Agricultural diversification represents an important strategy to overcome the challenges faced in many developing countries and allows to improve risk management practices, to adapt to heterogeneous production conditions and to increase income generating opportunities (Winters et al., 2006; Rahman and Kazal, 2015). Diversification in agriculture means developing a larger number of crop- or enterprise-mix to generate higher value and income stabilization, and may take different forms such as increasing number of crops grown, including high value crops, and types of livestock reared (Ali, 2004). It may also entail substituting less profitable crops with more profitable ones. It is a way to shift from a mono cultural cropping system to a multiple one, by introducing multiple crops with high market demand e.g. cereals, pulses, vegetables, fruits, oilseeds, fibers crops and odder (Singh, 2011). Promotion of crop diversification has important implications for agricultural biodiversity (Winters et al., 2006). Generally, agricultural diversification production is considered as function of commercialization and development in addition to being a function of enhanced income, sustainability and risk reduction (Ali et al., 2004). It is also widely perceived that agricultural diversification improves the nutrition status of rural households (World Bank, 2007). Diversified agricultural food production has been recognized as a way to improve nutrition and health (Frison et al., 2006; Johns and Eyzaguirre, 2006; Ecker et al., 2011; Veronesi and Lovo, 2019). There are two pathways: first, by improving the quality and quantity of on-farm food available for own consumption; and second, through stabilizing income during the period of price variability and yield fluctuations (Romeo et al., 2016). Agricultural commercialization moreover increases employment opportunities and income, with market being a key factor in the commercialization process (Kilimani et al. 2020; Von Braun, 1995).

To meet the challenges of the global food markets and the changing demand of the population, many countries in South Asia have been diversifying agriculture to enhance productivity and to cultivate high value crops, especially fruits, vegetables, and spices to augment farm income, generate employment and alleviate poverty. For instance, Indian agriculture during the last two decades has been diversifying towards high value commodities i.e., fruits, vegetables, milk, meat, and fish products (Bhattacharyya, 2008). During the 1980s, rising prices and crop

diversification were identified as the major sources of growth in Indian agriculture (Joshi et al., 2006).

In Bangladesh, rice is the main staple crop cultivated, accounting for more than 75 percent of the gross cropped area (BBS, 2017). The country is diversifying its crop sector towards other cereals (i.e., wheat and maize) as well as non-cereals e.g., potatoes, vegetables and spices, fruits etc. (Rahman and Kazal, 2014). The objectives of the national agricultural policy of 1999 were to promote diversified agriculture and reduce excessive dependence on any single crop, to minimize risk; increase production and supply of more nutritious food crops and thereby ensure food security and improved nutritional status (NAP, 1999). The Sixth Five Year Plan (SFYP: 2011–2015) emphasized self-sufficiency in food grain production, along with diversification into other cereal and commercial crops (Planning Commission, 2011). Attaining food self-sufficiency was a major milestone of this plan. In addition, steady progress with diversification in favour of fish, meat and vegetable production is contributing to the nutrition strategy of the country. The Seventh Five Year Plan (7^{th} FYP: 2016-2020) also emphasized maintaining self-sufficiency in staple food (rice) production and meeting the nutritional requirement of the population through supply of an adequate and diverse range of foods and consumption diversification with high value crops including vegetables and fruits (Planning Commission, 2016). Small farmers practice diversification more than other types of farmers and produce multiple crops with rice in order to meet subsistence and cash requirement (Islam and Hossain, 2017; Rahman, 2009). However, the expansion of non-cereals and non-food crops (e.g., potatoes, vegetables, onions, jute and cotton), which are more profitable than rice cultivation because of the existing irrigation system and soil conditions that are suitable for rice production (Mahmud et al. 1994; Rahman and Kazal, 2015).

With the policy emphasis to enhance diversified agriculture production, it is important to understand the economic and nutritional implications of such diversification. Understanding the nexus between agricultural diversification, commercialization and farm households' income, dietary diversity and nutrition is a key topic in scientific and policy debates particularly in the developing countries characterized by persistent food insecurity and poor nutrition outcomes of rural agricultural households. The present study uses a range of secondary data sets, to identify the determinants of crop diversification and, to assess the impact of diversified agriculture

production on economic and nutritional status of farm households. The detailed ToR of the study is in the Annex.

1.1 Objectives

The objectives of the study are:

1) To assess and unpack the linkages between agricultural diversification (including fisheries, poultry and livestock, and non-food crops), commercialization and farm households' income.
2) To identify, assess and analyze the linkages between agricultural diversification, commercialization and farming households' dietary diversity and nutritional status.

1.2 Hypotheses of the Study

i) Agricultural diversification and commercialization do not improve households' income and reduce poverty.
ii) Agricultural diversification and commercialization do not significantly affect intra-household dietary diversity and nutrition.
iii) Seasonality and market significantly affect the linkages between agricultural diversification and commercialization on farm households' income, intra-household dietary diversity and nutrition.
iv) Various internal and external or push and pull or demand and supply or macro and micro level factors determine farm households' decision to diversify or commercialise its agricultural production.

1.3 Expected outputs

- The study will produce an inception report, a note on methodology, an interim report, a policy brief, and final report and research summary. The product will include the following research results: Evidence on whether agricultural diversification or commercialization or both improve farm households' income, intra-household dietary diversity and nutrition.

- ❑ Evidence on which dimension of agricultural diversification and commercialization (e.g. high value food crops, non-food crops, non-crop agriculture):

  - improves farm households' income, intra-household dietary diversity and nutrition.

  - is appropriate for which agroecological setting, to improve farm households' income, intra-household dietary diversity and nutrition.

  - is appropriate for which types of farm households (e.g. subsistence versus commercial) to improve their income, intra-household dietary diversity and nutrition.

- ❑ Role of seasonality, market and gender roles on the linkages between agricultural diversification and commercialization on farm households' income, intra-household dietary diversity and nutrition.

- ❑ Determinants of agricultural diversification and commercialization.

Types of intervention include policy, institutional and technological interventions to enhance agricultural diversification and commercialization

2. Literature Review

As a background to the research, this section presents a review of the literature on the impact of diversified agricultural production and commercialization on income, dietary diversity, food and nutrition security. Crop diversification is an important strategy to build resilience in agricultural farming systems in different ways. It can reduce the sensitivity of production due to climate shocks (Kun et al. 2013; Bezabih & Sarr, 2013). It moreover improves livelihood and efficiency of farming system and promotes agro biodiversity and dietary diversity for improved food and nutritional security status. Numerous studies of crop diversification, agricultural diversification, commercialization and agro biodiversity have been conducted in different countries. The results show the impact of diversification and commercialization on different issues related to food and nutrition security, farm income and poverty reduction and are presented into the following five sub-sections.

2.1 Impact of diversification on dietary diversity, food and nutrition security

Agricultural production diversification has the potential to influence household dietary diversity and nutrient adequacy of diets and the nutritional status of individuals. Several studies have found that agricultural diversification positively affects dietary diversity (Jones et al. 2014; Jones, 2016; Hirvonen and Hoddinott, 2017; Hossain et al. 2016; Islam et al. 2018; Romeo et al. 2016; Sraboni et al. 2014) and households' income (Birthal et al. 2013& 2015; Thapa et al. 2017), in developing countries including Bangladesh. Some recent empirical studies have also found that diversified agricultural production significantly increased households' dietary diversity (Akerele and Shittu, 2017; Chegere and Stage, 2020; Ecker, 2018). Agrobiodiverse landscapes can contribute to food and nutrition security, and diversified local food production systems are essential to improve food and nutrition security (Fernandez and Mendez, 2018). However higher food price could substantially reduce dietary diversity. In another study, Kumar et al. (2015) found a positive association between production diversity and dietary diversity among children aged 6-23 months, and height for age z-scores and stunting in children aged 24-59 months. Nutrition-sensitive agriculture (NSA) is a food-based approach to agricultural development that increase nutritionally rich foods, dietary diversity, and overcome the malnutrition and micronutrient deficiencies (FAO, 2014). This program improve a variety of nutrition outcomes in both mothers and children and greater benefits for child nutrition outcomes (e.g. dietary diversity, nutrition intake) are achieved when programs also include action to improve health and wash practices (Ruel et al. 2018). However, a critical review from studies conducted in low- and middle-income countries revealed the mixed evidence of agricultural diversity on household- and individual-level diets (Jones, 2017). A recent review of 45 original studies from 26 countries claimed that less than 20% of the studies report consistently positive and significant associations between production diversity and dietary diversity (DD) while about 40% studies found no significant associations (Sibhatu and Qaim, 2018).

Diversified crop production is associated with households' nutritional access. Mazunda et al. (2015) found that production diversification is associated with a 35 percent increase in access to iron, 47 percent increase in access to vitamin A, 45 percent increase in access to folate, and 35 percent increase in access to zinc. For smallholder farming in developing countries, crop diversification is a viable option for the establishment of resilient agricultural systems that can significantly contribute to household food security (Mango et al. 2018). The diversity of crops

grown can, through DD improve household food security. In rural areas where households' access to food depends largely on food production, diversified crop production provides farmers with the different crops that they cannot access either because of the cost or because of poor infrastructure constraints (Adjimoti and Kwadzo, 2018). It also has positive role in areas with poor access to market (Kissoly et al. 2018). Kumar et al. (2019) found that cultivation of vegetables after rice production can improve farmers' livelihood as well as food and nutritional security (FNS) in the Eastern Himalayas area.

The relationship between farm production diversity and household food consumption diversity remains complex and empirical evidence is so far mixed. It is highly debated that diversification may not always be the best strategy for improving farm households' DD, due to the forgone income opportunity from specialization (Sibhatu et al., 2015). Farm production diversity may not be sufficient to ensure improved DD in rural households (Dillon et al. 2015; Frimpong, 2017).; Ayenew et al. (2018) found that increased farm production diversity was associated with seasonal food consumption diversity and dietary diversity in rural Nigeria and suggested seasonally targeted nutrition intervention. In addition, the impact of production diversity on DD varies across income levels. Market access is important for DD specifically in the lean season and key strategy to enhance nutrition (Sibhatu and Qaim, 2018; Zanello et al. 2019).

2.2 Impact of commercialization on dietary diversity, food and nutrition security

Agricultural commercialization is the transformation from subsistence to market-oriented farming that can improve smallholder farmers' livelihood. DeWalt (1993) reviewed the findings of different studies conducted to examine the impact of agricultural commercialization on food consumption and nutritional status over the previous 10 years. He found that, the impact of commercialization are mixed and highly dependent on various factors such as the nature of the crop, production and income, and allocation of labor and pricing policies for both cash crops and food stuffs. Sharma (1999) found that children's nutritional status largely depends on household demographics, the nutrition status and demographics of mothers. Moreover, access to food markets is found to be more effective than diversifying production in improving nutritional outcomes, particularly for subsistence farmers during the lean season (Sibhatu et al., 2015; Koppmair et al., 2016; Sibhatu and Qaim, 2017; Hirvonen and Hoddinott, 2017).

Kirimi (2013) showed that agricultural commercialization is associated with a reduced risk for smallholders of being in chronically food insecure and on the brink of insecurity households' groups. Agricultural commercialization significantly reduces food insecurity and poverty among commercial and subsistence smallholder farmers (Muricho, 2015). Recent studies also found evidence of positive relationship with small magnitude between agricultural commercialization and nutritional status (Carletto et al., 2017; Radchenko and Corral, 2018). However, in a recent study, Kilimani et al. (2020) found that while commercialization increases crop income, its impact on overall nutrient intake is negative.

2.3 Impact of diversification on income and poverty

Several studies indicate that diversification into high-value crops (e.g. fruits and vegetables) or non-crops (e.g. livestock's) increases employment, income, and results in poverty reduction (Birthal et al., 2013& 2015; Thapa et al., 2017; Von Braun, 1995). It is argued that a better income from specialization may provide better access to diversified foods from the market. Empirical evidence from developing countries found that the number of crops produced was positively significant with household income from crop production (Pellegrini and Tasciotti, 2014). Diversification by adding more lucrative crops increased farmers' income and spread it across lean times between the harvests of their traditional crops (Schroth and Ruf, 2014), increased farm productivity and farm income (Falco et al. 2010; Mandal and Bezbaruah, 2013), and is one of the most cost-effective ways of reducing uncertainty in farmer income, especially of smallholder farmers (Feliciano, 2018). It also a viable way to deal with the exigencies of being poor (Michler and Josephson, 2017).

Crop diversification is a good strategy to improve income and mitigate risk (Mital and Hariharan, 2016). Incorporation of horticultural crops in the mix can increase net expected returns from cultivation and including alternative crops reduces water use up to 30% (Chhatre et al. 2016). Crop diversification is an important ex-ante adaptation measure to climate shocks and benefits are more apparent, the dynamic role of crop diversification in improving resilience are reinforced (Birthal and Hazrana, 2019).

2.4 Impact of agricultural commercialization on poverty and income

Several studies have been conducted to evaluate the impact of agricultural commercialization on income poverty. Agricultural commercialization increases employment and income (Von Barun, 1995). Shively and Sununtnasuk (2015) found a positive association between the degree of agricultural commercialization and height-for-age Z scores (HAZ) among two years old children in Nepal. Ogutu and Qaim, (2019) found that commercialization increases income and reduces multidimensional poverty, and contributes to achieving sustainable development goals. However, some studies found different results: in Mitiku (2014), smallholder farmers' commercialization had no effect on poverty level in south western Ethiopia.

2.5 Determinants of farm diversification and commercialization

Agricultural diversified production and commercialization depends on various factors. Technological factors, land and labor availability constrain crop diversification among the poor farmers (Hitayezu et al. 2016). Crop diversification depends on land size, farming experience, asset, location, access to agricultural extension services, information on output prices, low transportation costs and access to information (Makate et al. 2016). Farmers' gender, age, land fragmentation, distance from development center and the market, and non-/off-farm income shares also significantly influenced the intensity of crop diversification in Ethiopia (Dessie et al. 2019). In Nigeria, Rahman and Chima (2016) found that farm size was the most important determinant for crop diversification and profitability. They also identified proximity to market and/or extension office, extension contact, training, agricultural credit, subsistence pressure and location as influencing factors. Crop diversity can potentially improve the sustainability of subsistence farming systems through improvement of soil pH (Ghimire and Bista, 2016). Many farmers are unable to diversify because of the characteristics of their fields, poor market access, market instability, and relatively high input costs (Burechfield et al. 2018). Diversification decision also depend on farmer characteristics such as education, financial situation and farm and family size (Schroth and Ruf, 2014). Soil quality, availability of irrigation also influenced crop diversification (Larikova et al. 2019). Kun et al. (2013) found that crop diversification was significantly influenced by extreme weather like drought and flood events. Covariate shocks from rainfall variability positively contributed to increased level of diversity (Bezabih and Sarr, 2013). Increased annual temperature resulted in increased crop diversification in Bangladesh

(Moniruzzaman, 2019). Crop diversity contribute to enhancing the agro ecosystem resilience (Matsushita et al, 2016).

Crop diversification also varies significantly across agro-ecological zones. Crop diversification may be promoted among different types of farmers with the aim of contributing to economic growth, risk reduction, and nutrition security (Kankwamba et al. 2018). Rahman and Kazal (2014) found that diversification significantly differs across regions in Bangladesh. Marginal contribution of crop diversification is substantial in the agro ecosystems where rainfall is low (Donfouet et al. 2017). Hence, boosting crop diversity is a viable strategy for maintaining stability of food supply in food system but this varies depending on market access (Bahadur KC et al. 2015).

Abdullah et al. (2019) assessed the factors that affect smallholder farmer's participation in market and the effect of commercialization on the farmers' welfare. They found that gender and age of the household's head, number of family members who help in farming, household and farm size, access to vocational training were the major determinants of market participation. Also farmers' welfare depends on whether the farmer participates in the output market. Large farm size and fertile soil, access to farm input credit, contacts with extension staff, mobile phone ownership and membership to rural agricultural production networks positively determined agricultural commercialization, while transport costs to the main market (household remoteness) was negatively related to commercialization (Muricho, 2015).

As aforementioned, existing empirical studies, assessing the linkages between agricultural diversification, commercialization and farming households' income, intra-household dietary diversity and nutrition is context specific. While some studies found a positive association, still there are other studies that revealed negative relationship or no relationship at all. Therefore, the relationship is case and context specific and it is highly pertinent to answer whether, and to what extent, diversification and commercialization leads to improved nutrition and income. Moreover, there are several past studies that are likely to suffer from the omitted variable bias and less efficient standard errors. Panel data and panel econometrics can better control such issue

(Wooldridge, 2012) and produce the causal estimates between agricultural diversity and dietary diversity (Jones, 2017).

Recently few studies (please see Mofya-Mukuka and Hichaambwa, 2018; Islam et al., 2018) have used panel data to study this issue. Islam et al. (2018) studied the linkages between farm diversification and food and nutrition security in Bangladesh using nationally representative Bangladesh Integrated Household Survey (BIHS) that collects 2 rounds of panel data. They found positive association between farm diversification and DD although the magnitude of association was small. They also found that market access, commercialization of farms, diversification of income towards off farm sources and women's empowerment, have positive and significant effects on household DD.

However, most of these studies including other studies in Bangladesh are at the aggregate level, which makes it difficult to conclude on the explicit link between agricultural diversification, commercialization, and farm households' income, intra-household DD and nutrition. In addition, how this link varies by agroecological zones, farm nature (e.g. subsistence vs. commercial), types (e.g. small, medium and large), and seasons (e.g. lean and lost harvest) remains puzzling. Which dimensions of agricultural diversification (including fisheries, poultry and livestock, and non-food crops) and commercialization improve farm households' income and nutrition? What are the determinants of agricultural diversification? What are the other factors, including market access, that influence this linkage? Additional research is required particularly in the Bangladeshi context, to answer these questions. It is of utmost important to provide effective policy direction, to understand the determinants of dietary and agricultural diversity and nexus between them.

3. Research Methodology

3.1 Conceptual framework: agricultural diversification and commercialisation to income and nutrition pathways

Figure 1 shows a simple conceptual framework for our empirical analysis. The upper portion of the framework shows hypothesized determinants of agricultural diversification and commercialisation and lower portion indicates various pathways through which agricultural

diversification and commercialisation can affect intra-household welfare including income, food security and nutrition. Different research shows that agricultural diversification and commercialisation are determined by "internal" and "external", or push and pull, or demand and supply, or macro and micro level factors (see the upper portion of the figure 1). Each combination of these choices selected by the household leads to a set of outcomes or results which are shown in the lower portion of the framework.

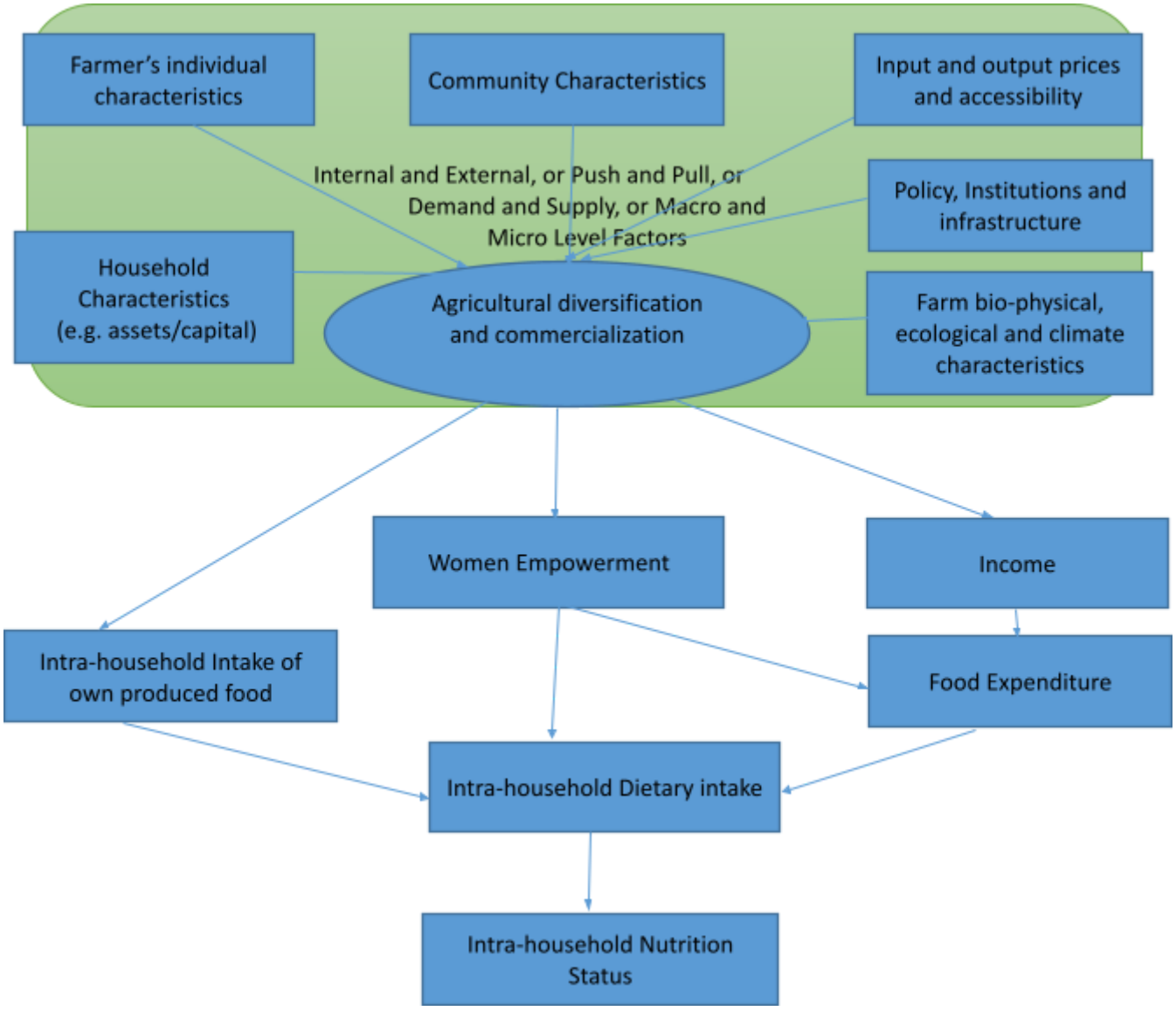

Figure 1: Agricultural diversification and commercialisation to income and nutrition pathways (Source: Own illustration based on related literatures review)

This framework highlights the different factors that influence a household's decision to adopt various agricultural production strategies, and how such strategies shape the outcomes such as income, food security, nutrition status, etc. and the linkages between these various factors. This framework provides a basis for the comprehensive understanding of the factors underlying the agricultural diversification and commercialisation decision-making process by individual farmers. It defines the influence of agricultural diversification and commercialisation as a function of various factors representing the endowment and constraints of farmers. Moreover, it also delineates the pathways through which agricultural diversification and commercialisation translate into improving farmers' income and intra-household nutrition.

3.2 Theoretical framework

Diversification and commercialization are defined in different ways but generally agricultural diversification refers to the shift from the dominance of one crop to production of a number of crops on a farm or in a region (Petit and Barghouti, 1992). However, typologies of diversification can be of different forms, including cultivation of more than one enterprise for example mixed farming systems by including number of crops or a number of livestock or a number of fish species or a mix of crops and livestock or a mix of crops and fish or a mix of crops, fish and livestock. As stated by Joshi et al. (2006b) agricultural diversification is crop mix, enterprise mix and activity mix at the household level. In this study, we will consider all these diversification categories to determine what works for whom and which one is more income and nutrition sensitive.

The agricultural household's decision to diversify the production portfolio is one of the major economic decisions that has a strong influence on their livelihood. We assume a household chooses a cropping strategy that will stabilize the income by farming mix of commodities (crops, livestock, aquaculture etc.). We followed Singh et al. (1986) to develop an agricultural household model (AHM) that explains the fundamentals of decision-making by rural households. Since small agricultural households in Bangladesh depend on their production to meet their food needs and also sell their surplus for income generation, our household model and behavior are based on both production and consumption theories. This study closely followed the theoretical model adopted by Benin et al. (2004) and Kankwamba (2018) based on AHM.

In any production cycle, a farm household seeks to maximize utility over a set of market purchased goods ($X_{m,}$), own household produced and consumed goods (X_a), agriculture produces that are sold $\left(X_s\right)$ and leisure (l). Moreover, household utility is a combination of factors that depends on preferences of household members (Ω_{hh}) and are derived from the household characteristics such as age, education and income.

The household utility function is expressed as follows:

$$U = U\left(X_a, X_s, X_{m,}, l; \Omega_{hh}\right) \quad (1)$$

The utility is maximized subject to a cash income constraint as follows:

$$P_m X_m + Y_0 = P_a\left(Q - X_a\right) - w(L - F) \quad (2)$$

where P_m is the prices of market purchased commodities, P_a is the prices of own household produced agricultural goods and Y_0 is exogenous income (such as remittance). Similarly, Q is the household's production of agricultural commodities, $Q - X_a$ is the marketed surplus (X_s), w is the market wage, L is total labor input, and F is family labor input. If $L - F$ is positive, a household hires outside labour, while if it is negative, a household supplies off-farm labour.

A household chooses the certain level of farm output to be consumed (X_a) and sold (X_s) from a vector Q of farm outputs. The household's decision to diversify the farm outputs are constrained by a fixed technology that uses a sets of inputs (X), labour, and fixed land endowment (A^o) to raise m commodities in the geographical location with the farm characteristics Ω_F and community characteristics Ω_c.

$$Q = F(\alpha, X, L|A^o, \Omega_F, \Omega_c) \quad (3)$$

The set of area shares α_i must sum to one and should be used to raise *m* commodities such as $\sum_{i}^{m} \alpha_i = 1$, i=1,2,…m. Overall, the objective function is expressed as:

$max_h V(X_a, X_s, X_{m,}; \Omega_{hh})$	(4)

where $h = (\alpha_1 ..... \alpha_m > 0; X_a, X_s, X_{m,} X, L)$. Interior solutions may not exist for all m[th] commodities since households may diversify to a few commodities only and thus it is likely to occur corner solutions. The study employs the suitable model such as tobit model to deal with the corner solution. Households' decision to allocated labour are constrained by time available for leisure and agricultural activities (T_a) such as:

$l = T - T_a$	(5)

If a household separability condition exists, then a farm household will be able to separate consumption and production decisions, and our objective function will be to maximize net profits from the farm subject to technology and income constraints. When markets are imperfect and production and consumption decision are inseparable, then prices are endogenous to the farm household characteristics and the extent of crop diversification and shadow prices is determined by an internal equation of demand and supply for a commodity within the household. The market characteristics can also influence the crop diversification choices. The market constraint can be expressed as a function of Ω_M. If the consumption and production decisions are non-separable, the household's optimal choice is $h^* = (\alpha^*, X_a^*, X_s^*, X_m^*, X^*, L^*)$ and can be presented as a reduced form equation of market characteristics and characteristics at farm, household head, and community levels:

$h^* = (A^o, Y^o, \Omega_{hh}, \Omega_F, \Omega_M, \Omega_c)$	(6)

and finally following Benin et al. (2004),

$$D = \alpha^{*}(A^{o}, Y^{o}, \Omega_{hh}, \Omega_{F}, \Omega_{M}, \Omega_{c}) \quad (7)$$

We will use equation (7) to estimate the determinants of agricultural diversification(D).

3.3 Data sources

The study used data from secondary sources. The existing data from BBS HIES 2000, 2005, 2010 and 2016 and IFPRI Bangladesh Integrated Household Survey (BIHS) of two rounds panel data (2011/12 and 2015) (Table 1). These two data sets are nationally representative and cover all Bangladesh.

Table 1 Secondary data sets

Items	HIES (Cross Sectional)				BIHS (Panel)	
	2000	2005	2010	2016	2011/12	2015
Rural	5040	6400	7840	32096	6503	6436
Urban	2400	3680	4400	13980	-	-
Total	7440	10080	12240	46076	6503	6436

3.4 Analytical methods

Outcome variables

We have measured dietary diversity by using the household dietary diversity score (HDDS), women dietary diversity score (WDDS), child dietary diversity score (CDDS) (Swindale and Bilinsky, 2006; FAO, 2011), and the food variety score (FVS); food consumption score (FCS) at household level (WFP, 2008) and hunger scale. Other outcome measures are the household income and expenditure, food expenditure, household calorie and micronutrient supply, dietary quality, and child anthropometric measures such as weight for height (WHZ), height for age (HAZ) and weight for age (WAZ) (WHO, 2006; Coates et al., 2007; Babatunde and Qaim, 2010).

Key explanatory variables

Based on the relevant literatures, several measures of agricultural diversification including share value of respective enterprise (e.g. fruits and vegetables), proportion of land area allocated to respective enterprise (Thapa, et al. 2017), and several indexes e.g. the Simpson Index of

Diversification (SID) (Kankwamba et al., 2018), Margalef species richness index, count measures (e.g. number of crops grown, number of food groups produced, etc.) have been used (Islam et al., 2018). Similarly, agricultural commercialization was calculated using various agricultural commercialization indices/ratios (ACIs) (see von Braun et al. 1994; Jaleta et al. 2009; Muriithi and Matz, 2015; Carletto et al. 2017). To properly capture the level of commercialization across all farm enterprises (food crops, cash crops, fish and livestock), we have constructed a commercialization index defined as the share of the total value of farm output sold during the 12-months period covered by the survey. This index has also been widely used (von Braun and Kennedy, 1994; Tipraqsa and Schreinemachers, 2009; Carletto et al. 2017; Ogutu et al. 2019). Depending on the availability of the data, we have used all these indicators in our study.

Analytical methods: First of all, we have conducted the non-parametric and graphical analysis related to the agricultural diversification, commercialization, dietary diversify, income and nutrition indicators, and were presented by AEZ, income quintile, farm size and farm types to present an anecdotal observation of the expected results. To obtain the causal estimates (by controlling the potential endogeneity issues), two steps methodological procedures was followed to address this core issue.

At the first step, for identifying the factors affecting agricultural diversification and commercialization we have estimated the following equation:

$$ADCI_{it}=\beta X_{it} + \eta_{it} \quad (1)$$

where $ADCI_{it}$ is agricultural diversification and commercialization indices, X_{it} is a vector of explanatory variables (see in the conceptual framework and Appendix A), β is a vector of parameters to be estimated, and η_{it} is the error term. The subscripts *i* and *t* index the households and time. Depending on the nature of the ADCI the equation 1 was estimated in several ways (e.g. if dichotomous then conditional fixed effect logit, if censored then random effect tobit or panel double hurdle model, if continuous then panel multi-level model, if cross sectional then two stage least squire approach). The equation 1 were estimated two times-one for agricultural diversification indices and another for the agricultural commercialization indices. These estimates gives us an understanding the motivations behind the choices made by farmers in choosing

what to produce that will help to design policy or interventions to promote diversification and commercialization of agriculture in Bangladesh.

In the second step, we examine the impact of agricultural diversification and commercialization using the following reduced form regression equation as follows:

$$OI_{it} = \beta X_{it} + \gamma_1 ADI_{it} + \gamma_2 ACI_{it} + \varepsilon_{it} \quad (2)$$

where OI is the respective outcome variables (see above). X is a vector of explanatory variables (other than agricultural diversification and commercialization) that influences the outcome variables, and the coefficient γ_1 and γ_2, measures the effect of agricultural diversification (ADI) and commercialization (ACI) on outcome variables respectively. Depending on the nature of the OI and nature of the data sources (e.g. panel, cross section, repeated cross section, etc.), the equation 2 was estimated in different specifications (e.g. if dichotomous then conditional fixed effect logit, if count then Poisson fixed effect, if continuous then standard household fixed effects, if cross sectional the two stage least squire regression). In addition to capture the effect of farm nature and type, seasonality and location different specification of equation 2 was estimated using different estimation techniques. Using these different methods, we thus aim to account for selection bias stemming from both the observable and unobservable time variant and time invariant characteristics.

The HH's decision to diversify the crop portfolio or probability to sell the agriculture produce may depend on the unobserved factors such as management skills, motivation, levels of risk aversion etc. Such unobservable factors are also likely to influence the HH dietary diversity and nutrient consumption status of the HHs. As a result, the agricultural diversification and agricultural commercialization seems to be the endogenous variable. In case of cross-sectional data particularly for analyzing HIES data sets the potential bias is addressed using IV regression technique. The Instrumental variable (IV) approach is used to deal with this potential endogeneity. In case of crop commercialization, we used the total expenditure on renting agri-machinery and expenditure on fertilizers as suitable IVs. Commercialized agricultural HHs are likely to adopt improved cultivation practices and thus spend more on renting agri-machinery and buying fertilizers. And these variables are likely to indirectly influence the dependent variables (dietary diversity and nutrient consumption) through directly influencing the intensity

of agricultural commercialization. For the livestock commercialization, we used the expenditure on livestock feed as a suitable IV. HHs spending higher on improved livestock feed are tend to be commercialized in nature but nothing to do with the dietary diversity and nutrition status of the HHs. In case of agricultural diversification, we used the maximum number of crops cultivated in a community. Due to the social-networking in a community, we expect that a HH is likely to diversify their crop portfolio if a large proportion of the HH in their community are already growing the diverse crops. We tested the suitability of the instrument using relevancy, under-identification and weak identification tests. The Stata command "ivreg2" corrects the standard errors of the predicted instrumented variable in the second stage equation. Although the fisheries commercialization is likely to be endogenous variable, we simply estimated the model using the linear regression approach in absence of suitable IV. Therefore, the results should be interpreted in terms of correlation rather than causation.

4. Research Findings and Discussion

4.1 Results from IFPRI BIHS data set

4.1.1 Descriptive statistics

The IFPRI BIHS panel data set is first analyzed by means of descriptive statistics using parametric tests. Comparison of the means of variables that describe the farm diversification and dietary diversity status and other confounders between the two rounds which are used in econometric analysis are shown in Table 2 and 3. From Table 2 it is evident that household dietary diversity score (HDDS) is quite high compared to women dietary diversity score (WDDS) in both the rounds. This indicates the intrahousehold disparities in dietary diversity. HDDS significantly increased from the first round to second round which is impressive. Almost all the dietary diversity indicators are increasing over the years except dietary diversity score

based on purchased foods only. This may indicate that households are diversifying their consumption from diversification of own production.

Table 2 Descriptive statistics of outcome variables

Variable	Measurement and definition	Round 1 (2011/12)	Round 2 (2015)	Mean diff.
Household Dietary diversity score	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	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	Number of food groups consumed by the women in the last 24 hours	4.374 (1.150)	4.563 (1.170)	0.189***
Number of observations		6503 (5118)	6435 (6071)	

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. Data Source: IFPRI BIHS 2011-2015

Similarly, table 3 presents the key independent variables and other control variables used in this analysis. It is revealed that farm diversity is very low in Bangladesh but interesting that it is increasing over very significantly between the two rounds. It is also evident that commercialization of the farm measured by the share of produce sold in the market is also increasing over the years. Therefore, it is difficult to determine whether commercialization or farm diversity is associated with dietary diversity since other factors may also directly or indirectly influence the dietary diversity. These complexities are examined in more detail in the subsequent sections.

Table 3 Descriptive 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)	47329.170 (74716.360)	67138.700 (98263.600)	19809.530***
Produce sold to market	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 main women of the HH	=1 if main women of the HH earns 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)	

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. Data Source: IFPRI BIHS 2011-2015

4.1.2 Income, total expenditure, food expenditure and dietary diversity patterns

Pattern of household dietary diversity measured in various ways, food consumption score and hunger scale over the years using IFPRI BIHS panel data are shown in Figure 2. It is evident that between the two rounds, all the household food and nutrition indicators are improving. Similarly, it is seen from Figure 3 that except energy intake, all other indicators including per capita food expenditure, protein, vitamins A & C, iron and zinc intake are increasing between the rounds. In terms of per capita consumption of different food items, more or less similar trend is seen (see Figure 4). Particularly the nutrient enrich food items including pulses, vegetables, leafy vegetables, meat, egg, milk, fruits, big fish consumption is increasing while the rice consumption is decreasing. A similar trend is also evident in case of household per capita expenditure on

different food items (Figure 5). Moreover, household income and expenditure shown in Figure 6 also show a significant improvement over the round.

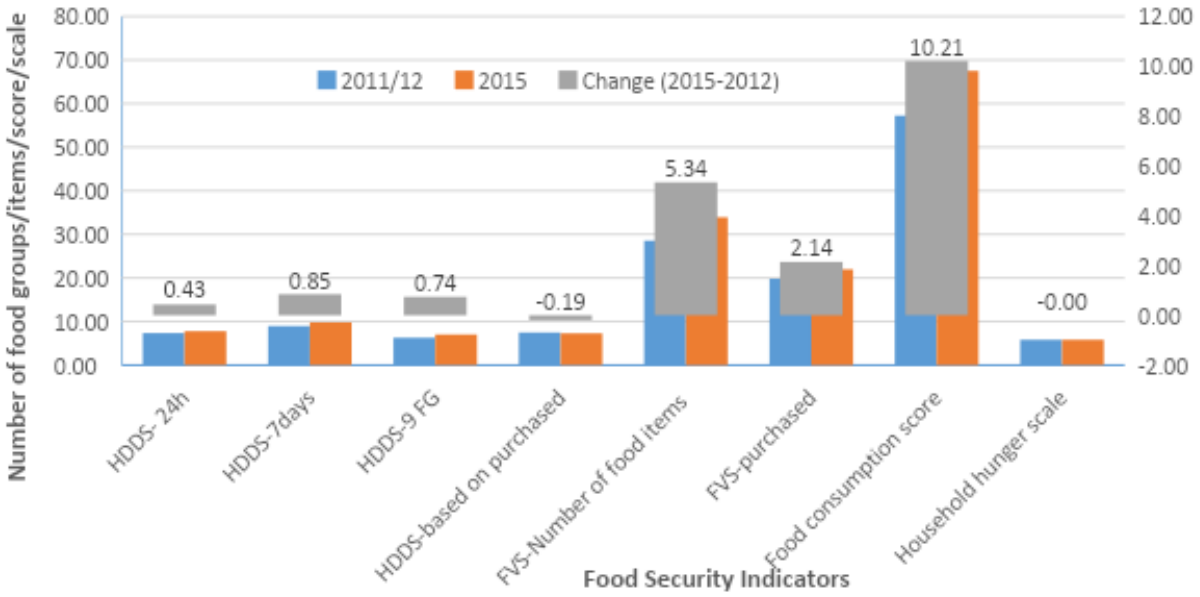

Figure 2: Household food security indicators: household dietary diversity, food consumption score and hunger scale, Data Source: IFPRI BIHS 2011-2015

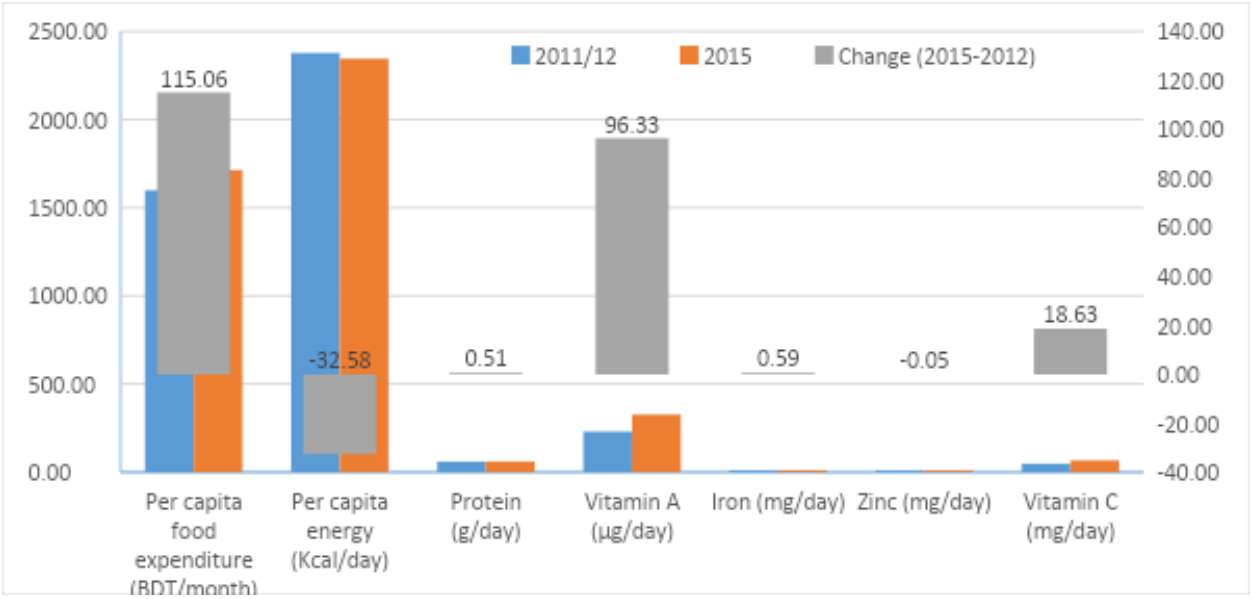

Figure 3: Household food security and nutrition indicators: household food expenditure, energy and different nutrients consumption, Data Source: IFPRI BIHS 2011-2015

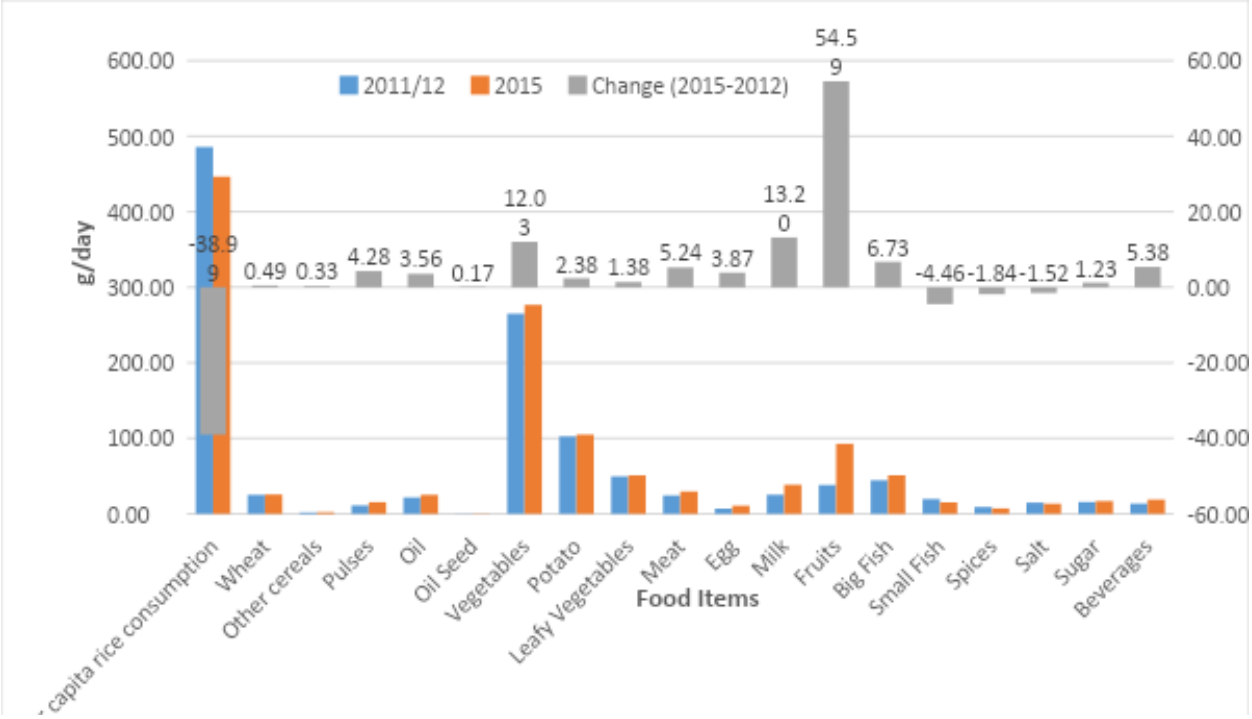

Figure 4: Household per capita consumption of different food items (g/day), Data Source: IFPRI BIHS 2011-2015

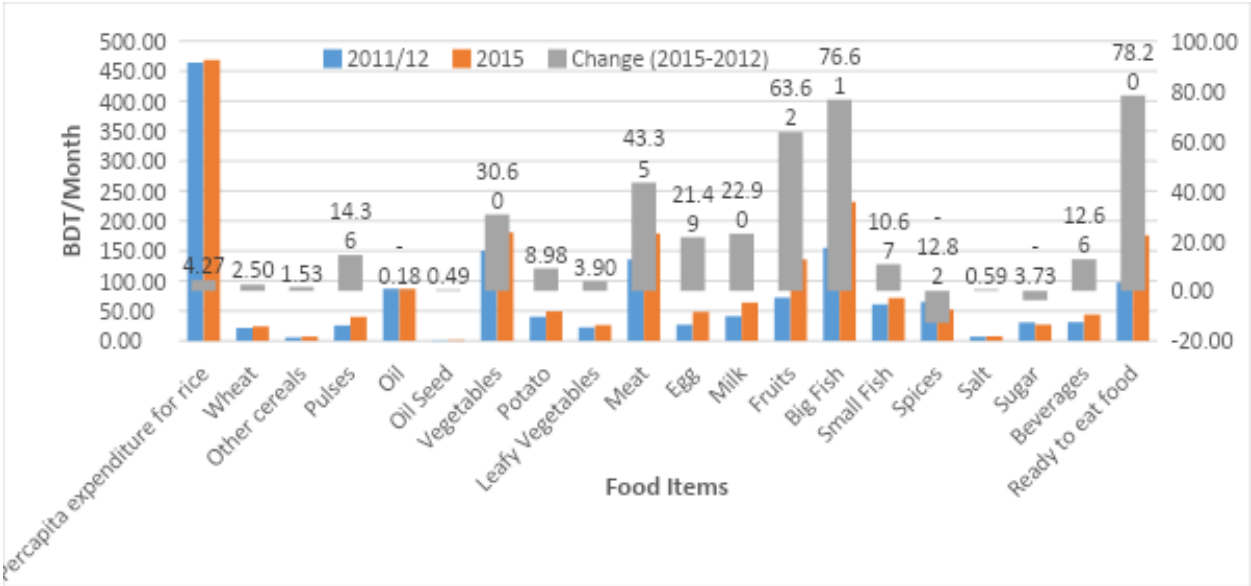

Figure 5: Household per capita consumption expenditure on different food items (BDT/Month), Data Source: IFPRI BIHS 2011-2015

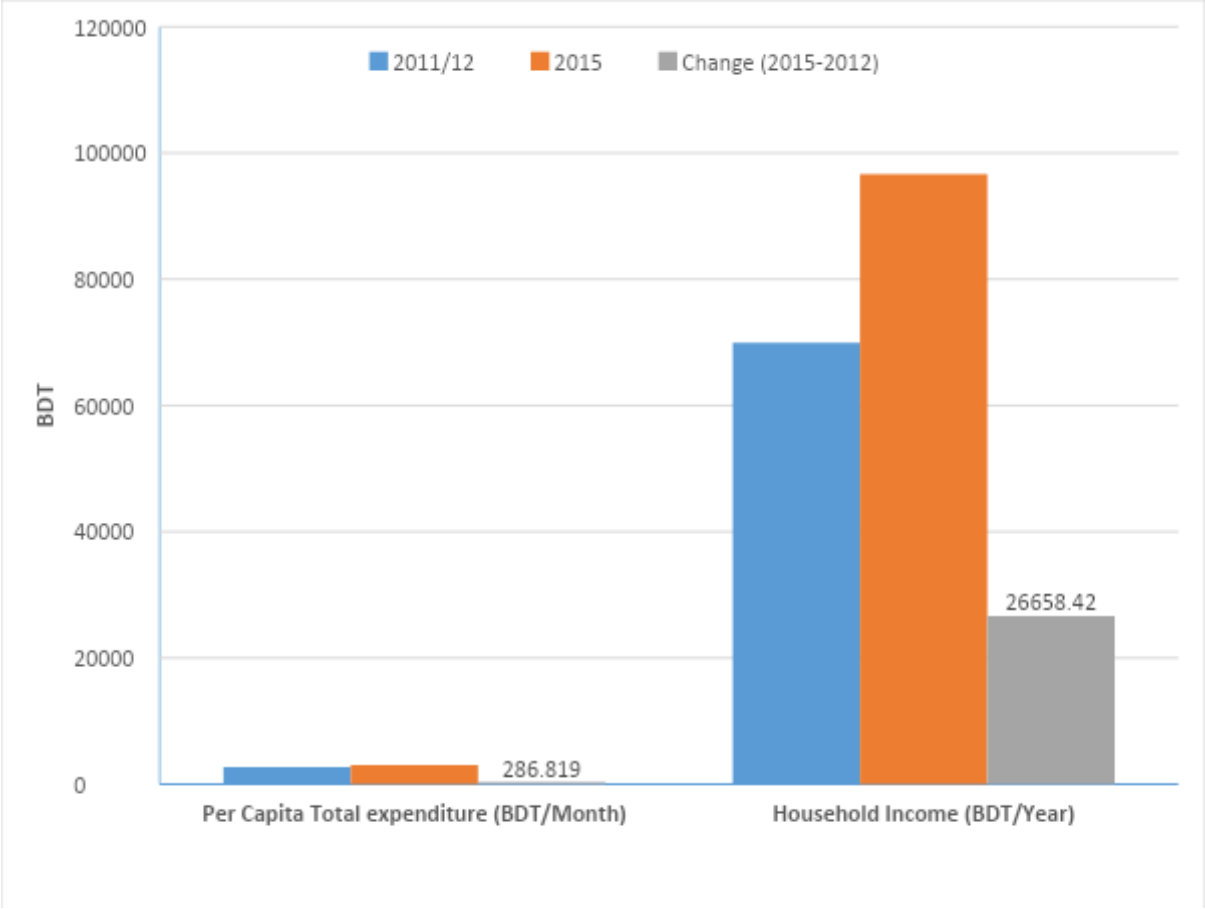

Figure 6: Household income and expenditure (BDT), Data Source: IFPRI BIHS 2011-2015

Likewise, the status and extent of DD using HIES data sets is discussed at the agro-ecological zones, region (urban vs. rural), farm size, and whether HH sells the agriculture produce (subsistence vs. commercial).

4.1.3 Agricultural diversification and commercialization trend

Using IFPRI BIHS panel data sets, various agricultural diversification and commercialization indices are calculated and shown in Figures 7 & 8. It is evident that agricultural diversification and overall agricultural and crop commercialization has increased between the two rounds. Within agricultural commercialization, crop and fish commercialization dominate and within crop commercialization cereals dominate and share of other crops including pulse, vegetables, and fruits in total commercialization is decreasing (Figure 9).

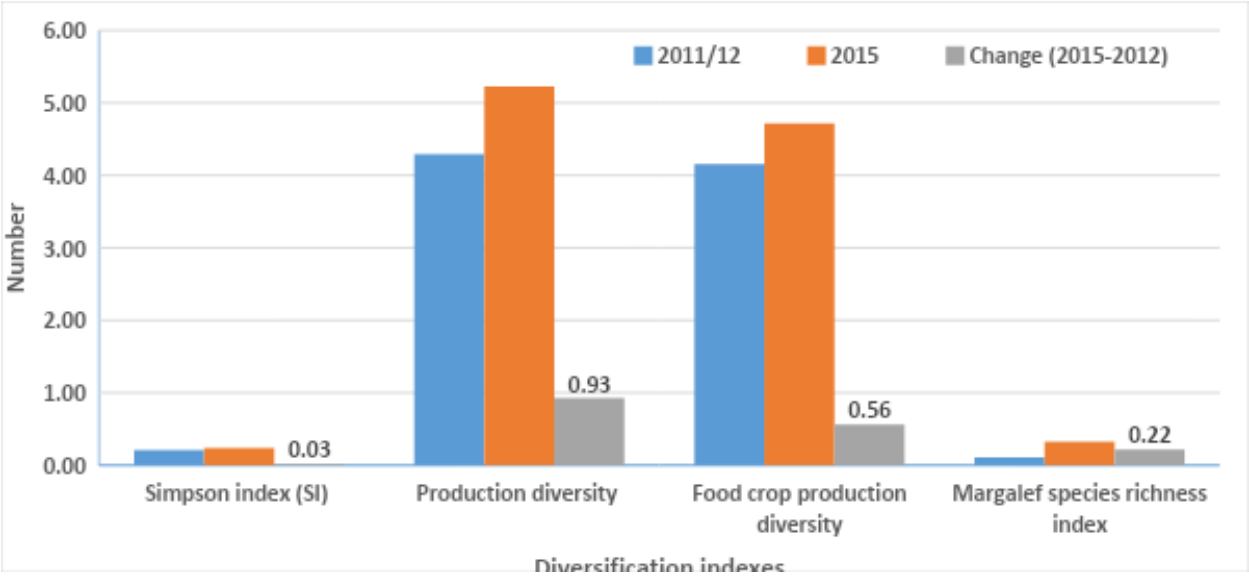

Figure 7: Various agricultural diversification indexes, Data Source: IFPRI BIHS 2011-2015

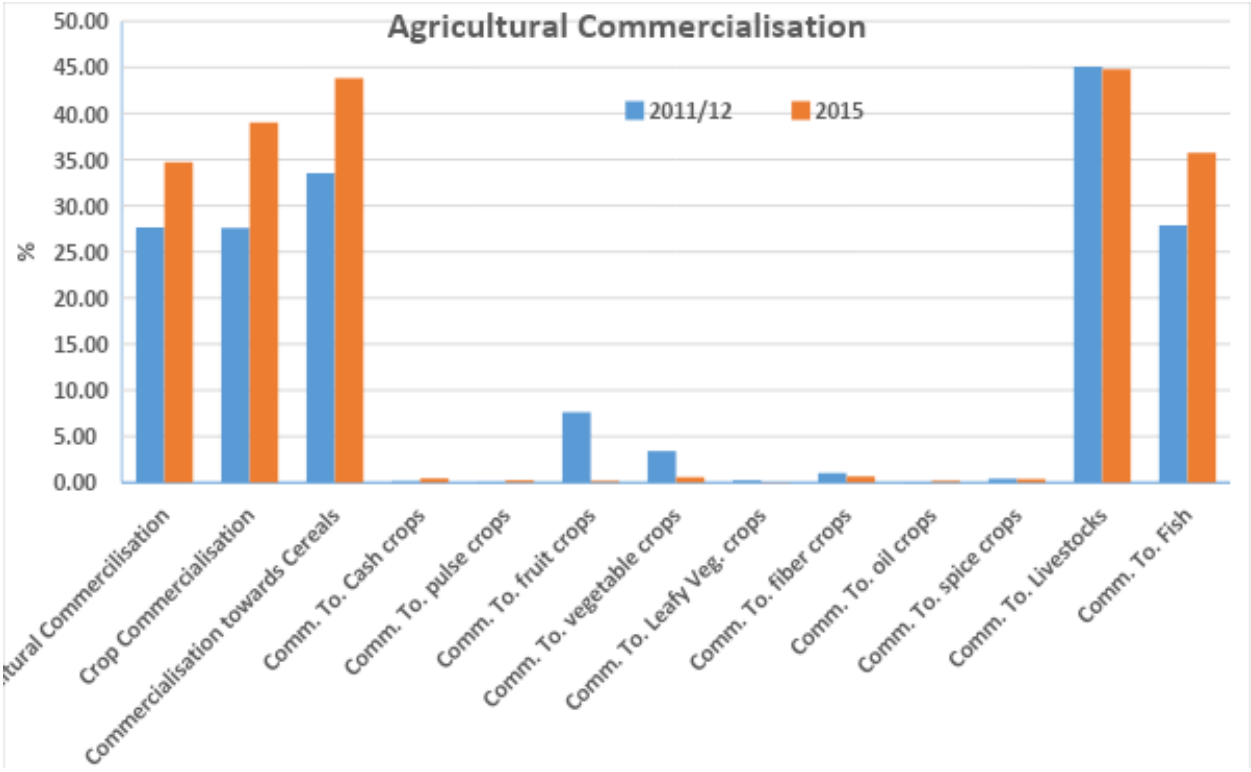

Figure 8: **Various agricultural commercialization indexes, Data Source: IFPRI BIHS 2011-2015**

4.1.4 Impact of agricultural diversification on HH dietary diversity and nutrient consumption

As we are using two data sets, first using BIHS panel data sets we conducted non-parametric analysis to examine the association between the agriculture diversification (number of crops grown & Simpson index) and HH dietary diversity (Figure 9) and the results revealed that agricultural diversification - measured through number of crops grown and household DD - is positively associated. Results show that agricultural diversification is significantly and positively associated with dietary diversity and nutrition (Tables 4, 5 and 6). Similarly, the association between diversification and income is also positive and significant (Table 5). In most of the cases squared term of the diversification is negative which indicates that the relation is nonlinear. Round fixed also shows that second round data is significant and positive which indicates the relation over time is increasing.

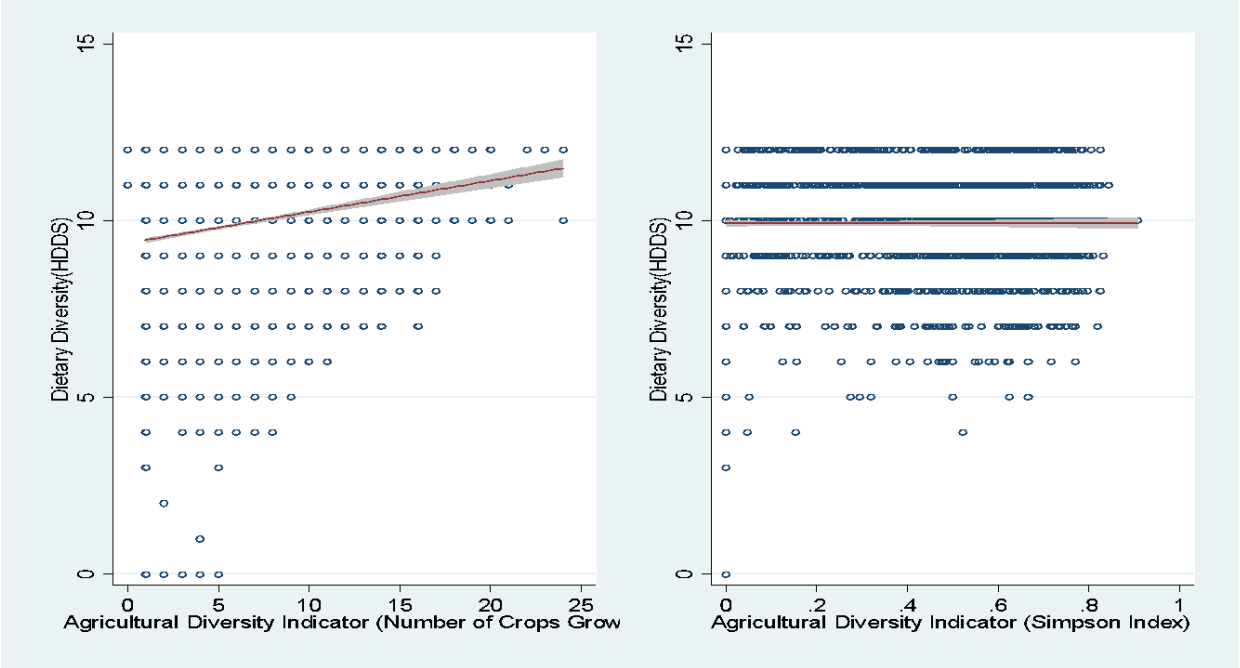

Figure 9: Relation between agricultural diversity and dietary diversity in Bangladesh, Data Source: IFPRI BIHS 2011-2015

Table 4 Fixed effects model results on association between farm production diversity and HH dietary diversity

HH Dietary diversity score (HDDS)	Coef.	Robust Std. Err.
Production diversity	0.019***	0.002
Production diversity squared	-0.001***	0.000
HH Dietary diversity score (HDDS) of healthy foods		
Production diversity	0.023***	0.002
Production diversity squared	-0.001***	0.000
HH Purchase foods Dietary diversity score		
Production diversity	-0.003	0.002
Production diversity squared	0.000	0.000
Food variety score		
Production diversity	0.044***	0.004
Production diversity squared	-0.002***	0.000
Purchase food variety score		
Production diversity	0.028***	0.003
Production diversity squared	-0.001***	0.000

Note: *, **, *** Statistically significant at the 10%, 5%, and 1% level, respectively Data Source: IFPRI BIHS 2011-2015

Table 5 Fixed effects model results on association between farm production diversity and household Income, expenditure, food expenditure, and FCS

	Coef.	**Robust Std. Err.**
Total Expenditure (per capita)		
Production diversity	0.0107***	0.0036
Production diversity squared	-0.0001	0.0002
2.round	0.0854***	0.0074
Household Income (annual)		
Production diversity	1535.7**	776.9
Production diversity squared	-13.5	46.4
2.round	26210.8***	1548.8
Food Expenditure (per capita)		
Production diversity	15.63**	7.83
Production diversity squared	-0.15	0.44
2.round	92.22***	14.36
Food consumption score (FCS)		
Production diversity	0.460***	0.149
Production diversity squared	-0.012*	0.007
2.round	9.796	0.302

Note: *, **, *** Statistically significant at the 10%, 5%, and 1% level, respectively Data Source: IFPRI BIHS 2011-2015

Table 6 Fixed effects model results on association between farm production diversity and energy and nutrient consumption

Variables	Coef.	Robust Std. Err.
Per capita energy (kcal)		
Production diversity	23.88***	6.23
Production diversity squared	-0.61	0.34
2.round	-60.20***	13.28
Protein		
Production diversity	0.611***	0.193
Production diversity squared	-0.013	0.010
2.round	-0.281	0.420
Vitamin A		
Production diversity	-4.190	4.396
Production diversity squared	0.315*	0.178
2.round	98.406	11.185
Iron		
Production diversity	0.078*	0.043
Production diversity squared	-0.001	0.002
2.round	0.466***	0.097
ZINC		
Production diversity	0.082***	0.029
Production diversity squared	-0.002	0.001
2.round	-0.156**	0.064
Vitamin C		
Production diversity	0.903***	0.367
Production diversity squared	-0.006	0.018
2.round	17.608***	1.038

Note: *, **, *** Statistically significant at the 10%, 5%, and 1% level, respectively Data Source: IFPRI BIHS 2011-2015

Table 6 presents the results of the effect of agricultural diversification on dietary diversity and nutrient consumption. Results indicate a positive and significant association of agricultural diversification with dietary diversity and nutrient consumption. All the coefficients are statistically significant at less than one percent level. An increase in the agricultural diversification index (SI) by an additional unit increases the dietary diversity (SI) by 0.24, kilo calorie by 984, protein by 35, vitamin by 738, and zinc by 4 units, respectively. Overall, the results underscore the importance of agricultural diversification towards improving dietary diversity and better nutrient consumption.

4.1.5 Impact of agricultural commercialization on HH dietary diversity and nutrient consumption

Non-parametric analysis results on association between the agriculture commercialization index and crop commercialization index and HH dietary diversity are presented in figure 10. The relation between dietary diversity and agriculture commercialization is positive with tight confidence interval. This suggests that qualitatively, agricultural commercialization matters for dietary diversity. However, for robust quantitative evidence, the fixed effect model results on the link between agriculture commercialization index and crop commercialization index and HH dietary diversity, income and expenditure are shown in Table 7. Results reveal a positive association between agriculture commercialization index and HH dietary diversity and income. Furthermore, to investigate further about which dimension of agricultural commercialization more nutrition and welfare sensitive we examine the relation which are presented in Tables 8 and 9. Result shows that commercialization towards cash crops, livestock and fish are both nutrition and expenditure sensitive.

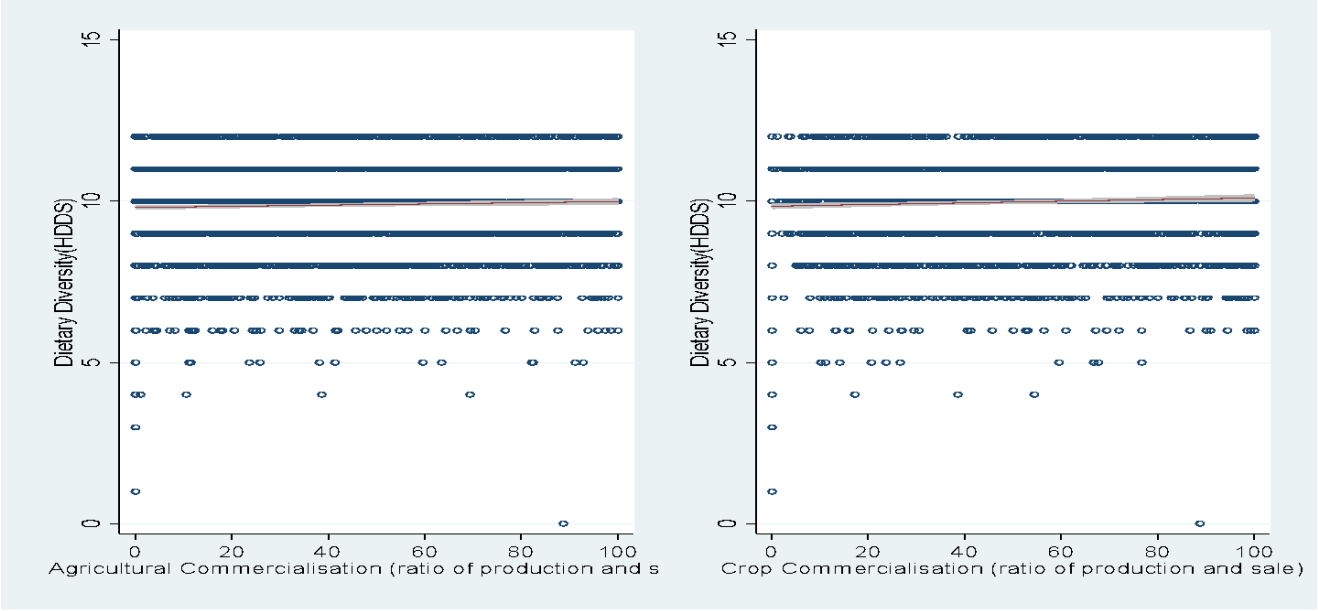

Figure 10: Association between agricultural and crop commercialization and dietary diversity

Table 7 Fixed effects model results on association between agricultural commercialization and dietary diversity, income and expenditure

HDDS-7days	Coef.	Robust Std. Err.
Agricultural Commercialization	0.0005*	0.0003
Agricultural Commercialization squared	0.0000	0.0000
2.round	0.0879***	0.0030
HDDS- 24h		
Agricultural Commercialization	0.0003	0.0003
Agricultural Commercialization squared	0.0000	0.0000
2.round	0.0603***	0.0033
Expenditure (per capita)		
Agricultural Commercialization	0.0001	0.0007
Agricultural Commercialization squared	0.0000	0.0000
2.round	0.0923***	0.0078
HH_Income		
Agricultural Commercialization	330.38**	145.21
Agricultural Commercialization squared	-0.40	1.54
2.round	27568.51***	1663.86

Note: *, **, *** Statistically significant at the 10%, 5%, and 1% level, respectively Data Source: IFPRI BIHS 2011-2015

Although qualitative evidence suggests the slight positive effect of agricultural commercialization on dietary diversity and nutrient consumption, robust empirical evidence needs to be sought. A relevancy test indicates the instrument to be statistically significant at less than 5% level. Also, under-identification, weak identification and over-identification tests suggest that the instruments are suitable, strong and valid for this model.

Table 8 Fixed effects model results on association between different dimensions of agricultural commercialization and HH dietary diversity

HH Dietary diversity score (HDDS)	Coef.	Robust Std. Err.
Commercialization towards Cereals	0.0008*	0.0005
Comm. To. Cash crops	0.0024***	0.0008
Comm. To. pulse crops	-0.0195	0.0128
Comm. To. fruit crops	-0.0024	0.0025
Comm. To. vegetable crops	0.0014	0.0015
Comm. To. Leafy Veg. crops	0.0422***	0.0081
Comm. To. fiber crops	-0.0099***	0.0015
Comm. To. oil crops	0.0010	0.0021
Comm. To. spice crops	-0.0011**	0.0005
Comm. To. Livestock	0.0013***	0.0005
Comm. To. Fish	0.0008*	0.0005
2.round	0.0608	0.0077

Note: *, **, *** Statistically significant at the 10%, 5%, and 1% level, respectively Data Source: IFPRI BIHS 2011-2015

Table 9 Fixed effects model results on association between different dimensions of Agricultural Commercialization and HHs total expenditure

Total Expenditure (per capita)	Coef.	Robust Std. Err.
Commercialization towards Cereals	0.002	0.001
Comm. To. Cash crops	0.003**	0.001
Comm. To. pulse crops	0.013	0.023
Comm. To. fruit crops	0.000	0.004
Comm. To. vegetable crops	0.004	0.004
Comm. To. Leafy Veg. crops	-0.001	0.023
Comm. To. fiber crops	-0.001	0.003
Comm. To. oil crops	0.008	0.009
Comm. To. spice crops	-0.005***	0.001
Comm. To. Livestock	0.002*	0.001
Comm. To. Fish	0.003**	0.001
2.round	0.057***	0.018

Note: *, **, *** Statistically significant at the 10%, 5%, and 1% level, respectively Data Source: IFPRI BIHS 2011-2015

4.1.6 Impact of agricultural diversification and commercialization on women and child dietary diversity and child nutrition status

Since HIES data sets do not have intra household level information, we conducted women and child level analysis with only the IFPRI BIHS panel data sets. Similarly, before conducting the econometric analysis, the status of women and child DD and child anthropometric information are assessed in figures 11 and 12. The results indicate that women and child dietary diversity over the two rounds are increasing (figure 11). Moreover, while child stunting is decreasing, underweight and wasting are slightly increasing (figure 12).

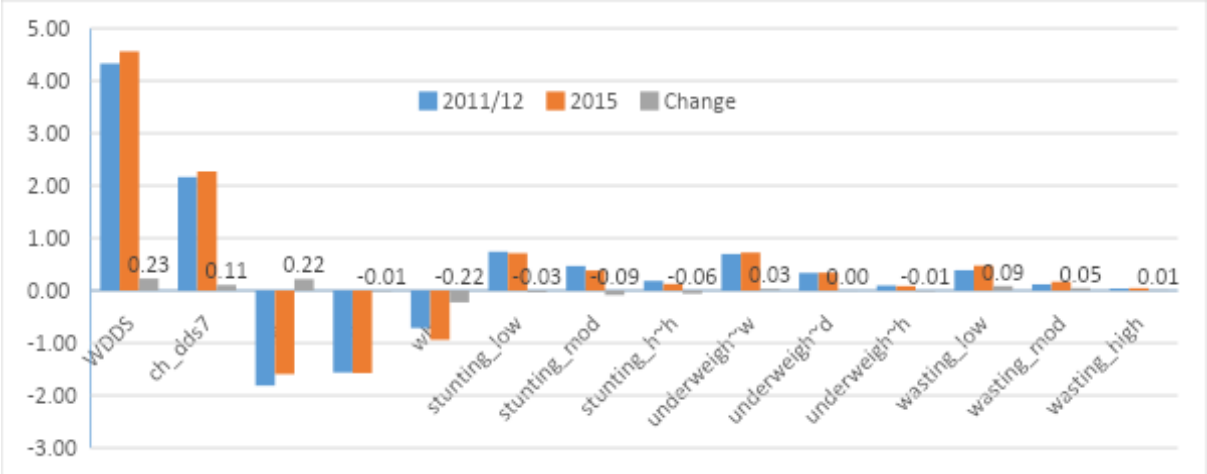

Figure 11: Women and child dietary diversity and child anthropometry, Data Source: IFPRI BIHS 2011-2015

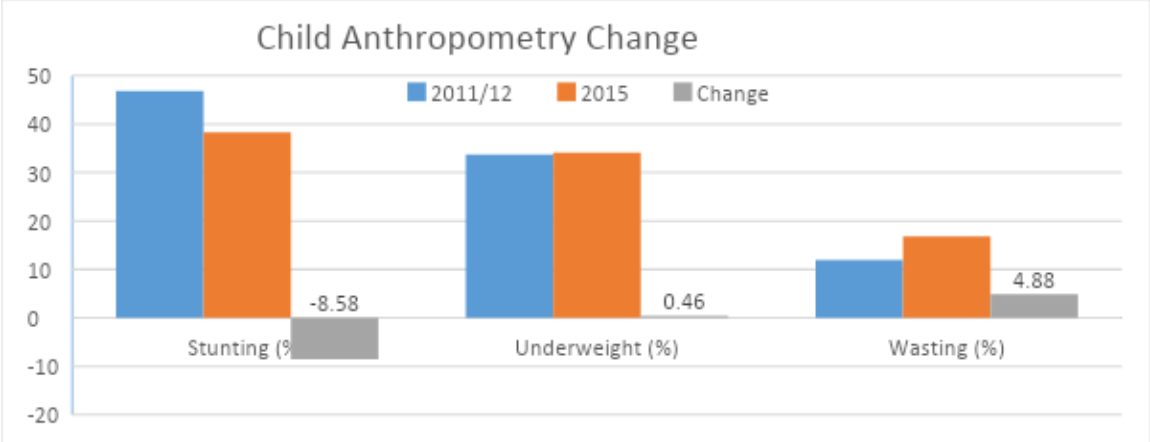

Figure 12: Under 5 child stunting, underweight and wasting status, Data Source: IFPRI BIHS 2011-2015

Table 10 Fixed effect model results on association between Agricultural diversification & Commercialization and Women dietary diversity

WDDS	**Coef.**	**Robust Std. Err.**
Production diversity	0.0015	0.0023
Production diversity squared	0.0001	0.0001
2.round	0.0533***	0.0050
WDDS		
Simpson index (SI)	0.231***	0.088
Simpson index (SI) squared	-0.388***	0.138
2.round	0.042***	0.007
WDDS		
Agricultural Commercialization	0.0005	0.0005

Agricultural Commercialization squared	0.0000	0.0000
2.round	0.0530***	0.0056
WDDS		
Crop Commercialization	0.0016***	0.0006
Crop Commercialization squared	-0.0000**	0.0000
2.round	0.0447***	0.0064

Note: *, **, *** Statistically significant at the 10%, 5%, and 1% level, respectively, Data Source: IFPRI BIHS 2011-2015

Table 11 Random effects (RE) Poisson/Probit model results on association between Agricultural diversification & Commercialization and Child dietary diversity & stunting

Child dietary diversity score (CDDS)	Coef.	Robust Std. Err.
Production diversity	0.007	0.013
Production diversity squared	0.000	0.001
2.round	0.047	0.041
CDDS		
Agricultural Commercialization	0.002	0.002
Agricultural Commercialization squared	0.000	0.000
2.round	0.061	0.043
CDDS		
Crop Commercialization	0.003	0.002
Crop Commercialization squared	0.000	0.000
2.round	0.085*	0.049
Stunting		
Production diversity	-0.059***	0.017
Production diversity squared	0.002**	0.001
2.round	-0.200***	0.047
Stunting		
Agricultural Commercialization	-0.007***	0.003
Agricultural Commercialization squared	0.000**	0.000
2.round	-0.278***	0.053
Stunting		
Crop Commercialization	-0.006**	0.003
Crop Commercialization squared	0.000	0.000
2.round	-0.300***	0.066

Note: *, **, *** Statistically significant at the 10%, 5%, and 1% level, respectively, Data Source: IFPRI BIHS 2011-2015

To examine the impact of agricultural diversification and commercialization on women and child dietary diversity and child nutrition, we conducted a quantitative econometric analysis using fixed effect and random effect Poisson and Probit models. Presented in Table 10 and 11, results reveal that Simpson index of agricultural diversification and crop commercialization is positively significantly associated with women dietary diversity (Table 10). In the case of child, the results show that both agricultural diversification and commercialization, including crop commercialization, reduce child stunting which is very much encouraging (Table 11).

4.2 Results from HIES BBS data set

4.2.1 Descriptive statistics

Table 12 defines the variables used in the empirical analysis of HIES data sets and present its descriptive statistics. The dependent variables are the indicators of HH food security outcomes such as dietary diversity (SI), FCS, and nutrient consumption (calories, protein, vitamin A and zinc). The average SI- HH dietary diversity in the sample was 0.73. It increased from 0.68 to 0.74 between 2010 and 2016. Although the SI-dietary diversity has increased over the survey period, the FCS, another indicator of HH dietary diversity, has decreased from 61.71 to 58.28 between 2010 and 2016. On average, the consumption of calorie and protein have decreased while consumption of micro-nutrient (zinc) and vitamins has increased between 2010 and 2016.

The explanatory variables of interest are agricultural diversification (measured by SI), and agricultural commercialization (crop commercialization, livestock commercialization and fisheries commercialization). Although the crop commercialization has declined (almost by 50%) over time, livestock and fisheries commercialization have increased between 2010 and 2016 with highest percentage point increase witnessed by fisheries (about 10%).

We controlled for the HH and agriculture characteristics expected to influence food security outcomes of the HH. The expenditure on renting agri-machinery has slightly increased between 2010 and 2016 although the difference is statistically insignificant. The expenditure on fertilizer has decreased while expenditure on irrigation use has increased between 2010 and 2016. HHs with between 0 and 1 hectare of land are classified marginal and smallholder farmers. A HH with greater than 1 hectare of land and less than 3.03 hectare of land is considered as medium farmer and a HH with greater than 3.03 hectare of land is classified as large farmer. About 70% of the HHs are either marginal or smallholder farmers; about 7% are medium farmer HHs and 12% are large farmer HHs. The proportion of subsistence farmer HHs have increased between 2010 and 2016. On an average, about 20% HHs are subsistence farmers and do not sell their own produce; about 3 HH members works as labour (age between 15 and 64 years). The average crop income has increased between 2010 and 2016 although income from aquaculture and forestry is stable

and the increase is not statistically significant. The average income (in thousand Taka) from crop (1.86) is highest followed by the aquaculture (0.27) and forestry (0.08).

On average, 68% of HH belongs to rural region while 32% HH are from urban region. About 8% of HH have bank account, 16% have refrigerator, 39% have television, 83% have mobile, and 6% have internet access at home. The HHs owning refrigerator, television, mobile and access to internet increased between 2010 and 2016. About 27% of the HH head works in urban areas. Majority of HH heads are male (87%) while only 13% of HH heads are female. The average age of a HH head is 45 years. The average family size is about four. The average HH dependency ratio (calculated as total HH members below age of 15 and 65, divided by the total family size) is 69%. The average number of out-migrants in a HH have increased between 2010 and 2016 and the increase is statistically significant at less than 5% level. Accordingly, the average amount of remittance received by a HH has increased between 2010 and 2016.

Table 12 Definition and description of the variables used in the econometric analysis

		2010		2016		All	
Variables	Definition	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Dependent variable							
SI-Dietary diversity	Dietary diversity-Simpson index	0.68	0.11	0.74	0.09	0.73	0.10
FCS	Food consumption scores	61.71	20.27	58.28	18.53	59.00	18.96
Calorie	Kcal of energy/per day per capita	2352.26	825.81	2201.91	1008.65	2233.54	974.97
Protein	gram of protein/per day per capita	58.49	25.18	56.57	30.97	56.97	29.85
Vitamin A	microgram of vitamin A/per day per capita	199.85	193.79	226.35	319.57	220.78	297.75
Zinc	microgram of zinc/per day per capita	4.02	4.20	4.09	4.46	4.08	4.41
Explanatory variable							
SI-Crop diversity	Simpson Index (Crop diversification index)	0.48	0.28	0.52	0.34	0.51	0.33
Crop commercialization	Agricultural commercialization Index (proportion of crops output sold	20.96	28.50	11.79	25.14	14.46	26.49

Livestock commercializatio n	Livestock commercialization index (proportion of livestock products sold)	21.12	29.69	25.13	32.44	23.29	31.27
		2010		2016		All	
Variables	Definition	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Fisheries commercializatio n	Fisheries commercialization index (proportion of aquaculture products sold)	20.43	35.33	30.47	39.12	27.06	38.17
Control variable							
Ag machinery rent expenditure	Expenditure on renting agri-machinery	0.74	2.00	0.75	2.34	0.75	2.27
Expenditure on Fertilizer	Annual expenditure on fertilizer purchase	1.40	4.46	1.24	5.95	1.28	5.67
Expenditure on irrigation use	Annual expenditure on irrigation use	2.87	3.90	3.08	4.33	3.02	4.23
Cultivated area	Area cultivated (in hectare)	25.45	52.16	0.27	2.00	5.55	26.06
Medium HH!	If a HH has medium farm size, then 1, otherwise 0	0.23	0.42	0.03	0.18	0.07	0.26
Marginal or Small HH!	If a HH has marginal or small farm size, then 1, otherwise 0	0.14	0.35	0.85	0.35	0.70	0.46
Large HH!	If a HH has large farm size, then 1, otherwise 0	0.56	0.50	0.01	0.08	0.12	0.33
Subsistence HH!	If a HH do not sells its agriculture produce, then 1,otherwise 0	0.14	0.34	0.21	0.41	0.20	0.40
		2010		2016		All	
Variables	Definition	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
HH labour	HH labour (proxy)	2.75	1.34	2.55	1.15	2.59	1.20
Crop income	Monthly income from crops('000 taka)	1.38	4.37	1.99	42.22	1.86	37.58
Aquaculture income	Monthly income from aquaculture ('000 taka)	0.28	2.61	0.27	5.24	0.27	4.81
Forest income	Monthly income from forest ('000 taka)	0.07	0.43	0.08	1.06	0.08	0.96
Rural!	If a HH belongs to rural areas, then 1, otherwise 0	0.64	0.48	0.70	0.46	0.68	0.46
Refrigerator!	If a HH owns refrigerator, then 1,otherwise 0	0.12	0.33	0.17	0.38	0.16	0.37
Television!	If a HH owns television, then 1,otherwise 0	0.38	0.48	0.39	0.49	0.39	0.49

Mobile!	If a HH owns mobile, then 1,otherwise 0	0.64	0.48	0.89	0.32	0.83	0.37
Internet!	If a HH has access to internet, then 1, otherwise 0	0.01	0.11	0.07	0.26	0.06	0.24
Work in urban!	If a HH head works in urban areas, then 1, otherwise 0	0.30	0.46	0.26	0.44	0.27	0.44

		2010		2016		All	
Variables	Definition	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Male headed!	If a HH head is male, then 1, otherwise 0	0.86	0.35	0.87	0.33	0.87	0.34
Age of HH head	Age of HH head	46.01	13.88	44.78	14.04	45.04	14.01
HH Size	HH size	4.54	1.89	4.04	1.56	4.15	1.65
Dependency ratio	HH dependency ratio	77.06	69.15	66.73	61.18	68.90	63.08
Out migrants	Number of HH members who were abroad for more than 5 years	0.02	0.15	1.22	0.72	0.97	0.81
Remittances	Monthly remittance ('000 taka)	0.85	3.83	1.32	7.77	1.22	7.12

Notes: Indicates dummy variable; the average for dummy variable is expressed in terms of the percentage; 12240 HHs were surveyed in 2010, 46075 HHs were surveyed in 2016.

4.2.2 Income, total expenditure, food expenditure and dietary diversity patterns

The status and extent of household DD using HIES data sets are discussed under different settings by: agro-ecological zones; urban vs. rural: farm size; subsistence vs. commercial farming. Table 13 shows the status of food expenditure pattern and DD in Bangladesh. Although FSC and HH dietary diversity scores remain more or less stable, the SI increased between 2000 and 2016, suggesting an improvement in DD and food security in Bangladesh. Among twelve food groups, on average, cereals contributed to the highest share of food expenditure at overall 41%, followed by fish/seafood (18%), vegetables (8.73%), and meat and poultry (8.39%). The expenditure share on cereals reduced by about 15 percentage points while the expenditure share on fish/seafood increased by about 6 percentage points.

Table 13 Food expenditure pattern and dietary diversity in Bangladesh, 2000–2016

	2000	2005	2010	2016	Overall
HH dietary diversity scores	8.17	8.22	8.52	8.71	8.48
Food consumption scores	61.02	61.49	61.21	60.36	59.65
Dietary diversity (Simpson Index)	0.66	0.66	0.68	0.74	0.71
Share of different commodities in food expenditure (%)					

Cereals	50.23	50.20	47.69	35.20	41.01
Pulses	3.46	3.05	3.06	3.55	3.39
Fruits	3.01	3.26	4.01	3.98	3.66
Eggs	1.63	1.36	1.90	2.76	2.36
Fish/seafood	14.03	13.84	15.80	20.74	18.11
Oil	4.68	5.40	5.69	6.09	5.96
Roots/tubers	3.72	3.27	3.34	3.50	3.49
Vegetables	8.21	7.27	6.92	9.43	8.73
Milk and its products	3.15	3.09	2.95	2.81	2.85
Meat and poultry	5.79	7.14	6.50	9.84	8.39
Sugar/honey	2.03	2.09	2.00	1.95	1.95
Miscellaneous items	0.06	0.05	0.14	0.15	0.11

Source: Author's work based on HIES datasets. Values are weighted estimates

Figure 13 shows the kernel density plots of the SI-dietary diversity, fish expenditure, meat expenditure, and cereal expenditure across the surveyed years (2000, 2005, 2010 and 2016). The figure shows that the distribution of the expenditure share on meat, fish/seafood and SI-dietary diversity shifted to the right while the distribution of the cereals (staple foods) shifted to the left during the 2000-2016 period suggesting an improvement in DD. Further results from Table 13 shows increase in the expenditure share of fruits, eggs, pulses and vegetables indicating the increased consumption of high-value food products in Bangladesh.

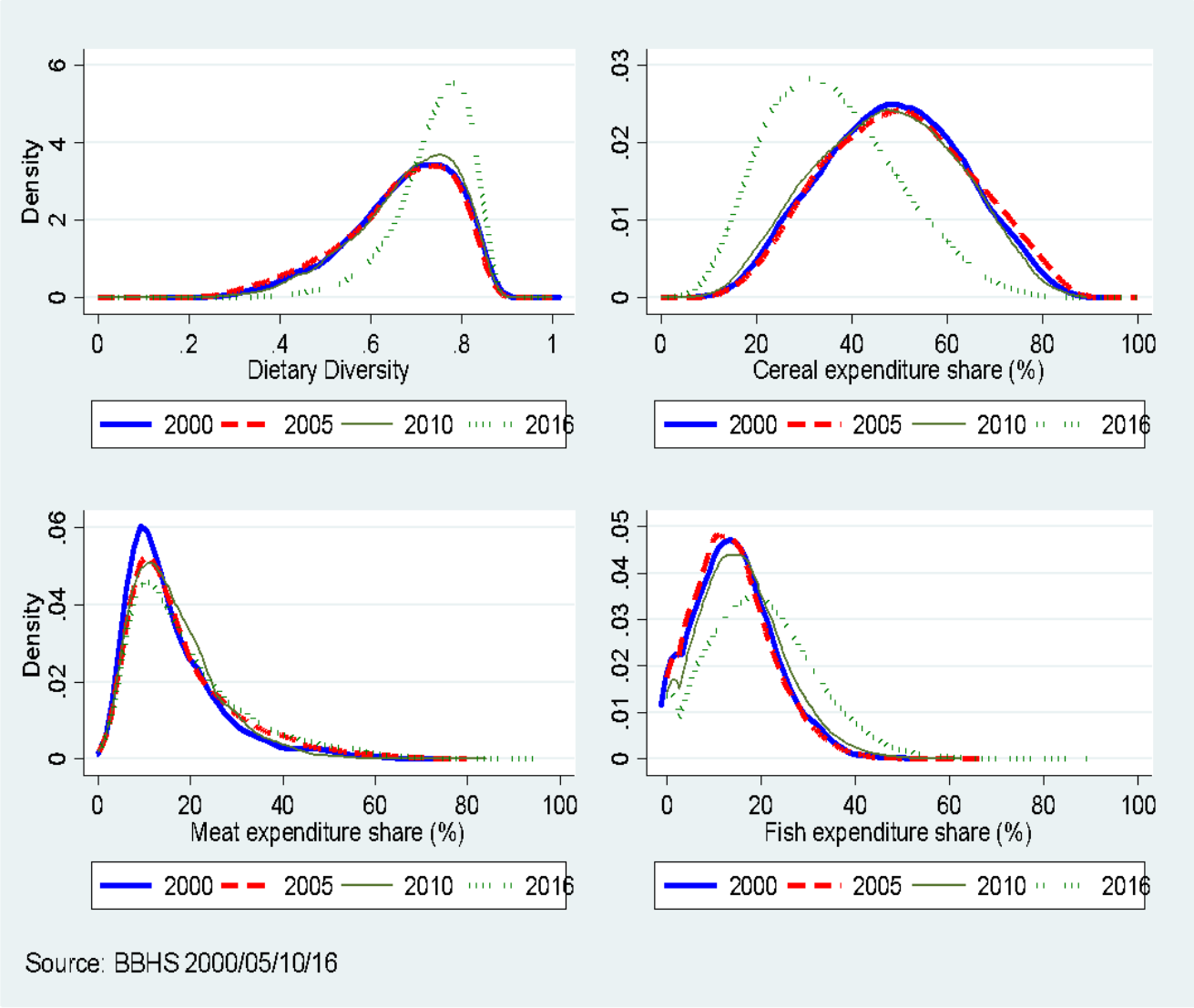

Figure 13: Status of dietary diversity and food expenditure share from 2000 to 2016 in Bangladesh. Source: Author's work based on HIES datasets.

Table 14 presents the status of DD and food expenditure share patterns by rural and urban HHs in Bangladesh. The SI is higher in urban areas compare to rural ones, which indicates a better HH dietary diversity of the urban HHs. Among rural HHs, the expenditure's share is higher for cereals and lower for fruits and meats, fish and seafood compared to urban HHs. Overall, this indicates the lower quality of the rural HHs' diet. Moreover, Figure A1 shows the distribution of SI for rural and urban HHs. The average SI is higher and the distribution of SI has a lower variability for urban HHs than for rural HHs.

Table 15 presents the status of DD and food expenditure by the farming status and types of farm for those who are involved in farming in 2000 and 2016. Clearly, the large farm and non-farmers have better HH dietary diversity. In 2016, the FSC is highest for the large farms and lowest for the marginal farms, indicating a positive relationship with farm size. Irrespective of farm size, the expenditure shares of cereals decreased while the share of fruits, vegetables and meat increased between 2000 and 2016.

Table 14 Status of dietary diversity and food expenditure pattern, rural and urban, Bangladesh, 2000-2016

	Rural					Urban				
	2000	2005	2010	2016	Overall	2000	2005	2010	2016	Overall
HH dietary diversity scores	7.90	8.02	8.24	8.48	8.24	9.18	8.70	9.27	9.29	8.97
Food consumption scores	58.46	58.35	58.06	58.31	57.23	70.72	68.96	69.82	65.61	64.64
Dietary diversity (Simpson Index)	0.64	0.63	0.66	0.73	0.70	0.74	0.72	0.74	0.77	0.74
Share of different commodities in food expenditure (%)										
Cereals	52.87	53.31	51.13	37.20	43.15	40.22	42.78	38.30	30.09	36.60
Pulses	3.26	2.68	2.77	3.53	3.24	4.22	3.93	3.88	3.59	3.70
Fruits	2.66	3.03	3.58	3.51	3.34	4.34	3.78	5.18	5.18	4.33
Eggs	1.40	1.15	1.60	2.61	2.17	2.50	1.86	2.72	3.13	2.74
Fish/seafood	13.51	12.86	14.78	20.21	17.64	16.00	16.17	18.59	22.08	19.06
Oil	4.57	5.11	5.58	6.19	5.89	5.09	6.10	6.00	5.84	6.10
Roots/tubers	3.76	3.25	3.49	3.70	3.64	3.58	3.33	2.95	2.97	3.19
Vegetables	8.26	7.19	6.96	9.36	8.87	8.02	7.45	6.80	9.61	8.45
Milk and its products	2.89	2.87	2.74	2.72	2.60	4.12	3.59	3.52	3.05	3.37
Meat and poultry	4.89	6.46	5.36	9.00	7.57	9.23	8.74	9.61	11.99	10.07
Sugar/honey	1.87	2.04	1.89	1.84	1.80	2.60	2.23	2.29	2.25	2.27
Miscellaneous items	0.05	0.04	0.14	0.12	0.09	0.09	0.05	0.16	0.23	0.14

Source: Author's work based on HIES datasets. Values are weighted estimates

Table 15 Status of dietary diversity and food expenditure pattern, farmer types, Bangladesh, 2000 and 2016

	2000				2016			
	Non-farmers	Marginal HH	Small & Medium HH	Large HH	Non-farmers	Marginal HH	Small & Medium HH	Large HH
HH dietary diversity scores	8.16	8.06	8.72	8.15	8.40	8.75	8.82	8.76
Food consumption scores	60.96	59.88	66.51	61.93	56.43	60.73	63.67	64.15
Dietary diversity (Simpson Index)	0.68	0.65	0.67	0.64	0.74	0.74	0.74	0.76
Share of different commodities in food expenditure (%)								
Cereals	48.61	52.58	50.27	52.85	35.53	35.20	34.84	31.36
Pulses	3.78	3.09	2.99	2.90	3.72	3.54	3.10	4.03
Fruits	3.17	2.82	3.12	2.01	3.47	4.04	3.89	4.35
Eggs	1.82	1.41	1.42	1.36	2.88	2.74	2.62	3.37
Fish/seafood	14.53	13.38	13.86	12.77	20.39	20.75	21.61	22.32
Oil	4.96	4.39	4.25	3.98	6.43	6.07	5.71	5.80
Roots/tubers	3.84	3.67	3.54	2.58	3.81	3.47	3.11	3.17
Vegetables	8.47	8.11	7.10	7.09	10.07	9.38	8.67	9.02
Milk and its products	2.93	3.20	4.22	4.11	2.29	2.85	3.44	3.94
Meat and poultry	5.89	5.28	6.65	8.24	9.55	9.84	10.97	10.59
Sugar/honey	1.97	2.01	2.51	2.05	1.74	1.98	1.99	1.97
Miscellaneous items	0.06	0.06	0.06	0.05	0.14	0.15	0.07	0.09

Source: Author's work based on HIES datasets. Values are weighted estimates

Further, Figure A2 indicates that farmers have high SI variability and low average SI in comparison to non-farmers indicating the better diet quality among non-farmers. This is due to non-farmers obtaining a higher income from off-farm compared to farmers, especially of marginal and smallholders which is translated into better food security outcomes.

Table 16 presents the status of DD and food expenditure by the subsistence versus commercial HHs. Clearly, the commercial HHs have better dietary diversity in comparison to subsistence HHs. While the expenditure share of cereals is higher for subsistence HHs, the share is lower for commercial HHs indicating the higher share of food expenditure towards non-cereals and better diet quality for the commercial HHs. This underscores the importance of markets and need to promote the commercial agriculture farming to improve the welfare of the farmers.

Table 17 presents the status of DD and food expenditure by agro-ecological zones. The best performing agro-ecological zones in terms of dietary diversity are Middle Meghna River Floodplain and Chittagong Coastal Plain and St. Martin's Coral Island. The worst performing agro-ecological zone in terms of dietary diversity are Old Himalayan Piedmont Plain and Tista Floodplain. HHs from Greater Dhaka have the lowest cereal expenditure share and the highest non-cereal expenditure (such as pulses, fruits, fish/seafood, meat etc) indicating their better diet quality. Overall, the distribution of the dietary diversity scores and the expenditure share shows which agro-ecological zone deserves more attention to improve the dietary diversity and food security outcomes.

Table 16 Status of dietary diversity and food expenditure pattern based on subsistence and commercial farming HHs, Bangladesh, 2000-2016

	Subsistence HHs					Commercial HHs				
Indicators	2000	2005	2010	2016	Overall	2000	2005	2010	2016	Overall
HH dietary diversity scores	8.00	8.22	8.42	8.38	8.34	8.16	8.18	8.53	8.85	8.48
Food consumption scores	60.73	60.79	60.10	57.19	57.67	60.33	58.82	61.05	61.80	60.34
Dietary diversity (Simpson Index)	0.66	0.66	0.67	0.72	0.71	0.65	0.63	0.66	0.75	0.69
Share of different commodities in food expenditure (%)										
Cereals	50.68	50.58	48.77	39.16	42.18	52.63	53.59	50.59	35.18	46.05
Pulses	3.45	3.09	2.90	3.13	3.06	3.06	2.46	2.65	3.65	3.04
Fruits	2.94	3.34	4.06	3.04	3.20	2.78	3.09	3.72	5.44	3.99
Eggs	1.41	1.35	1.60	2.48	2.22	1.46	1.22	1.70	2.90	2.01
Fish/seafood	14.43	14.17	15.93	19.18	17.85	13.13	12.14	14.31	19.08	15.28
Oil	4.39	5.35	5.63	5.95	5.81	4.39	4.95	5.33	6.27	5.51
Roots/tubers	3.69	3.26	3.45	3.63	3.55	3.59	3.20	3.25	3.66	3.44
Vegetables	8.26	7.04	7.06	9.34	9.07	7.93	6.93	6.77	8.72	7.83
Milk and its products	3.00	2.63	2.50	2.62	2.50	3.45	3.34	3.44	3.92	3.52
Meat and poultry	5.91	6.90	6.03	9.71	8.67	5.44	6.92	6.05	8.94	7.18
Sugar/honey	1.79	2.24	1.92	1.69	1.79	2.09	2.12	2.09	2.13	2.08
Miscellaneous items	0.05	0.06	0.18	0.08	0.09	0.06	0.05	0.13	0.10	0.09

Source: Author's work based on HIES datasets. Values are weighted estimates

Table 17 Status of dietary diversity and food expenditure pattern based on agro-ecological zones, Bangladesh, 2016

	Brahmaputra-Jamuna Floodplain	Chittagong Coastal Plain & St. Martin's Coral Island	Eastern Hills	Ganges Tidal Floodplain	Grater Dhaka	High Ganges River Floodplain	Karatoya Floodplain And Atrai Basin	Low Ganges River Floodplain	Lower Meghna River and Estuarine Floodplain	Middle Meghna River Floodplain	Old Himalayan Piedmont Plain and Tista Floodplain	Sylhet Basin and Surma-Kusiyara Floodplain
HH dietary diversity scores	8.20	9.31	8.14	8.13	9.22	8.24	7.93	8.32	9.18	9.06	7.63	8.29
Food consumption scores	60.77	73.61	62.68	56.71	71.0	54.57	50.09	60.20	69.09	73.60	47.42	65.69
Dietary diversity (Simpson Index)	0.67	0.73	0.70	0.69	0.76	0.66	0.65	0.69	0.74	0.75	0.62	0.70
Share of different commodities in food expenditure (%)												
Cereals	48.44	38.89	44.94	44.59	35.61	49.94	50.72	45.49	37.37	37.26	54.71	43.50
Pulses	3.28	3.07	2.87	3.36	4.30	2.98	2.60	4.16	4.25	3.95	1.88	3.18
Fruits	2.84	4.73	4.18	3.13	4.96	3.05	3.33	3.35	5.62	4.62	2.25	3.31
Eggs	1.77	2.02	1.32	2.07	2.69	2.06	1.80	2.23	1.80	1.83	1.68	1.45
Fish/seafood	16.98	20.85	18.70	18.70	19.49	12.38	11.64	16.57	20.36	20.30	10.09	20.96
Oil	4.60	5.04	4.84	5.94	5.80	6.02	6.08	6.43	5.13	5.83	5.19	5.10
Roots/tubers	2.99	3.44	3.05	3.16	2.82	3.15	4.27	2.76	3.23	3.10	5.15	3.71
Vegetables	7.23	8.36	11.27	8.04	8.15	8.69	7.03	7.96	8.20	9.44	7.54	7.75
Milk and its products	3.44	2.86	1.75	2.29	3.85	2.73	2.44	3.60	2.60	4.03	2.25	2.73
Meat and poultry	6.64	7.81	5.48	6.81	10.00	7.10	8.01	5.48	8.42	7.23	7.66	5.76
Sugar/honey	1.71	2.71	1.48	1.87	2.18	1.84	1.96	1.94	2.62	2.32	1.56	2.48

Miscellaneous items	0.07	0.22	0.11	0.04	0.16	0.07	0.11	0.04	0.41	0.09	0.05	0.08

Source: Author's work based on HIES 2016 dataset. Values are weighted estimates

4.2.3 Agricultural diversification and commercialization trend

Using HIES data sets, the status of agricultural diversification and commercialization in Bangladesh are shown in Table 18. The SI, a measure of crop diversity, increased across the surveyed years (2005-2016) indicating the increasing crop diversification over the reference period. While fisheries and livestock commercialization indices increased, the crop commercialization index declined over time. The results show that the aquaculture farmers are producing and selling market-oriented aquaculture products. The reason for the decline of the crop commercialization index needs to be further investigated. The production shares of staple crops, cash crops, pulses, and high value crops increased over the time period. For example, in survey year 2016, staple crops especially cereals dominate the production (55.06%) followed by the livestock (22.41%) and high value crops (16.34%).

Table 18 Status of agricultural diversification and commercialization, Bangladesh, 2005-2016

	2005	2010	2016
Crop diversity (Simpson index-SI)	0.43	0.48	0.52
Agriculture commercialization (fisheries)	17.16	19.75	32.76
Agriculture commercialization (livestock)	30.46	21.55	26.06
Agriculture commercialization (crops)	32.83	22.49	10.91
Production share of agricultural commodities (%)			
Staple crops	47.61	42.53	55.06
Cash crops	3.79	4.35	4.92
Pulses	0.70	1.11	1.78
Vegetables	4.46	10.01	9.64
High value crops	8.95	15.46	16.34
Livestock (animal products)	35.69	37.21	22.41
Aquaculture (aquaculture products)	7.74	4.80	6.19

Source: Author's work based on HIES dataset. Values are weighted estimates

Table 19 presents the status of agricultural diversification and commercialization based on the area (rural versus urban). The measure of crop diversity i.e. SI is higher in urban areas compared to rural ones indicating the higher diversity of crop production in urban areas. Moreover, the SI is increasing across the time period, indicating the increase crop diversity in both the rural and urban areas. Although the fisheries commercialization index is higher in urban areas, both the livestock commercialization index and crop commercialization index is higher in rural areas. The

reasons behind the decreasing crop commercialization index both in the rural and urban areas needs to be further investigated. Except the production share of livestock and aquaculture products, the production shares of staple crops, cash crops, pulses, vegetables, and high value crops are higher in rural areas compared to urban ones.

Table 19 Status of agricultural diversification and commercialization based on rural and urban areas, Bangladesh, 2005- 2016

	Rural				Urban			
	2005	2010	2016	Overall	2005	2010	2016	Overall
Crop diversity (Simpson index)	0.44	0.48	0.51	0.49	0.43	0.52	0.58	0.52
Agriculture commercialization (fisheries)	16.95	18.65	30.96	24.54	18.65	32.44	46.41	26.59
Agriculture commercialization (livestock)	30.76	21.89	26.03	30.53	28.67	18.54	26.28	24.90
Agriculture commercialization (crops)	33.16	23.61	11.36	20.15	30.85	12.61		17.57
Production share of agricultural commodities (%)	6	1	1		5	4	7.00	
Staple crops	50.08	44.42	56.17	53.10	32.89	25.92	44.33	36.02
Cash crops	3.93	4.60	5.04	5.08	2.98	2.11	3.78	3.71
Pulses	0.76	1.16	1.82	1.58	0.32	0.62	1.38	1.09
Vegetables	4.22	10.13	9.63	9.39	5.92	8.98	9.77	8.62
High value crops	8.91	15.89	16.41	16.04	9.22	11.71	14.93	13.42
Livestock (animal products)	33.54	35.05	21.69	25.31	48.51	56.19	29.89	42.73
Aquaculture (aquaculture products)	7.47	4.63	5.71	5.55	9.37	6.23	10.83	7.82

Source: Author's work based on HIES dataset. Values are weighted estimates

Table 20 shows the status of agricultural diversification and commercialization based on the agro-ecological zones in Bangladesh in 2016. The three agro-ecological zones with the lowest SI are Sylhet Basin and Surma-Kusiyara, Floodplain Eastern Hills and Middle Meghna River Floodplain. Similarly, the three agro-ecological zones with the highest SI are Ganges Tidal Floodplain, Grater Dhaka, and Chittagong Coastal Plain & St. Martin's Coral Island. The top three agroecological zones in fisheries commercialization are Grater Dhaka, Eastern Hills and Ganges Tidal Floodplain while the lowest are Sylhet Basin and Surma-Kusiyara Floodplain, Old Himalayan Piedmont Plain and Tista Floodplain, and Karatoya Floodplain and Atrai Basin.The three agroecological zones with the lowest crop commercialization index are Lower Meghna River and Estuarine Floodplain, Ganges Tidal Floodplain Sylhet Basin and Surma-Kusiyara

Floodplain. Similarly, the Table 20 shows the agroecological zones with the highest and lowest production share of specific agricultural commodities which will help the policy makers to formulate and implement the policies to promote the specific commodities of comparative advantage

Table 20 Status of agricultural diversification and commercialization based on the agro-ecological zones, Bangladesh, 2016

	Crop diversity (Simpson index)	Agriculture commercialization (fisheries)	Agriculture commercialization (livestock)	Agriculture commercialization (crops)	Production share of staple crops (%)	Production share of cash crops (%)	Production share of pulse crops (%)	Production share of vegetable (%)	Production share of high value crops (%)	Production share of animal protein (%)	Production share of fish (%)
Brahmaputra-Jamuna Floodplain	0.48	26.66	30.07	10.70	67.94	2.44	0.39	4.40	7.23	18.27	6.57
Chittagong Coastal Plain & St. Martin's Coral Island	0.60	27.96	27.07	10.31	41.95	0.01	0.00	23.42	23.43	24.94	9.68
Eastern Hills	0.42	45.42	46.49	16.44	58.97	1.29	0.09	28.88	30.26	9.98	0.79
Ganges Tidal Floodplain	0.55	41.24	25.97	5.93	36.40	2.34	2.12	8.11	12.57	28.27	22.76
Grater Dhaka	0.59	78.58	25.75	15.91	36.14	4.41	1.05	14.58	20.04	37.21	6.61
High Ganges River Floodplain	0.53	26.24	26.50	14.00	47.52	12.78	4.84	14.63	32.25	17.83	2.40
Karatoya Floodplain And Atrai Basin	0.54	24.35	30.75	13.47	58.77	4.09	3.38	13.00	20.46	18.20	2.57
Low Ganges River Floodplain	0.54	38.14	24.38	12.97	34.97	22.40	4.63	10.62	37.64	23.34	4.05
Lower Meghna River and Estuarine Floodplain	0.53	30.99	15.09	5.09	47.35	3.59	2.72	3.06	9.37	35.86	7.42
Middle Meghna River Floodplain	0.46	33.95	32.30	6.82	68.43	1.87	0.04	3.62	5.53	23.79	2.24
Old Himalayan Piedmont Plain and Tista Floodplain	0.54	20.28	22.42	12.09	67.44	2.21	0.26	7.12	9.57	21.10	1.89
Sylhet Basin and Surma-Kusiyara Floodplain	0.38	14.86	17.45	6.67	61.24	0.06	0.00	10.73	10.79	20.59	7.38

Source: Author's work based on HIES dataset. Values are weighted estimates

Table 21 Status of agricultural diversification based on the subsistence and commercial farming HHs, Bangladesh, 2005- 2016

	Subsistence HHs			Commercial HHs		
	2005	2010	2016	2005	2010	2016
Crop diversity (Simpson index)	0.31	0.34	0.37	0.46	0.54	0.70
Production share of agricultural commodities (%)						
Staple crops	35.15	48.54	73.33	51.34	40.76	32.13
Cash crops	0.37	3.00	6.40	4.82	4.75	3.07
Pulses	0.29	0.56	2.28	0.82	1.27	1.14
Vegetables	3.60	14.12	10.49	4.72	8.80	8.59
High value crops	4.26	17.68	19.17	10.36	14.81	12.79
Livestock (animal products)	50.61	28.76	4.12	31.23	39.71	45.37
Aquaculture (aquaculture products)	9.99	5.02	3.39	7.07	4.73	9.71

Source: Author's work based on HIES dataset. Values are weighted estimates

Table 21 presents the status of agricultural diversification based on the subsistence and commercial farming HHs in Bangladesh. The crop diversity-SI is higher for commercial farming HHs in comparison to the subsistence farming HHs indicating that the former tend to cultivate diverse crops. Subsistence farming HHs on the other hand, mainly rely on producing staple crops with production share of about 73.33% in 2016 compared to just 32.13% for the commercial farming HHs. The commercial farming HHs produced higher shares of livestock and aquaculture products.

4.2.4 Determinants of agricultural commercialization

Table 22 presents the results of the determinants of agricultural commercialization with the accounting of the district fixed effects. Under agricultural commercialization, we separately assessed the determinants of crop commercialization (first column), livestock commercialization (second column) and fisheries commercialization (third column). These results are derived from predicting the equation (4), i.e. first stage of the 2SLS regression. All the models are statistically significant with crop commercialization model explaining 27% of the variation, livestock commercialization model explaining 9% of variation and fisheries commercialization model explaining 34% of the variation.

First, we discuss the results on the determinants of crop commercialization (proxy by the percent of crop produce sold in the market) (Table 22). Higher expenditure on renting agri-machinery and fertilizer purchase are positively correlated with crop commercialization index. HHs owning

refrigerator and mobile have higher crop commercialization index in comparison to HHs without refrigerator and mobile. Further HHs with higher number of out-migrants and cultivating more agricultural land have higher commercialization index. All these variables are statistically significant at 10% or less.

HHs renting agriculture land or engaged in share-cropping have lower crop commercialization index (about 0.02%) in comparison to HHs cultivating their own land (Table 22). A HH with access to internet have lower crop commercialization index. A HH head working in urban areas tends to have lower crop commercialization index (3% lower) in comparison to HH head working in rural areas. The older aged HH head has lower crop commercialization index in comparison to the young aged HH head. HH size is negatively correlated with the crop commercialization index

Second, we discuss the results on the determinants of livestock commercialization (proxy by the percent of animal products sold in the market) (Table 22). HHs renting agriculture land or engaged in share-cropping have higher livestock commercialization index (about 0.02%) in comparison to HHs cultivating their own land. A HH producing more number of livestock products will have higher livestock commercialization index. With respect to HHs farm size, HHs with medium, small and marginal farm size have higher livestock commercialization index. Increase in purchase of livestock feed is positively correlated with the livestock commercialization index. HHs owning refrigerator, mobile and with access to internet have lower livestock commercialization index. An increase in cultivated area is negatively correlated with the livestock commercialization index.

Third, we discuss the results on the determinants of fisheries commercialization (proxy by the percent of aquaculture products sold in the market). Urban HHs have higher fisheries commercialization index in comparison to rural HHs. This suggests that the rural HHs raise fish mainly for their own family consumption. Increase in number of fish cultured is positively associated with the fisheries commercialization index. The HH with marginal and small farm size have lower fisheries commercialization index in comparison to HH with larger farm size.

Market oriented aquaculture production usually requires the bigger pond size. The older aged HH head has lower crop commercialization index in comparison to the HH head who is young.

Table 22 Determinants of Agricultural Commercialization in Bangladesh

Variables	Crops	Livestock	Fisheries
Total cultivable agricultural land rented/ share-cropped/mortgaged in: (Acres)	-0.0227***	0.0138**	0.0130
	(0.0073)	(0.0064)	(0.0105)
Expenditure on renting agri-machinery	0.3827***		
	(0.1306)		
Annual expenditure on fertilizer purchase	0.2313***		
	(0.0623)		
Annual expenditure on irrigation use	0.0814		
	(0.0985)		
If a HH belongs to rural areas, then 1, otherwise 0	1.0278	1.1842	-4.6033*
	(1.0613)	(1.1483)	(2.4322)
If a HH has opened a bank account, then 1, otherwise 0	0.3378	-0.3000	-0.9678
	(1.0899)	(1.2886)	(2.5632)
If a HH owns refrigerator, then 1,otherwise 0	2.0954*	-3.3267**	-1.7939
	(1.2300)	(1.3883)	(2.7718)
If a HH owns television, then 1,otherwise 0	0.3772	-2.2165***	1.3896
	(0.7124)	(0.7860)	(1.7609)
If a HH owns mobile, then 1,otherwise 0	1.4569*	-2.9808***	-2.3990
	(0.8608)	(0.8223)	(1.9131)
If a HH has access to internet, then 1, otherwise 0	-3.1237**	-1.3411	0.1125
	(1.3708)	(2.0733)	(3.2020)
If a HH head works in urban areas, then 1, otherwise 0	-3.3287***	-1.3738	-1.1779
	(1.0931)	(1.0935)	(2.4076)
If a HH head is male, then 1, otherwise 0	2.0725	-1.4013	-2.5378
	(1.4173)	(1.2004)	(2.7257)
Age of HH head	-0.0374*	0.0276	-0.0935*
	(0.0225)	(0.0250)	(0.0508)
HH dependency ratio	0.0076	-0.0031	-0.0071
	(0.0107)	(0.0110)	(0.0252)
HH size	-1.0350**	-0.2095	0.9138
	(0.4690)	(0.4938)	(1.2002)
Number of HH members who were abroad for more than 5 years	1.0887**	0.0200	2.7055*
	(0.5165)	(0.7352)	(1.4427)
Monthly remittance (taka)	0.0957	-0.0781	-0.0543
	(0.0746)	(0.0672)	(0.1084)
Cultivated area (hectare)	0.1174***	-0.0327***	0.0177
	(0.0137)	(0.0070)	(0.0158)
Medium farm size (>1 ha & <= 3 ha)	-3.3101	3.1225**	-2.3243
	(2.9403)	(1.2583)	(2.5596)

Marginal and small farm size (>0 ha & <=1 ha)	-4.3268	4.9754***	-9.3113***
	(2.7189)	(1.5229)	(3.3420)
HH labour (proxy)	-0.0886	-0.6376	-0.7820
	(0.6915)	(0.7436)	(1.6409)
If year is 2016, then 1, otherwise 0	-10.9429***	1.0524	22.3444***
	(2.9335)	(1.7980)	(4.2263)
Survey conducted season (Kharif)	-7.4200***	-0.9494	-2.8203
	(0.7219)	(0.7993)	(1.9620)
Survey conducted season (Rabi)	-13.2713***	-1.7401*	2.8900
	(0.7233)	(1.0569)	(2.3864)
Annual expenditure on purchase of livestock feed		0.0002***	
		(0.0001)	
Animal product diversification		6.1727***	
		(0.4528)	
Fish diversification (number of fish cultured)			10.4597***
			(2.3934)
Constant	23.9156***	26.2039***	63.5472***
	(4.3928)	(3.6041)	(6.7950)
District fixed effects	YES	YES	YES
Observations	12,952	12,417	2,994
R-squared	0.2703	0.0948	0.3389

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1, Data Source: HIES 2000-2016

4.2.5 Determinants of agricultural diversification (Simpson Index)

Table 23 illustrates the factors influencing agricultural diversification (SI) in Bangladesh. The model is statistically significant explaining 24% of the variation of SI. The agriculture diversification increased between 2011 and 2016 in Bangladesh. A HH from a community with a higher number of crops raised will have higher agricultural diversification. HH with mobile and access to internet have higher agricultural diversification. A HH head working in urban areas have higher agricultural diversification. HH with higher income have higher agricultural diversification.

HHs from rural areas have lower agricultural diversification in comparison to urban HHs (Table 23). A HH with higher number of out-migrants have lower agricultural diversification. A male headed HH have lower agricultural diversification in comparison to female headed HH. An increase in cultivated area is negatively correlated with agricultural diversification indicating that a HH with small farm size cultivate diverse crops in comparison to the HH with large farm size. This is further supported by the positive and statistically significant coefficients of the medium

farm size and small and marginal farm size. Subsistence HHs have lower agricultural diversification than the commercial HHs. HHs receiving higher income from crop have lower agricultural diversification while HHs receiving higher income from forestry have higher agricultural diversification.

Table 23 Factors influencing Agricultural Diversification (Simpson index) in Bangladesh

VARIABLES	Coefficient
If year is 2016, then 1, otherwise 0	0.0655***
	(0.0158)
Maximum number of crops produced in a community	0.0053***
	(0.0006)
If a HH belongs to rural areas, then 1, otherwise 0	-0.0527***
	(0.0104)
If a HH has opened a bank account, then 1, otherwise 0	-0.0099
	(0.0095)
If a HH owns refrigerator, then 1,otherwise 0	0.0114
	(0.0115)
If a HH owns television, then 1,otherwise 0	0.0042
	(0.0056)
If a HH owns mobile, then 1,otherwise 0	0.0130**
	(0.0064)
If a HH has access to internet, then 1, otherwise 0	0.0351**
	(0.0144)
If a HH head works in urban areas, then 1, otherwise 0	0.0313***
	(0.0094)
Age of HH head	-0.0001
	(0.0002)
HH dependency ratio	0.0001
	(0.0001)
HH size	-0.0006
	(0.0040)
Number of HH members who were abroad for more than 5 years	-0.0128***
	(0.0047)
If a HH head is male, then 1, otherwise 0	-0.0387***
	(0.0108)
Monthly remittance (taka)	-0.0000
	(0.0006)
Monthly HH income (taka)	0.0000*
	(0.0000)
Cultivated area (hectare)	-0.0003***
	(0.0001)
Medium farm size (>1 ha & <= 3 ha)	0.0813***
	(0.0153)
Marginal and small farm size (>0 ha & <=1 ha)	0.0794***
	(0.0142)
If a HH do not sells its agriculture produce, then 1,otherwise 0	-0.2567***
	(0.0059)
HH labour (proxy)	0.0008
	(0.0059)
Monthly income from crops(taka)	-0.0005**
	(0.0003)

Monthly income from aquaculture (taka)	-0.0002
	(0.0006)
Monthly income from forest (taka)	0.0068**
	(0.0031)
Survey conducted season (Kharif)	0.0164***
	(0.0059)
Survey conducted season (Rabi)	0.0266***
	(0.0065)
Constant	0.4572***
	(0.0286)
District fixed effects	Yes
Observations	22,569
R-squared	0.2401

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1, Data Source: HIES 2000-2016

4.2.6 Impact of agricultural diversification on HH dietary diversity and nutrient consumption

Using HIES data sets, first we conducted non-parametric analysis to examine the association between the agriculture diversification (Simpson index) and HH dietary diversity (SI) (Figure 14) and between the agriculture diversification and the nutrition consumption (Figure 15). The relation between dietary diversity and agriculture diversification is positive suggesting that the agricultural diversification matters for the dietary diversity (Figure 10).

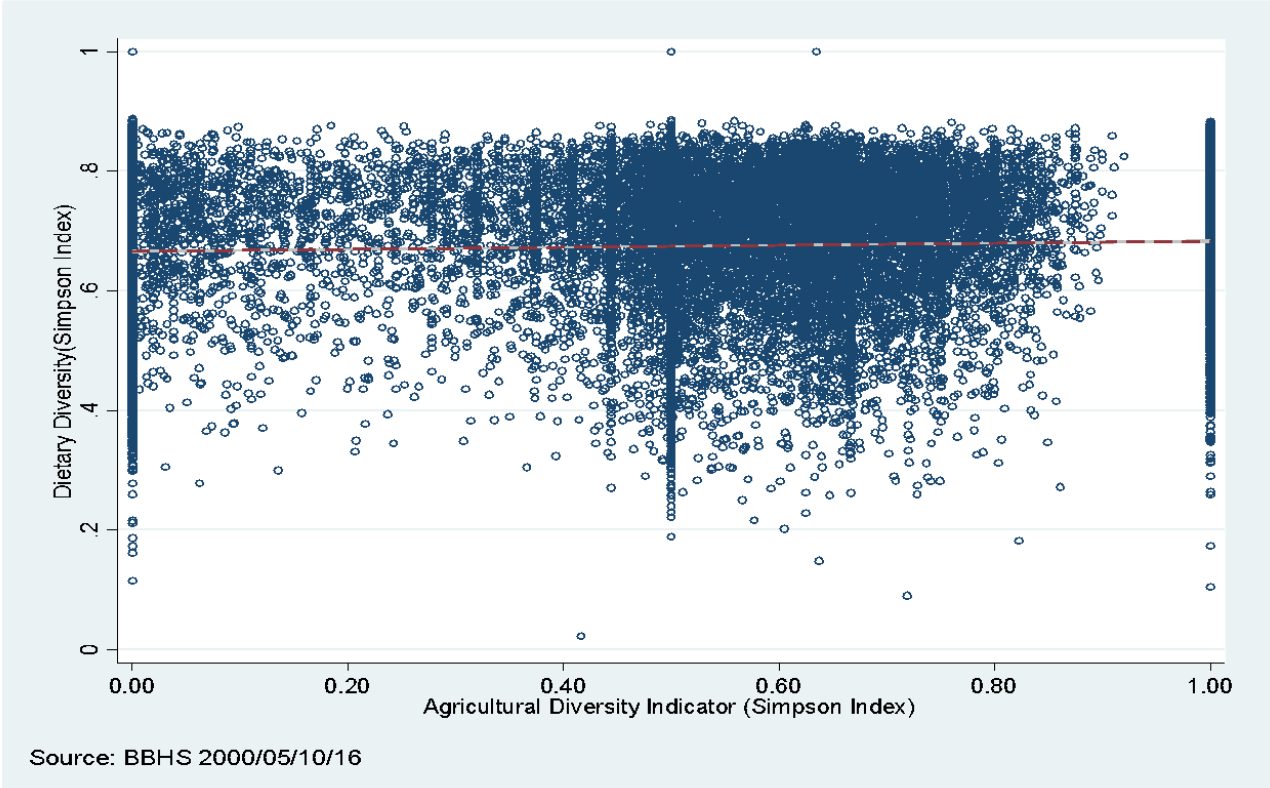

Figure 14: Relation between agricultural diversity (Simpson index) and the dietary diversity (Simpson index) in Bangladesh, Data Source: HIES 2000-2016

Furthermore, agricultural diversification seems to matter for the consumption of vitamin, protein and zinc consumption but not likely the consumption of calorie. We further conducted quantitative analysis controlling for several confounding factors.

A relevancy test indicates the instrument to be statistically significant at less than 5% level. Also, under-identification and weak identification suggest that the instrument are suitable and are a strong instrument, is valid and strong. Since we found a single instrument, the over-identification test could not be conducted.

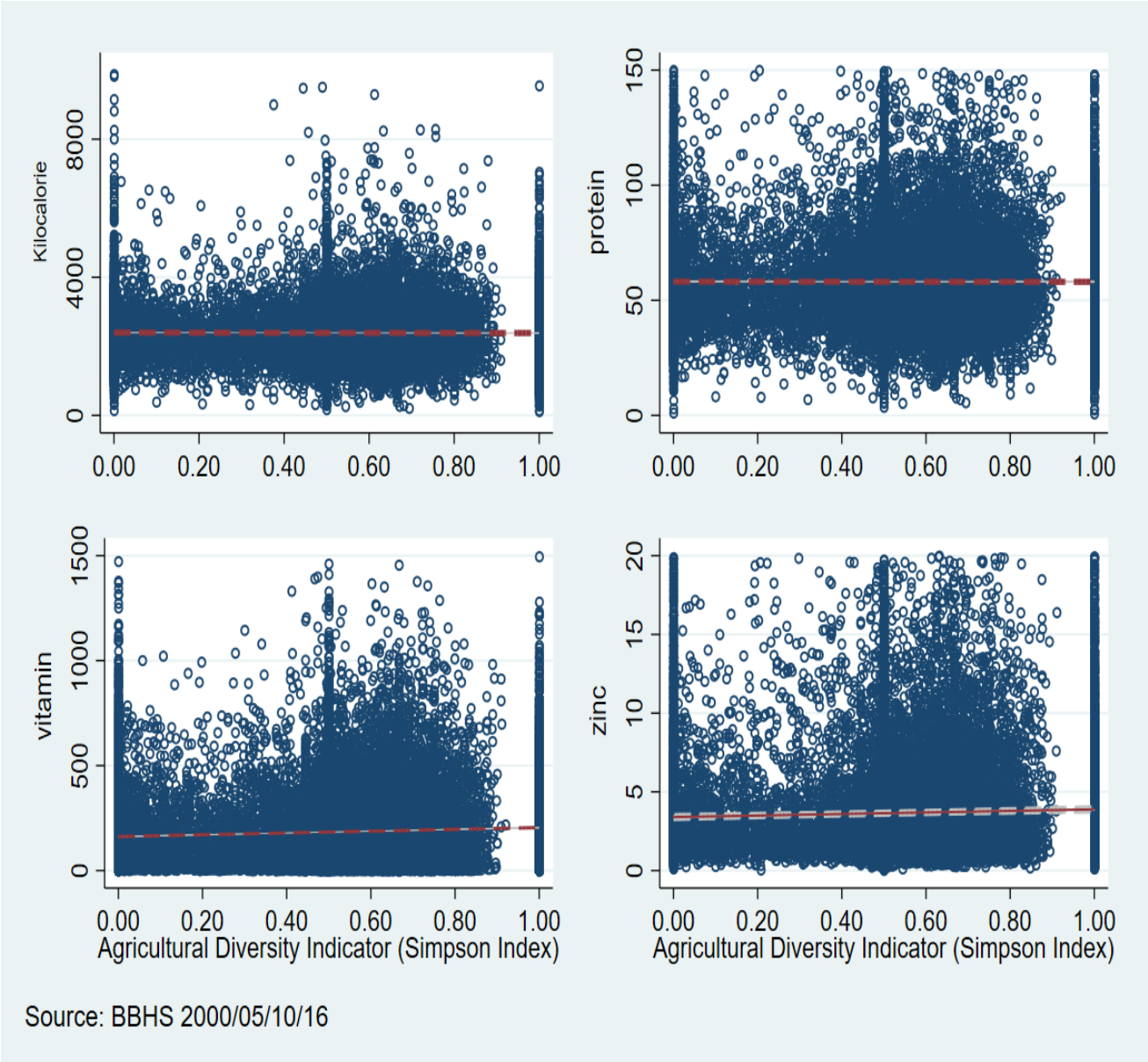

Figure 15: Relation between agriculture diversification and nutrient consumption (per capita adult equivalent) in Bangladesh, Data Source: HIES 2000-2016

Table 24 presents the results of the effect of agricultural diversification on dietary diversity and nutrient consumption. Results indicate a positive and significant association of agricultural diversification with dietary diversity and nutrient consumption. All the coefficients are statistically significant at less than one percent level. An increase in the agricultural diversification index (SI) by an additional unit increases the dietary diversity (SI) by 0.24, kilo calorie by 984, protein by 35, vitamin by 738, and zinc by 4 units, respectively. Overall, the

results underscore the importance of agricultural diversification towards improving dietary diversity and better nutrient consumption.

Table 24 Impact of agricultural diversification on dietary diversity and nutrient intake of a HH in Bangladesh

VARIABLES	Dietary diversity	kcal	Protein	vitamin	zinc
Simpson Index (Crop diversification index)	0.2354***	983.6241***	35.4172***	738.4910***	4.0617***
	(0.0422)	(337.7664)	(9.9735)	(116.3447)	(1.4560)
If a HH belongs to rural areas,then 1, otherwise 0	-0.0050	58.9281*	1.0479	28.5769**	-0.2094
	(0.0040)	(30.7153)	(0.9137)	(11.8730)	(0.1450)
If a HH has opened a bank account, then 1, otherwise 0	0.0105***	41.8927	2.0512**	24.2164**	0.5362***
	(0.0037)	(29.6753)	(0.9137)	(9.8981)	(0.1511)
If a hh owns refrigerator, then 1,otherwise 0	0.0213***	15.3193	4.0850***	-1.8291	1.0355***
	(0.0037)	(29.8482)	(0.9638)	(11.3875)	(0.1557)
If a hh owns telivision, then 1,otherwise 0	0.0239***	43.4083**	2.5727***	6.7495	0.5374***
	(0.0022)	(19.1527)	(0.5835)	(5.9429)	(0.0908)
If a hh owns mobile, then 1,otherwise 0	0.0354***	-6.5222	1.3957**	-2.5116	0.5188***
	(0.0028)	(19.9550)	(0.5956)	(7.2315)	(0.0942)
If a hh has access to internet, then 1, otherwise 0	-0.0028	-101.0910**	-2.2509*	-33.6650**	-0.2263
	(0.0050)	(39.4312)	(1.2173)	(14.7258)	(0.1706)
If a HH head works in urban areas, then 1, otherwise 0	0.0082**	-201.2667***	-4.7054***	-20.9811*	-0.1586
	(0.0036)	(26.0793)	(0.8035)	(11.5945)	(0.1257)
Age of HH head	0.0000	9.1424***	0.2435***	0.8453***	0.0156***
	(0.0001)	(0.6325)	(0.0186)	(0.1937)	(0.0030)
HH dependency ratio	-0.0001**	-1.0804***	-0.0275***	-0.3169***	-0.0029**
	(0.0000)	(0.2837)	(0.0083)	(0.0949)	(0.0014)
HH size	-0.0082***	-61.6321***	-2.1743***	-11.7100***	-0.3185***
	(0.0015)	(12.5905)	(0.3724)	(4.0600)	(0.0583)
Number of HH members who were abroad for more than 5 years	0.0058***	-13.0474	-0.0883	19.0770***	0.0563
	(0.0018)	(14.9336)	(0.4804)	(6.6155)	(0.0687)
If a HH head is male, then 1, otherwise 0	0.0058	26.1918	1.7097	1.4709	0.1017
	(0.0043)	(35.9627)	(1.0608)	(13.0176)	(0.1649)
Monthly remittance (taka)	0.0004**	9.8926***	0.3809***	1.1421	0.0368***
	(0.0002)	(2.1940)	(0.0775)	(0.9744)	(0.0103)
Monthly HH income (taka)	0.0000**	-0.0004	0.0000	-0.0002	0.0000***
	(0.0000)	(0.0004)	(0.0000)	(0.0002)	(0.0000)
Cultivated area (hectare)	0.0002***	2.7160***	0.0831***	0.3397***	0.0084***
	(0.0000)	(0.3021)	(0.0095)	(0.0688)	(0.0011)
Medium farm size (>1 ha &	-0.0163**	-16.3948	-1.2320	-40.9470**	-0.0401

<= 3 ha)					
	(0.0066)	(48.4658)	(1.3985)	(18.2860)	(0.2222)
Marginal and small farm size (>0 ha & <=1 ha)	-0.0252***	-92.5891*	-3.4940***	-43.3894**	-0.3300*
	(0.0062)	(48.5553)	(1.3255)	(17.6269)	(0.1943)
If a hh do not sells its agriculture produce, then 1,otherwise 0	0.0471***	280.4711***	9.6626***	201.4383***	0.9089**
	(0.0116)	(93.7276)	(2.7573)	(31.8982)	(0.3928)
HH labour (proxy)	-0.0038*	-101.6427***	-2.4623***	-17.6619***	-0.2976***
	(0.0022)	(19.0071)	(0.5620)	(6.2670)	(0.0897)
Monthly income from crops(taka)	-0.0002**	0.3966	-0.0031	0.2044	-0.0082***
	(0.0001)	(0.4072)	(0.0119)	(0.1896)	(0.0025)
Monthly income from aquaculture (taka)	0.0001	2.0265	0.0813	0.5821	0.0129
	(0.0002)	(1.8284)	(0.0561)	(0.5134)	(0.0108)
Monthly income from forest (taka)	0.0009	11.8566	0.4478	-0.8968	0.0882*
	(0.0009)	(10.9674)	(0.3253)	(2.3638)	(0.0522)
If year is 2016, then 1, otherwise 0	0.0556***	-123.4457***	-2.0657	-39.8029**	-0.3210*
	(0.0059)	(44.4726)	(1.2615)	(16.7584)	(0.1821)
Survey conducted season (Kharif)	-0.0030	-3.1235	1.4327***	-4.9291	0.6198***
	(0.0023)	(18.1304)	(0.5498)	(6.5833)	(0.0873)
Survey conducted season (Rabi)	-0.029***	-37.5032*	-0.6402	-37.9889***	-0.546***
	(0.0027)	(20.2238)	(0.6064)	(7.1167)	(0.0838)
Constant	0.5711***	2,011.3969***	41.2900***	-107.6819	4.0645***
	(0.0256)	(205.2266)	(6.1230)	(67.8620)	(0.9421)
District fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	22,569	22,568	22,568	22,568	22,568
Relevancy test (F statistics from the first stage regression)	89.22	89.21	89.21	89.21	89.21
Under-identification test (Kleibergen-Paap rk LM statistics)	87.12	87.11	87.11	87.11	87.11
Weak identification test (Cragg-Donald Wald F statistic)	133.61	133.61	133.61	133.61	133.61

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1, Data Source: HIES 2000-2016

4.2.7 Impact of agricultural commercialization on HH dietary diversity and nutrient consumption

Non-parametric analysis results on association between the agriculture commercialization index and HH dietary diversity (Simpson index) (Figure 16) and between the agriculture commercialization index and the nutrition consumption (Figure 17). The relation between dietary diversity and agriculture commercialization is positive with tight confidence interval. This

suggests that qualitatively, agricultural commercialization matters for the dietary diversity. Barring vitamin consumption, agricultural commercialization seems to matter for the calorie, protein and zinc consumption.

Although qualitative evidence suggests the slight positive effect of agricultural commercialization on dietary diversity and nutrient consumption, robust empirical evidence needs to be sought. A relevancy test indicates the instrument to be statistically significant at less than 5% level. Also under-identification, weak identification and over-identification tests suggest that the instruments are suitable and are strong and valid for the model.

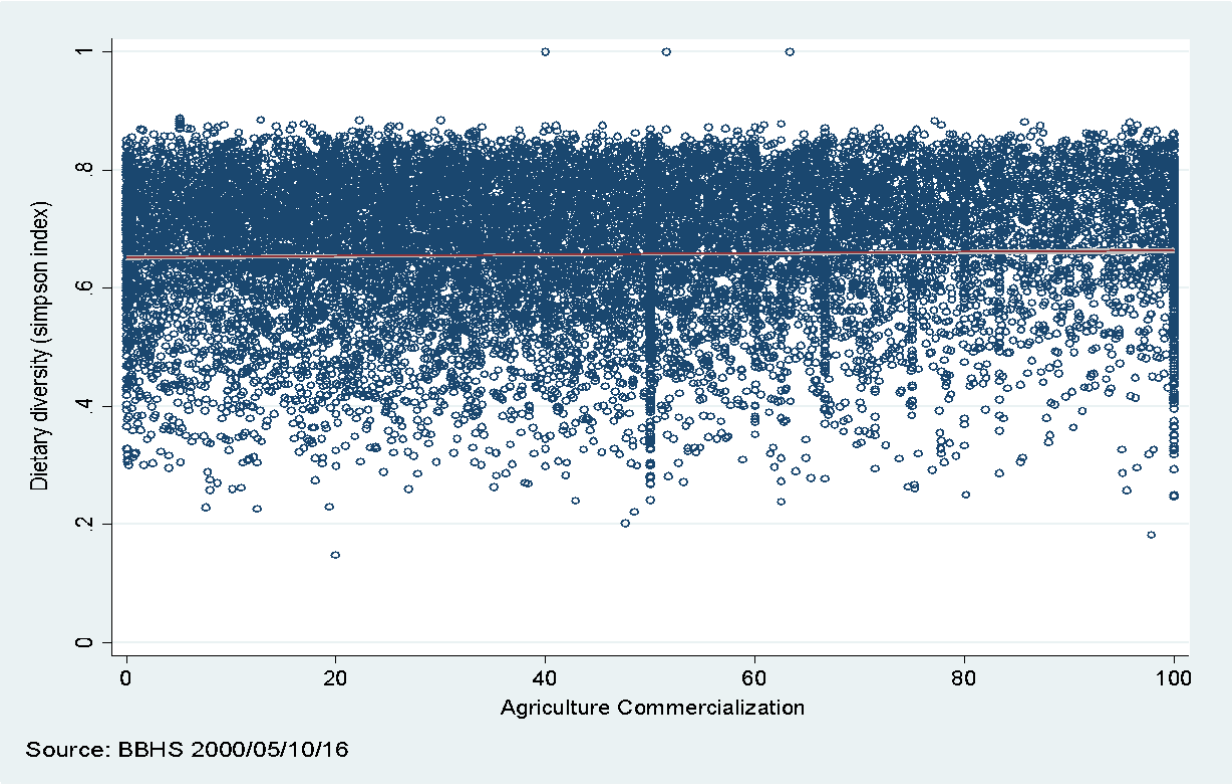

Figure 16: Relation between agriculture commercialization and dietary diversity in Bangladesh, Data Source: HIES 2000-2016

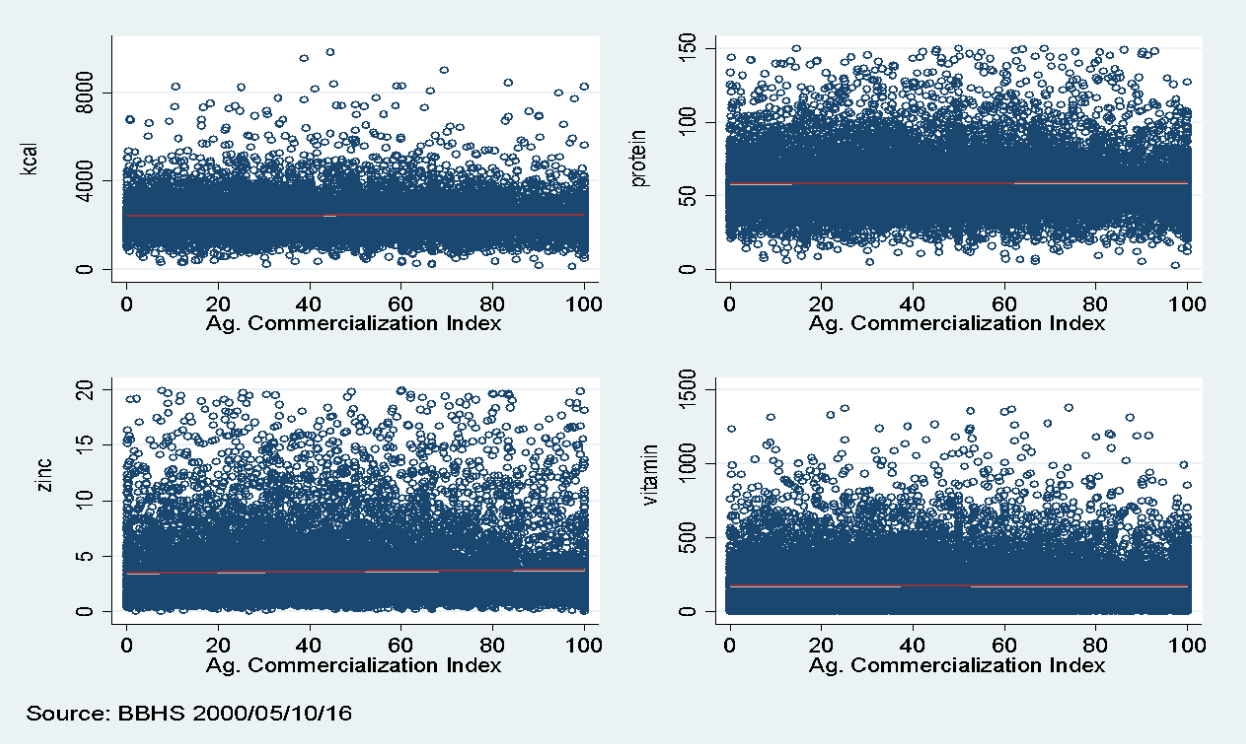

Figure 17: Relation between agriculture commercialization and nutrient consumption (per capita adult equivalent) in Bangladesh, Data Source: HIES 2000-2016

Table 25 presents the results of the effect of crop commercialization on HH dietary diversity using both the ordinary least squares (OLS) and 2SLS approaches. We interpreted the results from 2SLS model although the sign and magnitude of the coefficients between OLS and 2SLS models are not significantly different. Results indicate a positive and significant association of crop commercialization with dietary diversity. We find an increase in the share of crop produces sold in the market by 1% increases the dietary diversity (SI) by 0.001%.

HHs with bank account, owning refrigerator, television, mobile, and having access to internet have better dietary diversity (Table 25). Female headed HHs and HHs with the head working in urban areas have higher dietary diversity. Number of out-migrants (working in abroad for more than five years), remittances, cultivated area, and income (crops, aquaculture, and fisheries) are positively associated with the dietary diversity. HH from rural areas, increase in dependency ratio, bigger family size, and increase in HH labour size are negatively associated with the dietary diversity.

Table 25 Regression results on the effects of agricultural commercialization on the HH dietary diversity

VARIABLES	OLS	2SLS
Agricultural commercialization index (proportion of crops produced sold)	0.0003***	0.0008***
	(0.0000)	(0.0002)
If a HH belongs to rural areas, then 1, otherwise 0	-0.019***	-0.020***
	(0.0024)	(0.0024)
If a HH has opened a bank account, then 1, otherwise 0	0.0083***	0.0077***
	(0.0028)	(0.0028)
If a hh owns refrigerator, then 1,otherwise 0	0.0281***	0.0285***
	(0.0023)	(0.0024)
If a hh owns television, then 1,otherwise 0	0.0264***	0.0264***
	(0.0018)	(0.0018)
If a hh owns mobile, then 1,otherwise 0	0.0415***	0.0414***
	(0.0022)	(0.0022)
If a hh has access to internet, then 1, otherwise 0	0.0056	0.0067*
	(0.0036)	(0.0037)
If a HH head works in urban areas, then 1, otherwise 0	0.0190***	0.0212***
	(0.0025)	(0.0026)
If a HH head is male, then 1, otherwise 0	-0.0052*	-0.0071**
	(0.0028)	(0.0029)
Age of HH head	-0.0000	-0.0000
	(0.0001)	(0.0001)
HH dependency ratio	-0.0001**	-0.0001**
	(0.0000)	(0.0000)
HH size	-0.008***	-0.007***
	(0.0012)	(0.0013)
Number of HH members who were abroad for more than 5 years	0.0030**	0.0025*
	(0.0014)	(0.0014)
Monthly remittance (taka)	0.0008***	0.0008***
	(0.0002)	(0.0002)
Cultivated area (hectare)	0.0001***	0.0001*
	(0.0000)	(0.0000)
Medium farm size (>1 ha & <= 3 ha)	-0.0016	0.0048
	(0.0031)	(0.0039)
Marginal and small farm size (>0 ha & <=1 ha)	-0.0127***	-0.0054
	(0.0036)	(0.0048)
HH labour (proxy)	-0.0031*	-0.0033*
	(0.0018)	(0.0018)
Monthly income from crops(taka)	-0.0000	-0.0000*
	(0.0000)	(0.0000)
Monthly income from aquaculture (taka)	0.0004***	0.0004***
	(0.0001)	(0.0002)
Monthly income from forest (taka)	0.0032***	0.0030***
	(0.0012)	(0.0011)
If year is 2016, then 1, otherwise 0	0.0664***	0.0641***
	(0.0039)	(0.0041)
Survey conducted season (Kharif)	0.0007	0.0031
	(0.0018)	(0.0020)
Survey conducted season (Rabi)	-0.026***	-0.022***
	(0.0019)	(0.0025)

Constant	0.6850***	0.6784***
	(0.0089)	(0.0092)
District fixed effects	Yes	Yes
Observations	24,396	24,396
R-squared	0.3560	0.3431
Relevancy test (F statistics from the first stage regression)	-	61.14
Under-identification test (Kleibergen-Paap rk LM statistics)	-	159.31
Weak identification test (Cragg-Donald Wald *F* statistic)	-	231.82
Hansen J statistic (overidentification test of all instruments)	-	0.92

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1, Data Source: HIES 2000-2016

Table 26 presents the effects of livestock and fisheries commercialization on dietary diversity. Although we find the suitable instrument in case of livestock commercialization, we did not find the suitable instrument in case of fisheries commercialization. The coefficients of livestock and fisheries commercialization index is positive and statistically significant at less than ten percent. This indicates that increase in livestock and fisheries commercialization increases the HH dietary diversity.

Table 26 Impact of animal and fisheries commercialization on dietary diversity (simpson index)

VARIABLES	Livestock	Fisheries
Animal commercialization index[a]	0.0005*	
	(0.0003)	
Fisheries commercialization index		0.0001*
		(0.0001)
If a HH belongs to rural areas, then 1, otherwise 0	-0.0226***	-0.0225***
	(0.0033)	(0.0056)
If a HH has opened a bank account, then 1, otherwise 0	0.0133***	0.0155**
	(0.0038)	(0.0064)
If a hh owns refrigerator, then 1,otherwise 0	0.0333***	0.0296***
	(0.0036)	(0.0062)
If a hh owns telivision, then 1,otherwise 0	0.0292***	0.0252***
	(0.0025)	(0.0049)
If a hh owns mobile, then 1,otherwise 0	0.0431***	0.0415***
	(0.0028)	(0.0063)
If a hh has access to internet, then 1, otherwise 0	0.0077	-0.0024
	(0.0060)	(0.0097)
If a HH head works in urban areas, then 1, otherwise 0	0.0206***	0.0170**
	(0.0033)	(0.0069)
If a HH head is male, then 1, otherwise 0	-0.0014	0.0010
	(0.0037)	(0.0073)
Age of HH head	-0.0001	0.0002
	(0.0001)	(0.0002)
HH dependency ratio	-0.0000	-0.0000
	(0.0000)	(0.0001)
HH size	-0.0099***	-0.0079**
	(0.0016)	(0.0032)
Number of HH members who were abroad for more than 5 years	0.0076***	-0.0021

	(0.0023)	(0.0038)
Monthly remittance (taka)	0.0009***	0.0004
	(0.0003)	(0.0003)
Cultivated area (hectare)	0.0002***	
	(0.0000)	
Medium farm size (>1 ha & <= 3 ha)	-0.0081**	-0.0096
	(0.0037)	(0.0098)
Marginal and small farm size (>0 ha & <=1 ha)	-0.0196***	-0.0258**
	(0.0049)	(0.0103)
If a hh do not sells its agriculture produce, then 1,otherwise 0	-0.0039	-0.0110**
	(0.0029)	(0.0045)
HH labour (proxy)	-0.0005	-0.0021
	(0.0024)	(0.0047)
If year is 2016, then 1, otherwise 0	0.0736***	0.0768***
	(0.0056)	(0.0115)
Survey conducted season (Kharif)	0.0000	0.0022
	(0.0024)	(0.0050)
Survey conducted season (Rabi)	-0.024***	-0.0053
	(0.0034)	(0.0056)
Constant	0.6619***	0.6889***
	(0.0157)	(0.0161)
District fixed effects	Yes	Yes
Observations	12,420	2,994
Relevancy test (F statistics from the first stage regression)	17.37	
Under-identification test (Kleibergen-Paap rk LM statistics)	31.48	
Weak identification test (Cragg-Donald Wald F statistic)	58.45	
Hansen J statistic (over-identification test of all instruments)	-	

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1, [a] animal commercialization has been instrumented but not the fisheries commercialization, Data Source: HIES 2000-2016

Further, we estimated the impact of agricultural commercialization on nutrient (calorie, protein, zinc and vitamin) consumption. The effect of crop commercialization and animal commercialization is positive and statistically significant on calorie consumption (Table 27). However, the fisheries commercialization index is negatively correlated with calorie consumption. Both the crop and livestock commercialization are important for increasing calorie consumption in HH but crop commercialization matters more than livestock commercialization. Given that all our samples are rural and mainly crop dominated and agricultural policies are also predominately crops focus, therefore, crop effect may be higher which need further investigation by focusing on disaggregated and representative sample from both the sectors and this may also true for later regression results in the following Table.

Table 27 Impact of commercialization on kilo calorie consumption

VARIABLES	Crop	Animal	Fish
Crop commercialization Index (proportion of agricultural output sold	7.9137***		
	(1.8917)		
Animal commercialization index		6.1754**	
		(2.7892)	
Fisheries commercialization index			-1.2950**
			(0.6307)
Yearly fixed effects	Yes	Yes	Yes
Constant	2,421.9401***	2,286.0474***	2,774.1667***
	(92.8033)	(150.8675)	(227.8306)
District Fixed Effects	Yes	Yes	Yes
Relevancy test (F statistics from the first stage regression)	91.20	17.38	-
Under-identification test (Kleibergen-Paap rk LM statistics)	272.09	31.48	-
Weak identification test (Cragg-Donald Wald F statistic)	361.49	58.44	-
Hansen J statistic (over-identification test of all instruments)	0.83	-	-
Observations	24,392	12,418	2,992

Notes: All the control variables presented in Table 1 have been used in the model. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. No suitable instrument was found in case of the fish commercialization index model. Data Source: HIES 2000-2016

Table 28 Impact of commercialization on protein consumption

VARIABLES	Crop	Animal	Fish
Crop commercialization Index (proportion of agricultural output sold	0.2820***		
	(0.0572)		
Animal commercialization index		0.1834**	
		(0.0863)	
Fisheries commercialization index			-0.0347*
			(0.0205)
Constant	55.6920***	52.3525***	67.6147***
	(2.8166)	(4.7238)	(7.2291)
District fixed effects	Yes	Yes	Yes
Yearly fixed effects	Yes	Yes	Yes
Observations	24,392	12,418	2,992
Relevancy test (F statistics from the first stage regression)	91.20	17.37	

Under-identification test (Kleibergen-Paap rk LM statistics)	272.09	31.13
Weak identification test (Cragg-Donald Wald F statistic)	361.49	57.78
Hansen J statistic (over-identification test of all instruments)	2.44	

Notes: All the control variables presented in Table 1 have been used in the model. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. No suitable instrument was found in case of the fish commercialization index model. Data Source: HIES 2000-2016

The effect of crop commercialization and animal commercialization is positive and statistically significant on protein consumption (Table 28). However, the fisheries commercialization index is negatively correlated with the protein consumption, which is not expected. Similar to the calorie model, both the crop and livestock commercialization are important for increasing protein consumption in HH but crop commercialization matters more than livestock commercialization.

In case of vitamin consumption, only the effect of crop commercialization is positive and statistically significant (Table 29). We did not find statistically significant effects of livestock and fisheries commercialization on vitamin A consumption.

Table 29 Impact of commercialization on vitamin A consumption

VARIABLES	Crop commercialization	Animal commercialization	Fish commercialization
Crop commercialization Index (proportion of agricultural output sold	1.0570*		
	(0.5939)		
Animal commercialization index		-0.0089	
		(0.6820)	
Fisheries commercialization index			-0.0873
			(0.1209)
Constant	265.7786***	261.4894***	255.3248***
	(21.2498)	(31.7161)	(45.4887)
District fixed effects	Yes	Yes	Yes
Yearly fixed effects	Yes	Yes	Yes
Relevancy test (F statistics from the first stage regression)	91.20	17.37	
Under-identification test (Kleibergen-Paap rk LM statistics)	272.09	31.13	
Weak identification test (Cragg-Donald Wald F statistic)	361.49	57.78	
Hansen J statistic (over-identification test of all instruments)	0.29		
Observations	24,392	12,418	2,992

Notes: All the control variables presented in Table 1 have been used in the model. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. No suitable instrument was found in case of the fish commercialization index model. Data Source: HIES 2000-2016

Table 30 presents the effects of commercialization on zinc consumption. The effect of crop commercialization and fisheries commercialization on zinc consumption is positive and statistically significant.

Table 30 Impact of commercialization on zinc consumption

VARIABLES	Crop commercialization	Animal commercialization	Fish commercialization
Crop commercialization Index (proportion of agricultural output sold	0.0229***		
	(0.0080)		
Animal commercialization index		0.0137	
		(0.0129)	
Fish commercialization index			0.0051*
			(0.0031)
Constant	5.4013***	5.6536***	5.9499***
	(0.4550)	(0.7768)	(1.0604)
District fixed effects	Yes	Yes	Yes
Yearly fixed effects	Yes	Yes	Yes
Relevancy test (F statistics from the first stage regression)	91.20	17.37	
Under-identification test (Kleibergen-Paap rk LM statistics)	272.09	31.13	
Weak identification test (Cragg-Donald Wald F statistic)	361.49	57.78	
Hansen J statistic (over-identification test of all instruments)	5.50		
Observations	24,392	12,418	2,992

Notes: All the control variables presented in Table 1 have been used in the model. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. No suitable instrument was found in case of the fish commercialization index model. Data Source: HIES 2000-2016

4.2.8 Robustness test

We assessed whether the results on the effect of the agricultural commercialization and agricultural diversification on the dietary diversity and nutrient consumption are sensitive towards changes in model specification and sample size. Table 31 present the robustness test on the impact of crop commercialization on dietary diversity. First model uses food consumption scores instead of dietary diversity—SI as dependent variable. The result is robust even after using the different measure of HH dietary diversity. Second model uses dietary diversity—SI as dependent variable but the model is separately estimated for the male headed (Model 2) and female headed HH (Model 3). Similar model 4 includes only the sample for rural HHs while Model 5 includes the sample from urban HHs. Overall, the results are robust in the case of male

headed and urban HHs. However, the impact of commercialization on HH dietary diversity and nutrient consumption should be cautiously interpreted in case of female headed and rural HHs.

Similarly, Table 32 present the results from robustness on the impact of agricultural diversification on dietary diversity. We estimated seven models. First model uses different measure of dietary diversity i.e., food consumption scores; second model includes the sample for male headed HHs, third model includes the sample for female headed HHs, fourth model includes the sample for rural HHs, fifth model includes the sample for urban HHs, sixth model includes the sample for the subsistence HHs, and seventh model includes the sample for commercial HHs. The impact of agricultural diversification on dietary diversification is positive and statistically significant for all the models except the model 5 i.e., model limiting to urban sample. This shows the results are highly robust.

Table 31 Robustness test on the impact of crop commercialization on dietary diversity

VARIABLES	Model 1[a]	Model 2[b]	Model 3	Model 4	Model 5
Agricultural commercialization Index (proportion of agricultural output sold[c]	0.2650***	0.0011***	0.0005	0.0008***	0.0003
	(0.0329)	(0.0002)	(0.0006)	(0.0002)	(0.0003)
If a HH belongs to rural areas,then 1, otherwise 0	-2.8033***	-0.0471***	-0.0219***		
	(0.4988)	(0.0024)	(0.0073)		
If a HH has opened a bank account, then 1, otherwise 0	2.6534***	0.0134***	0.0109	0.0070**	0.0086*
	(0.5588)	(0.0031)	(0.0085)	(0.0031)	(0.0050)
If a hh owns refrigerator, then 1, otherwise 0	9.4247***		0.0179***	0.0246***	0.0373***
	(0.5863)		(0.0063)	(0.0029)	(0.0040)
If a hh owns telivision, then 1,otherwise 0	4.7877***		0.0337***	0.0264***	0.0233***
	(0.3413)		(0.0056)	(0.0019)	(0.0037)
If a hh owns mobile, then 1,otherwise 0	4.9247***		0.0558***	0.0408***	0.0365***
	(0.3553)		(0.0067)	(0.0023)	(0.0049)
If a hh has access to internet, then 1, otherwise 0	2.6060***		0.0147*	0.0095**	-0.0022
	(0.7849)		(0.0083)	(0.0038)	(0.0103)
If a HH head works in urban areas, then 1, otherwise 0	1.3845***		0.0233**	0.0258***	0.0006

	(0.5046)		(0.0113)	(0.0034)	(0.0037)
If a HH head is male, then 1, otherwise 0	1.2858**			-0.0076**	-0.0020
	(0.5262)			(0.0032)	(0.0055)
Age of HH head	0.0670***	-0.0001*	0.0002	-0.0000	-0.0001
	(0.0103)	(0.0001)	(0.0002)	(0.0001)	(0.0001)
HH dependency ratio	0.0111**	-0.0001***	-0.0000	-0.0001**	-0.0000
	(0.0044)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
HH size	0.4070*	-0.0060***	-0.0046	-0.0086***	-0.0047**
	(0.2109)	(0.0016)	(0.0033)	(0.0014)	(0.0021)
Number of HH members who were abroad for more than 5 years	-0.6058**	-0.0003	0.0049	0.0028*	0.0042
	(0.2741)	(0.0015)	(0.0047)	(0.0015)	(0.0034)
Monthly remittance (taka)	0.1716***	0.0014***	0.0008**	0.0008***	0.0007**
	(0.0417)	(0.0002)	(0.0003)	(0.0002)	(0.0003)
Cultivated area (hectare)	-0.0013	0.0001***	-0.0001	0.0001**	0.0001
	(0.0051)	(0.0000)	(0.0002)	(0.0000)	(0.0001)
Medium farm size (>1 ha & <= 3 ha)	2.2942***	0.0098**	-0.0029	0.0034	0.0008
	(0.6865)	(0.0046)	(0.0089)	(0.0045)	(0.0059)
Marginal and small farm size (>0 ha & <=1 ha)	1.8680**	-0.0037	-0.0157	-0.0069	-0.0063
	(0.7831)	(0.0053)	(0.0134)	(0.0054)	(0.0087)
If a hh do not sells its agriculture produce, then 1,otherwise 0	4.6733***	0.0101*	0.0070	0.0048	0.0040
	(0.8511)	(0.0054)	(0.0105)	(0.0055)	(0.0064)
HH labour (proxy)	0.9277***	-0.0007	-0.0075	-0.0032*	-0.0007
	(0.3141)	(0.0023)	(0.0049)	(0.0019)	(0.0032)
Monthly income from crops(taka)	-0.0048***	-0.0000***	0.0000	-0.0000	-0.0000**
	(0.0015)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Monthly income from aquaculture (taka)	0.1325***	0.0006***	-0.0010*	0.0005***	0.0002
	(0.0388)	(0.0002)	(0.0006)	(0.0002)	(0.0002)
Monthly income from forest (taka)	0.4493***	0.0038***	0.0176**	0.0030**	0.0025**
	(0.1698)	(0.0013)	(0.0087)	(0.0012)	(0.0010)
If year is 2016, then 1, otherwise 0	-2.7490***	0.0852***	0.0453***	0.0682***	0.0248**
	(0.7851)	(0.0053)	(0.0125)	(0.0052)	(0.0099)
Survey conducted season (Kharif)	3.0108***	0.0037*	0.0039	-0.0001	0.0058
	(0.3335)	(0.0020)	(0.0055)	(0.0020)	(0.0042)
Survey conducted season (Rabi)	-3.6872***	-0.0225***	-0.0233***	-0.0250***	-0.0283***
	(0.3436)	(0.0023)	(0.0063)	(0.0022)	(0.0048)
Constant	42.4345***	0.7201***	0.6019***	0.6554***	0.7281***
	(1.5593)	(0.0097)	(0.0310)	(0.0099)	(0.0138)
District Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	24,396	22,477	1,955	20,682	3,714

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1, Notes [a] instead of simpson index, food consumption scores is used as a dependent variable; [b] simpson index is used as a dependent variable but regression is run separately for male headed HH (Model 2), female headed HH (Model 3), rural HH (Model 4) and urban HH (Model 5); [c]instrumented using instrument variables (expenditure on fertilizers and renting farm machineries) , Data Source: HIES 2000-2016

Table 32 Robustness test on the impact of agricultural diversity on the dietary diversity of the HH in Bangladesh

VARIABLES	Model 1[a]	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Simpson Index (Crop diversification index)	22.9578***	0.2289***	0.2251**	0.2246***	0.0918	0.1995***	0.3147***
	(6.3942)	(0.0440)	(0.1137)	(0.0445)	(0.1050)	(0.0453)	(0.0898)
If a HH belongs to rural areas, then 1, otherwise 0	-0.6539	-0.0051	-0.0061			-0.0206***	0.0062
	(0.6305)	(0.0041)	(0.0130)			(0.0041)	(0.0073)
If a HH has opened a bank account, then 1, otherwise 0	2.6255***	0.0096**	0.0161	0.0078**	0.0123	0.0022	0.0173***
	(0.5815)	(0.0037)	(0.0131)	(0.0038)	(0.0086)	(0.0049)	(0.0058)
If a hh owns refrigerator, then 1,otherwise 0	7.8706***	0.0222***	0.0220**	0.0191***	0.0352***	0.0192***	0.0278***
	(0.6323)	(0.0038)	(0.0108)	(0.0038)	(0.0057)	(0.0042)	(0.0064)
If a hh owns telivision, then 1,otherwise 0	4.5214***	0.0238***	0.0241***	0.0253***	0.0167***	0.0209***	0.0278***
	(0.3546)	(0.0022)	(0.0084)	(0.0023)	(0.0057)	(0.0029)	(0.0034)
If a hh owns mobile, then 1,otherwise 0	4.2900***	0.0326***	0.0552***	0.0339***	0.0373***	0.0363***	0.0334***
	(0.3966)	(0.0030)	(0.0107)	(0.0029)	(0.0061)	(0.0046)	(0.0038)
If a hh has access to internet, then 1, otherwise 0	1.3962*	-0.0038	0.0138	0.0013	-0.0067	0.0008	-0.0118
	(0.7899)	(0.0053)	(0.0125)	(0.0046)	(0.0131)	(0.0057)	(0.0099)
If a HH head works in urban areas, then 1, otherwise 0	-0.8449	0.0088**	0.0175	0.0085*	-0.0018	0.0101**	0.0026
	(0.5322)	(0.0036)	(0.0146)	(0.0045)	(0.0043)	(0.0046)	(0.0071)
Age of HH head	0.0714***	0.0000	0.0005	0.0000	-0.0001	0.0000	0.0001
	(0.0112)	(0.0001)	(0.0003)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
HH	0.0100*	-0.0001**	-0.0000	-0.0001**	-0.0000	-0.0001	-0.0001*

dependency ratio		*					
	(0.0052)	(0.0000)	(0.0001)	(0.0000)	(0.0001)	(0.0000)	(0.0001)
HH size	0.2183	-0.0065***	-0.0027	-0.0086***	-0.0039	-0.0088***	-0.0074***
	(0.2332)	(0.0017)	(0.0047)	(0.0016)	(0.0029)	(0.0019)	(0.0025)
Number of HH members who were abroad for more than 5 years	0.0372	0.0023	0.0097	0.0048***	0.0079*	0.0020	0.0112***
	(0.2901)	(0.0017)	(0.0079)	(0.0017)	(0.0047)	(0.0020)	(0.0037)
If a HH head is male, then 1, otherwise 0	3.5353***			0.0074	-0.0014	-0.0132**	0.0206***
	(0.6516)			(0.0046)	(0.0076)	(0.0055)	(0.0080)
Monthly remittance (taka)	0.1322***	0.0005**	0.0001	0.0004**	0.0003	0.0006**	0.0001
	(0.0386)	(0.0002)	(0.0005)	(0.0002)	(0.0004)	(0.0003)	(0.0003)
Monthly HH income (taka)	0.0000**	0.0000**	0.0000	0.0000**	0.0000	0.0000	0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Cultivated area (hectare)	0.0407***	0.0002***	0.0002	0.0002***	0.0002*	0.0002***	0.0002***
	(0.0048)	(0.0000)	(0.0002)	(0.0000)	(0.0001)	(0.0001)	(0.0000)
Medium farm size (>1 ha & <= 3 ha)	-1.4130	-0.0186***	0.0056	-0.0150**	-0.0138	0.0084	-0.0493***
	(0.9713)	(0.0072)	(0.0144)	(0.0070)	(0.0178)	(0.0066)	(0.0156)
Marginal and small farm size (>0 ha & <=1 ha)	-2.3478***	-0.0253***	-0.0224	-0.0244***	-0.0182	0.0003	-0.0546***
	(0.8766)	(0.0064)	(0.0199)	(0.0065)	(0.0135)	(0.0067)	(0.0163)
If a hh do not sells its agriculture produce, then 1,otherwise 0	4.0402**	0.0412***	0.0730*	0.0401***	0.0314		
	(1.7471)	(0.0117)	(0.0399)	(0.0118)	(0.0364)		
HH labour (proxy)	0.8780**	-0.0064**	-0.0070	-0.0038*	-0.0037	-0.0036	-0.0045
	(0.3462)	(0.0025)	(0.0070)	(0.0023)	(0.0043)	(0.0028)	(0.0036)
Monthly income from crops(taka)	-0.0338**	-0.0002**	-0.0007	-0.0002**	-0.0001	-0.0003	-0.0001
	(0.0139)	(0.0001)	(0.0005)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
Monthly income from aquaculture (taka)	0.0589	0.0001	-0.0033	0.0003	-0.0002	0.0005	0.0001
	(0.0371)	(0.0002)	(0.0024)	(0.0002)	(0.0004)	(0.0003)	(0.0002)
Monthly income from forest (taka)	0.3145*	0.0008	0.0061	0.0006	0.0029**	0.0018	0.0003

	(0.1687)	(0.0009)	(0.0131)	(0.0010)	(0.0012)	(0.0011)	(0.0012)
If year is 2016, then 1, otherwise 0	-2.0437**	0.0664***	0.0112	0.0622***	0.0254**	0.0556***	0.0523***
	(0.8415)	(0.0059)	(0.0228)	(0.0062)	(0.0127)	(0.0068)	(0.0105)
Survey conducted season (Kharif)	2.1793***	-0.0030	-0.0037	-0.0066***	-0.0024	0.0006	-0.0109***
	(0.3505)	(0.0024)	(0.0078)	(0.0024)	(0.0053)	(0.0033)	(0.0040)
Survey conducted season (Rabi)	-4.5117***	-0.0305***	-0.0196**	-0.0330***	-0.0304***	-0.0259***	-0.0409***
	(0.3808)	(0.0027)	(0.0098)	(0.0028)	(0.0057)	(0.0036)	(0.0054)
Constant	35.7150***	0.5857***	0.5508***	0.5745***	0.6759***	0.6389***	0.5326***
	(3.8254)	(0.0247)	(0.0786)	(0.0242)	(0.0777)	(0.0183)	(0.0511)
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	22,569	20,941	1,628	19,392	3,177	11,295	11,274

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1 While the dependent variable in model 1 is food consumption scores (proxy of dietary diversity), the dependent variable for rest of the models is simpson index (also proxy of dietary diversity). Model 2 limits the sample for only the male headed HHs, Model3 the female headed HHs, Model 4 the rural HHs, Model 5 the urban HHs, Model 6 the subsistence HHs and Model 7 the commercial HHs. , Data Source: HIES 2000-2016

5. Conclusion and Policy Implications

Our study examines the status of agricultural diversification and commercialization as well as the status of intra household dietary diversity, household income and child nutrition level using two nationally representative data sets. Based on the HIES and IFPRI BIHS data analysis (primary data has not been utilized for this analysis), results indicate that household income, expenditure, food and nutrition security indicators are significantly improving in Bangladesh. Similarly, agricultural, crops and overall farm diversification and commercialization are also increasing over the years. Furthermore, we assess quantitatively whether there is any link between agricultural diversification and commercialization with the status of intra household dietary diversity, household income and child nutrition. Results are encouraging and show that the higher farm production diversity and commercialization is positively associated with household income, nutrition consumption and reduces child stunting. But farm diversification and commercialization may not be sufficient nor always the best strategy to improve household nutrition since the association is nonlinear. Findings of this study have significant policy implications for agricultural diversification and commercialization which are very much important for agricultural development in Bangladesh. The results give policy makers an indication whether to encourage, discourage or simply guide the existing trend of farm production diversity and commercialization given its income and nutrition impacts. If there were

no positive association, policy makers would think about alternative option for investment. Therefore, given the positive association between higher farm production diversity and commercialization and household income, nutrition consumption, it is expected that there would be significant efforts on the part of governments, non-government, national and international organizations to promote agricultural diversification and commercialization with investment in research, extension, infrastructure particularly market network infrastructure and research and extension and market institutional development. Further, results would also strengthen the arguments to remove the barriers that hinder farmers from agricultural diversification and commercialization.

Furthermore, policy and programs that increase agricultural productivity should also be supported, to enable smallholders to release land for diversification and to produce a marketable surplus. This may include the development and spread of improved agricultural technologies including high yielding varieties, as well as increase access to extension and credit facilities which may facilitate information and liquidity constraints that often hinder technology adoption by smallholders in the developing country like Bangladesh. However, agricultural diversification and commercialization alone may not be sufficient to sustainably increase income and improving food and nutrition security of the smallholders. Thus, future policy and programs focusing on improving farm diversification and commercialization should also focus on complementary interventions such as income diversification towards off farm income and women empowerment to sustainably increase income and food security in Bangladesh. As we have seen agricultural diversification and commercialization increases income and this will obviously increase demand for basic goods and services thus enhancing market access is a key strategy to make smallholder agriculture more nutrition-sensitive.

Our study also identified what influence diversification and commercialization that have implications for policy in Bangladesh. Results show that peer effect via living in higher agricultural diversified areas i.e. clustering of diversification due to spillover effects, access to information via access to mobile phone, smaller and marginal farm size and commercialized household positively affect farm diversification. Similarly, access to machine, information via access to mobile phone, having migrant members and larger farm size positively and

significantly associated with higher crop commercialization while share cropping, working in urban areas and older aged household head are negatively associated with crop commercialization.

The findings of this study have important policy implications for agricultural diversification and commercialization which are essential for agricultural and rural development in Bangladesh. Therefore, policy and programs aiming for agricultural diversification and commercialization should aim for those interventions which encourage agricultural diversification and commercialization. Particularly to facilitate agricultural diversification and commercialization in Bangladesh, policy and programs should focus on: i) strengthening research and extension to develop and disseminate productivity, income and nutrition enhancing and climate adaptive agricultural technologies; ii) invest in access to information including climate, technology and market information, iii) invest in rural infrastructure including market infrastructure as it can complement agricultural diversification and commercialization by accessing market for diversified and commercialized products, accessing improved input and output production, postharvest and processing technologies; and iv) invest in mechanization along the agricultural value chains including production, postharvest and processing given the scarcity of labour and post-harvest losses and food safety concerns. As our results shows that access to machine and information are important determinants and, hence, such access needs to be facilitated among smallholders in Bangladesh to reap the full benefits from diversification and commercialization. There has been some effort by the Ministry of Agriculture through various projects where farmers can access to machine particularly labour saving machine including tillage, harvesting, threshing, transplanting and drying machines. Government including public–private partnership based mechanization has potential to promote diversification and commercialization and, ultimately, improving food security, nutrition, poverty alleviation and achieving SDG goals in Bangladesh. Further research on agricultural diversification and commercialization to find out the optimum patterns of agricultural diversity and commercialization so that Bangladesh can ensure food security, nutrition and incomes by using scarce resources to achieve the SDG goals.

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Appendix

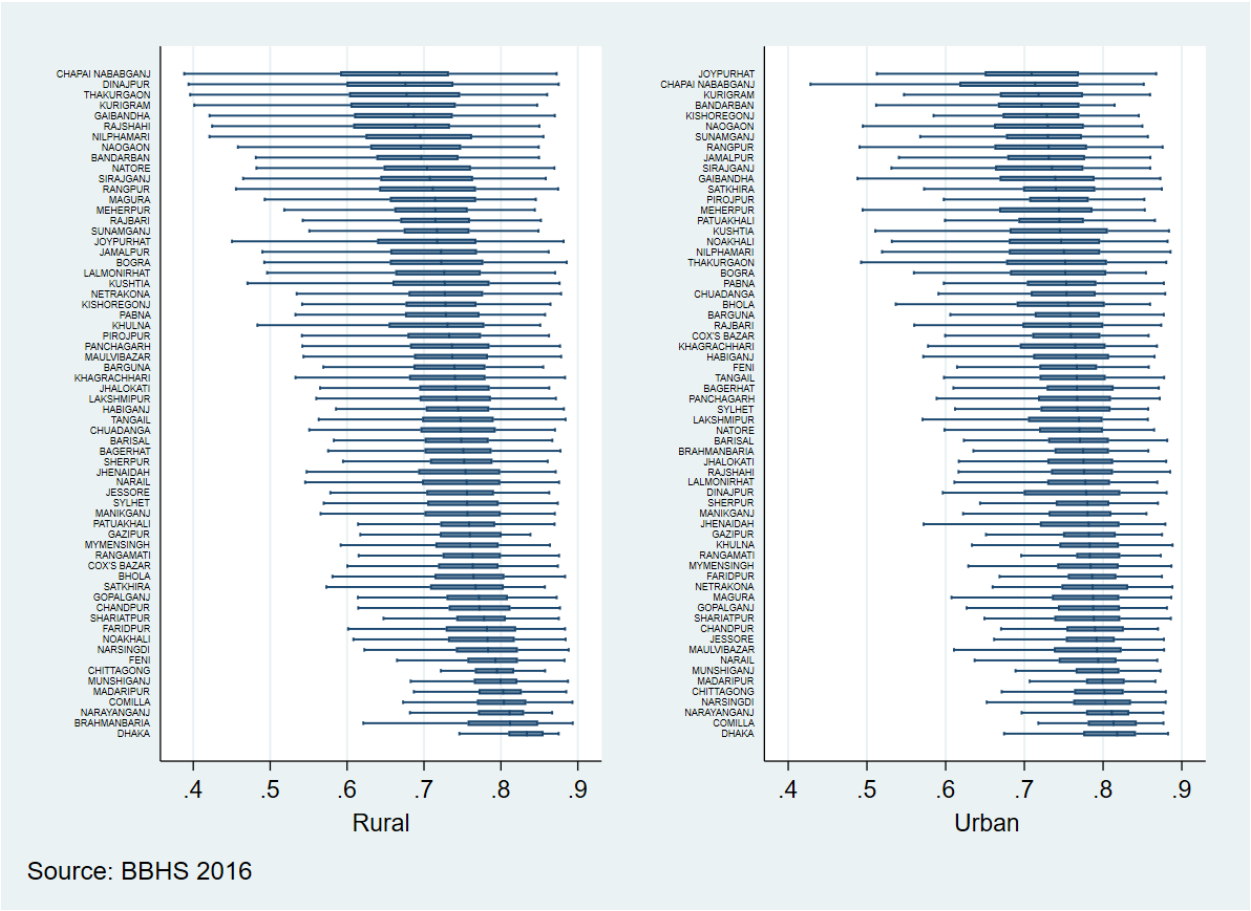

Figure A1: Distribution of Simpson index (dietary diversity) among rural and urban groups in Bangladesh

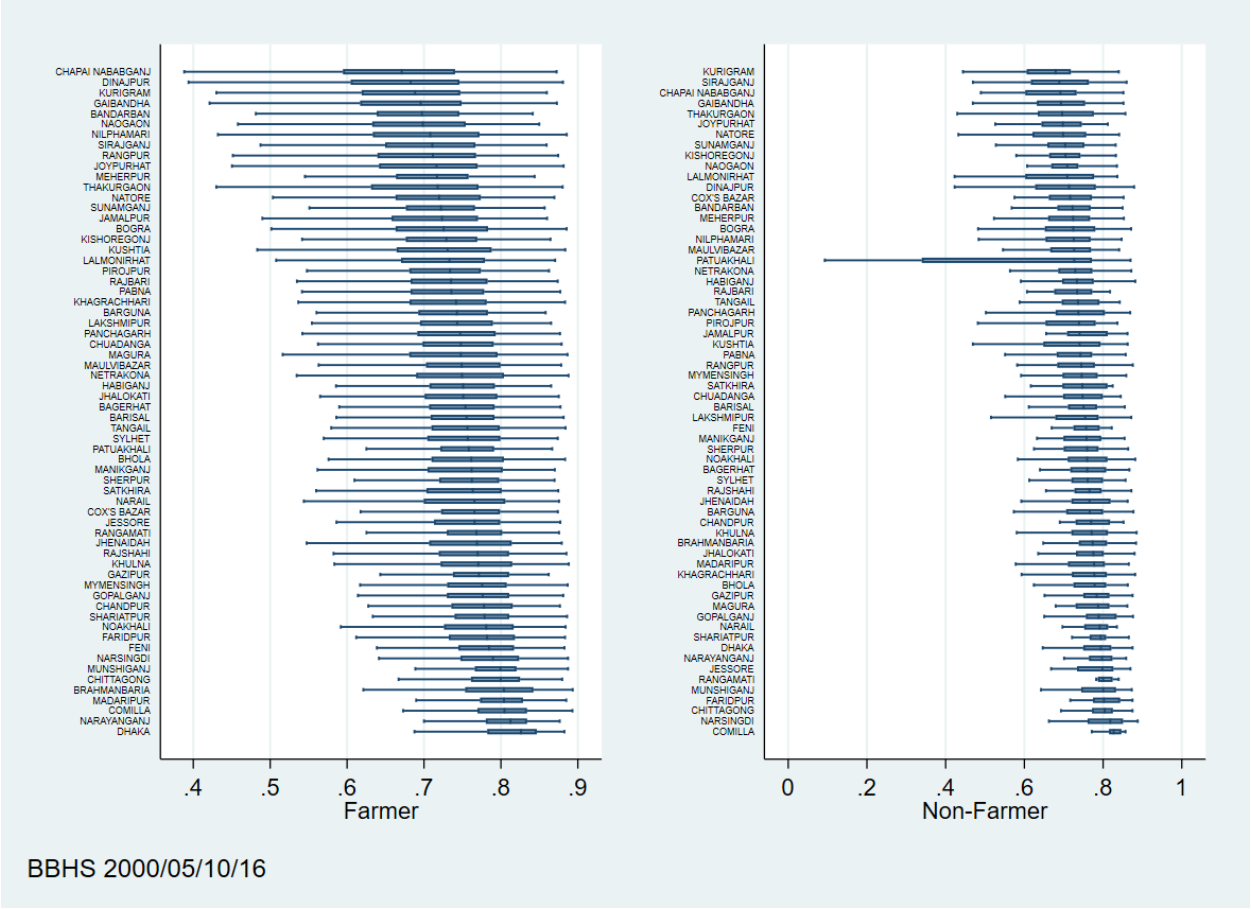

Figure A2: Distribution of Simpson index (dietary diversity) among farmer and non-farmer groups in Bangladesh