Farm Production Diversity and Dietary Diversity in Developing Countries

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Abstract

Enhancing the diversity of agricultural production systems is increasingly recognized as a potential means to sustainably provide diversified food for rural communities in developing countries, hence ensuring their nutritional security. However, empirical evidences connecting farm production diversity and farm-households' dietary diversity are scarce. Using comprehensive datasets of market-oriented smallholder farm households from Indonesia and Kenya, and subsistence farmers from Ethiopia and Malawi, the present study is carried out with an objective to investigate the effect of farm production diversity on households' dietary diversity, and the role of market access and other potential influencing factors. Often, farmers from the market-oriented production systems are found consuming more diversified diet than those from the subsistence systems. Even among the subsistence farms, the crucial role of farm diversity to augment dietary diversity is mixed and evident only among those who have limited access to food markets. While farm diversity enhances dietary diversity of Indonesian and Malawian households either through direct consumption, and/or by increasing and stabilizing farm income - which is also dependent on the type of crop on the farm. In Kenya and Ethiopia however no meaningful connection could be found. The study concludes that the link between farm production diversity and dietary diversity does not universally exist and diversifying diets through farm diversification need not require that the production system should be subsistence in nature.

Key words: Farm production diversity, Dietary diversity, Market access, Farm-household, Developing countries
JEL Codes: D13, I15, O12, Q10, Q12, Q18

1. Introduction

Hunger and malnutrition are complex global challenges that have become pivotal concerns in the formulation of policies and strategies to promote rural development in the global South. Although the share of global population affected by hunger significantly reduced from 60% to 15% during the past five decades (Godfray *et al.*, 2010), more than 800 million people are still suffering from chronic hunger with micronutrient deficiencies (FAO, 2013). These problems are of considerable relevance to the developing countries, where the majority of population derive food and employment directly from the agricultural sector. Hence, enhancing farm production diversity is increasingly recognized as a potential instrument to ensure supply of diverse food for rural communities in the developing countries (Khoury *et al.*, 2014; Jones *et al.,* 2014; Pellegrini & Tasciotti, 2014; World Economic Forum, 2013; Keding *et al.*, 2012; Remans *et al.*, 2011). Following the argument of causal relationship between farm production and dietary diversities, less-diversified agricultural systems could result in the loss of dietary diversity (Remans *et al.*, 2011), and induce health problems – obesity and non-communicable diseases – for rural households (Qaim *et al.*, 2014; Keding *et al.*, 2012; Frison, 2007). However, the transformation process connecting farming activities and nutritional outcomes involves more than just an increase in the quantity of food produced for subsistence consumption.

There could be different pathways through which farm diversity potentially influences dietary diversity, and the magnitude and direction of the effect depends on a multitude of confounding factors. The first major pathway could be directly by subsistence consumption of farm production (Jones *et al.,* 2014; World Bank, 2007). A number of studies indicated that diversified farming practices could improve farmers' health by improving nutritional profile of farm-produced foods that they consume (Keding *et al.,* 2012; Remans *et al.*, 2011; Arimond *et al.*, 2010; Frison*,* 2007; Deckelbaum *et al*., 2006; Arimond & Ruel, 2004; Schneeman, 2000). The second pathway is rather indirect, where market access as a confounding factor has a crucial role in defining the link between farm production and household nutrition. Smallholder farmers participate in agricultural markets both to sell part of their harvest, and using the cash income so obtained to purchase diverse foods that improve dietary quality (Qaim, 2014; FAO, 1998). Better market access could also facilitate farmers' involvement in specialized crop production and thereby to realize increased farm income (Qaim, 2014; World Bank, 2007). Jones *et al*. (2014) indicated that farmers who purchase food from the market might consume a more diversified diet.

However, other important factors could also determine whether the increased income leads to increase dietary quality. For example, Fischer and Qaim (2012) documented that apart from household income, gender plays a crucial role – control of women over farm revenues is found increasing dietary quality. So far, there have been only limited attempts to systematically analyse this link (Jones *et al*., 2014), and the existing literature fails to provide conclusive patterns. Among the few studies, diversified homestead production is linked to improved health of children in South Asia (Iannottti *et al*., 2009; Olney *et al*., 2009). Similar positive relationship is documented by Jones *et al.* (2014) and Pellegrini & Tasciotti (2014), while other recent studies could not establish such associations (Rajendran *et al.*, 2014; Remans *et al*., 2011). Furthermore, the global trend of declining number of food crop species (Khoury *et al*., 2014) upholds the relevance of research in this direction.

If rural food markets were well developed, increased farm income from specialization would result in households' greater dependability on markets as a source of food, making the first pathway less important. The existing literature hardly disaggregates between these two pathways and also the associated heterogeneity of effects. In other words, food items produced on farm is treated similar to those purchased from markets during the specified recall period (Jones *et al.,* 2014; Pellegrini & Tasciotti, 2014; Keding *et al.*, 2012). This paper also contributes to the literature on relevance of farm diversity by addressing the aforementioned research gap, by emphasising the role of market access and other confounding factors in shaping the relationship between farm diversity and dietary diversity. While this is not primarily an inter-country comparison, the study delineates common associations and patterns across households of multiple geographical locations, having starkly different political systems, agricultural activities, food habits and traditions.

2. Farm production diversity and dietary diversity indicators

Both farm diversity and dietary diversity are rather abstract concepts, modelling which necessitates the definition and description of relevant indicators. In this sub-section, these concepts are elaborated by reviewing the relevant literature.

In this study, the key variable and regressand is dietary diversity, which is a proxy variable for food security in nutrition surveys, and corresponds to various anthropometric measures (Pellegrini & Tasciotti, 2014; Moursi *et al*., 2008; Ruel, 2003). Dietary diversity is found positively associated with the intake of adequate nutrients and energy (Jones *et al*., 2014; Steyn *et al*., 2006; Kant, 2004), and is usually measured using two indicators – food variety score and dietary diversity score (Jones *et al*., 2014; Swindale & Bilinsky, 2006; Ruel, 2003; Drewnowski *et al*., 1997; Kant *et al.*, 1993). While the former is a simple count of the unique food items consumed (Drewnowski *et al*., 1997), dietary diversity score is the number of food groups consumed over a given recall period by the household (Ruel, 2003; Kant *et al.*, 1993). Due to the differences in dietary habits as well as the methodology used for data collection by different researchers, food variety scores might not be useful for an inter-country comparison. Instead, the differences in food-group indicator – dietary diversity score – could be computed (Pellegrini & Tosciotti, 2014; FAO, 2007). Different studies use different number of food groups for estimating the dietary diversity score. For example, Jones *et al*. (2014), Pellegrini & Tosciotti (2014) and Keding *et al.* (2012) categorized food items into 12-14 groups, respectively. Here, we use twelve food groups: cereals, white tubers and roots, legumes, legume products, nuts and seeds, vegetables and vegetable products, fruits, sweets sugars and syrups, meat, eggs, fish and fish products, milk and milk products, oils and fats, and spices, caffeine, and alcoholic beverages.

The most important explanatory variable across different models used in this paper is farm production diversity (farm diversity), which is a key component of agrobiodiversity. In the quantitative empirical analysis, agrobiodiversity indicators are adopted from the fields of biodiversity and ecology to measure the diversity of multispecies (Herforth, 2010; Di Falco & Chavas, 2009). A study conducted to identify potentially useful, feasible and relatively affordable tools to assess and monitor farming system agrobiodiversity recommended that farm species richness – the number of crop and livestock species on the farm – as a suitable indicator which can detect differences between farms, regions and dominant farm types (Last *et al*. 2014). For the present study, farm diversity is measured as a combined species count of crop and livestock across the production seasons in a year. Another species richness measure that is commonly used, and simple to calculate and interpret is a modified Margalef species richness index (Di Falco & Chavas, 2009; Meng *et al*., 1998; Smale *et al.,* 1998; Margalef, 1958)[1]. The Larger the index, the greater would be the crop species diversity per farm.

Another critical explanatory variable is household's access to food markets. In industrialized countries, food markets are functioning relatively well, nutritional information is readily accessible, and consumers can easily access diversified food items from supermarkets and grocery stores. In contrary, in most developing countries, markets for many food commodities are missing or limited to the seasonal wet markets, information is incomplete and asymmetric, and farm production is rather subsistence in nature (Dillon & Barrett, 2014; Hoddinot *et al*., 2014). In such cases, farm diversity may have a direct influence over dietary diversity (Pinstrup-Anderson, 2007; Schneeman, 2000). Variables, like distance to the nearest market, off-farm income, and whether harvest is sold in market, could be used as proxies for market access. Improved market access could generate seasonal agricultural labour, and supply inputs to rural petty manufacturing, handcrafts and groceries and improve expenditure on food consumption. Non-farm income is an important factor that generates cash, which allows rural households for a greater access to food (FAO, 1998). Here, off-farm income is defined as whether a farm household earns cash income from wage-paying activities, self-employments and other services that arise because of improved market access. Since the respondents are not temporary migrants who live only by farm wages and land rents, off-farm income and non-farm income could be used interchangeably in this study.

The contribution of dietary diversity to nutrients may also depend on socioeconomic, socio-cultural, farm and demographic factors (Jones *et al*., 2014; Pellegrini & Tasciotti, 2014, Keding *et al*., 2012; Remans *et al*., 2011). These variables may influence not only the choice of food consumed but also the choice of what and how much to produce, and hence would affect both farming and dietary diversity scores.

[1] The modified Margalef index *(D)* is computed as *(S-1)/ln(A)*, where *S* is the total number of crop species cultivated by the household and *ln(A)* is the natural logarithm of total cultivated area in square meters, with $A \geq 1$. Larger the index, the greater would be the crop species diversity in a given farm land. However, this index may not be compatible to measure diversity in crop-livestock systems.

3. Research methods and hypothesis

3.1. The data

The farm-household datasets, on which the study is built, are from four developing countries. The first two obtained from household surveys among market-oriented smallholder farmers of Indonesia and Kenya. The other two datasets are from the Integrated Household Survey of the World Bank Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) (37). The first round of LSMS-ISA dataset (2010-11) of Ethiopia and the third round of LSMS-ISA (2010-11) of Malawi are used. These datasets are from the nationally representative samples, comprising mostly of subsistence farmers, cultivating food crops and rearing livestock for home consumption (Jones *et al.,* 2014; World Bank, 2013b; Ethiopia Statistical Agency and World Bank, 2013). In all the four datasets, detailed information on food consumption over a 7-day recall period was collected.

The Indonesian dataset is based on a socioeconomic household survey covering 674 smallholder farmers from the Jambi province, Sumatra. Data were collected in 2012 through stratified random sampling approach to capture geographical and regional diversity. Further details are available at Krishna *et al*. (2014). Oil palm, plantation rubber and jungle rubber trees are the major crops. In addition, they practice diversified agricultural activities like cultivation staple crops, rear livestock, and rarely involve in fish culture.

The Kenyan dataset comprises of a sample of smallholder farmers in the rural Kiambu district, central province of Kenya, which supplies vegetables and other horticultural products to the capital city, Nairobi (Chege *et al*., 2014; Rao & Qaim, 2011). Using a structured questionnaire, the data were collected in 2012 from a sample of 397 smallholder farmers. A stratified random sampling approach was employed to select the respondents. The farm-households in the area are typical smallholder farmers with an average farm size about half a hectare. They practice different agricultural activities and engage in the production and marketing of vegetables to supermarkets and traditional channels. Many are also involved in small-scale livestock rearing. Further details are available at Chege *et al*. (2014).

Data on Malawi are drawn from the World Bank LSMS-ISA of 2010-11. The country representative survey was conducted between March 2010 and March 2011 (Jones *et al*., 2014; World Bank, 2013a; 2013b). A two-step stratified sampling methodology was used to collect data from a total of 12,671 farm household respondents distributed across three major regions of

Malawi. However, only 5,114 farm-households are included in this study, after omitting off-farming households, incomplete data points, and unclear conversion factors. Details of the household survey are also reported in Jones *et al*. (2014).

Nationally representative data from the Ethiopia Rural Socioeconomic Survey, implemented in collaboration with the World Bank LSMS team as part of the Integrated Surveys on Agriculture Program (38). A two-step probability sampling methodology was employed to select 3,969 households from rural and small town areas of Ethiopia. For the same reasons of the Malawian case, data from 2,045 households are used for this study. The datasets of Malawi and Ethiopia are collected employing a set of similar questionnaires. Detailed information about the household survey is also presented in Ethiopia Central Statistical Agency and World Bank (2013).

3.2. Research hypothesis and estimation methodology

The main objectives of this paper are to investigate (i) the effect of farm diversity on dietary diversity of farm-households, and (ii) the role of market access and other potential confounding factors in forging the relationship between these two variables. Four research hypotheses are constructed in this regard, and four sets of regression models are used to test them. We argue that, *ceteris paribus*, farmers diversify their production so as to ensure dietary diversity of home consumption. However, better market access could alter the relationship, as markets could provide diversified and seasonally-stable diet. Market-oriented farmers would be able to specialize in highly profitable cash crops and increase their farm income, which could be allocated to purchase nutrient-dense and diverse foods (Jones *et al*., 2014). With a better market access and the associated benefits like wide availability of off-farm income, and by selling of farm products and purchasing of better quality foods, the farm-households are expected to access more diversified diets and improve their nutritional status. Improved market access could also increase food availability across seasons for the rural poor by filling seasonal consumption gaps (Arimond *et al*., 2011).

The analytical procedure develops through four sets of regression models. The first set of regression models is specifically constructed to assess the link between dietary diversity and farm diversity, excluding all other covariates. In the succeeding set, the proxy variables for market access and interaction terms are included alongside farm diversity. In the third set, dietary diversity is calculated separately for the food items obtained from the market and its determinants are estimated. Finally, multiple regression models with all available covariates are constructed to examine the change in the effect of farm diversity. To provide direction, the following four research hypotheses are formulated.

Hypothesis 1. When the confounding factors are not controlled, farm diversity is positively associated with dietary diversity.

Model 1:

$$DD_i = \alpha_0 + \alpha_1 FPD_i + \alpha_2 FPD_i^2 + e_i$$

$$H_0: \frac{\delta DD}{\delta FSD} \equiv \alpha_1 + 2.\alpha_2 \overline{FPD} > 0$$

where DD_i is dietary diversity score and FPD_i is farm production diversity of i^{th} farm-household.

However, household's access to the markets could have an important role in defining the link between farm diversity and dietary diversity. Ignoring the linkages between farm specialization and nutrition may be to the disadvantage of the nutritional welfare of the poor (von Braun, 1995). Access to markets could weaken this as markets could act as an alternative source of nutrient-rich and diverse foods. On the other hand, access to markets could allow farmers to specialize on profitable farm enterprises, hence increase farm income that could be used to purchase diverse and quality food items. In this way, improved market access could increase dietary diversity.

Further, involvement in off-farm activities may also affect both farming diversity and dietary diversity. Farm-households are motivated to undertake off-farm income activities because of the risky nature of farming, institutional problems, and the relative profitability of off-farm activities (FAO, 1998). The study also suggested that farmers with better access to the off-farm income generating activities might have a higher food purchasing power and diversify their diets better from purchased foods. Hence, off-farm income opportunities help farmers to take risks of crop specialization and reduce farm diversity and create opportunities for consumption smoothing (filling the seasonal gaps) and separate decision-making between a farm and a household (FAO, 1998). Following hypothesis is constructed in this respect.

Hypothesis 2. The effect of farm diversity on dietary diversity is greater in magnitude when market access and off-farm income opportunities are limited.

Model 2:

$$DD_i = \beta_0 + \beta_1 FPD_i + \beta_2 FPD_i^2 + \beta_3 M_i + \beta_4 Of_i + \beta_5 M_i * FPD_i + \beta_6 Of_i * FPD_i + \varepsilon_i$$

$$H_0: \beta_5 > 0; H_0: \beta_6 < 0$$

where M_i is the distance from home to the nearest market (inversely related to market access), and Of_i is a dummy variable indicating household's involvement in off-farm activities. As mentioned earlier, distance to the market may have multiple, often contrasting, effects on household's dietary diversity. Farmers that are better connected with the markets would realize higher income from the increased trade opportunities resulting in an increase in disposable income, which could be utilized for ensuring increased dietary diversity. One way to distinguish the effect of household access to food markets is to estimate the dietary diversity of purchased foods obtained from the market.

H*ypothesis 3. The effect of farm diversity on dietary diversity weakens when only the purchased food items are included in computing dietary diversity.*

Model 3:

$$DD_{ij} = \gamma_0 + \gamma_1 FPD_i + \gamma_2 FPD_i^2 + \gamma_3 M_i + \gamma_4 Of_i + \gamma_5 M_i * FPD_i + \gamma_6 Of_i * FPD_i + \mu_i$$

Where, j = 1 for all food items consumed, j = 2 for purchased food items.

$$H_0: \frac{\delta DD_1}{\delta FSD} > \frac{\delta DD_2}{\delta FSD}$$

Finally, to what extent farm diversity and its interaction with market access affect dietary diversity could also be determined and controlled by various demographic characteristics, culture and traditions, religion and ethnicity, and nutritional knowledge (Jones *et al.,* 2014). Further analyse is required to test whether the relationship between farm and dietary diversity changes with the inclusion of these variables.

Hypothesis 4. Inclusion of socio-demographic characteristics in the regression model could alter the association between farm diversity and dietary diversity.

Model 4:

$$DD_i = \theta_0 + \theta_1 FPD_i + \theta_2 FPD_i^2 + \theta_3 M_i + \theta_4 Of_i + \theta_5 M_i * FPD_i + \theta_6 Of_i * FPD_i + \theta_7 Z_i + \upsilon_i$$

where, Z_i is the vector of socio-demographic characteristics of the household.

H_0: marginal effect of Model 4 ≠ marginal effect of Model 3 when j = 1; or

H_0: $[\theta_1 + 2.\theta_2\overline{FPD} + \theta_5\overline{M} + \theta_6\overline{Of}\,] \neq [\gamma_1 + 2.\gamma_2\overline{FPD} + \gamma_5\overline{M} + \gamma_6\overline{Of}\,]_{j\equiv1}$

In the pooled regression models, we have included country dummies as a proxy for agro-ecological conditions. Sample weights are also calculated and instrumented.

A common problem with multiple linear regression equations and using cross-section data is heteroskedasticity, that the existence of sub-populations with different variabilities (Greene, 2012). To avoid heteroskedasticity in the estimates, robust standard errors are used across the models. The Poisson regression methods are tested for degree of dispersion and Poisson goodness-of-fit for their applicability with respect to the dependent variables. The choice of variables was determined partly by a study of the literature and partly by the availability of data.

4. Results

4.1. Descriptive statistics

The details of selected dependent and explanatory variables across study areas are shown in Table 1. The sample households are smallholder farmers with an average farm size of 1.23 hectares. Indonesian farmers are found having large farms (4.5 hectares), as higher positive returns-to-scale is possible with perennial cash crops, such as oil palm and rubber trees. Farm species diversity is found lowest in Indonesia (1.7 species/farm) followed by Malawi (4.8). In comparison, Kenyan and Ethiopian farms are more diverse with 7.8 and 10.2 species, respectively. Computation of modified Margalef richness index, which normalizes the species richness by accounting for the area under cultivation, provides comparable results (Table 1).

[Table 1 about here]

Dietary diversity is high in Kenya with an average household consuming 11.4 food groups (Table 1) out of 12. It is also high in Indonesia (10.0), but relatively low among the farmers of Malawi (8.5) and Ethiopia (5.4). There is a significant difference between the study nations. While Indonesian and Kenyan farmers produce agricultural commodities primarily for the market, Ethiopian and Malawian farmers involve largely in subsistence production. When only the purchased food items are included in the computation, drastic reduction occurred in both food variety and dietary diversity scores in these countries (Table 1). This is indicative of the subsistence nature of farm production.

A quick inter-country comparison would imply that specialization in cash crops (e.g. Indonesian farmers in oil palm and rubber and Kenyan farmers in vegetables) is the key to diversifying household diets than to maintain a highly diversified subsistence farming system. However, the role of confounding factors, especially the market access, could not be overlooked. Multiple regression models are used to delineate the individual effects. The important indicator for market access is the distance from place of residence to the nearest food market. Significant inter-country differences are observed; sample farmers from Kenya are travelling 3 kilometres, while Ethiopian farmers 64 kilometres to reach the nearest market. Another variable determining market access is households' involvement in off-farm income generating activities. The involvement in off-farm activities is low among Ethiopian (32% of sample) and Malawian (35%) households compared to their Indonesian (48%) and Kenyan (51%) counterparts. The other variables – relevant only for Ethiopian and

Malawian cases as not much variability exist for the other two countries – are the share of food purchased and whether the households sell farm produce in the market. About 41% of the Ethiopian households stated selling at least some portion of their harvest to the market compared to 12% in Malawi. In both Ethiopia and Malawi, a large share (40-45%) of food consumed by the households comes from the subsistence production.

4.2. Linking farm production diversity to household dietary diversity

In this section, we test first of the four research hypotheses, so as to understand the basic connection between farm diversity and household dietary diversity. Four country-specific models and one pooled regressions model are estimated to test the hypothesis that farm production diversity is positively associated with household dietary diversity, when the confounding factors are not controlled. The regression coefficients and marginal effects are shown in Table 2. In this simplified version, farm diversity positively affects to the dietary diversity of Indonesia, Malawi and in the pooled sample. The marginal effects show that, neglecting the influence of other confounding factors, increasing farm production diversity by one species increases dietary diversity score by 0.54, 0.13, and 0.08 units in Indonesia, Malawi, and the pooled sample respectively. Although positive, the effect is not statistically significant in Kenya and Ethiopia. The marginal impact of farm diversity is the highest when the farm diversity at the lowest in a system, possibly indicating diminishing returns of diversity as a production input. The negative coefficient of the square term in case of Indonesia, Malawi and the pooled samples also denotes that the size of effect diminishes with increase in farm diversity.

[Table 2 about here]

In order to check the possible bias due to variable measurement, models are estimated with food variety score as dependent variable, and Margalef crop species richness index in place of simple farm species richness count. Across the countries, Margalef crop species richness index is strongly correlated with farm species count (Table A1). Although the food variety score variable is not compatible for cross-country analysis and, regressions with this as the dependent variable yielded comparable results with in the countries (Table A2). The regression estimates with Margalef species richness index as the measure of farm diversity are consistent to the estimates with simple species count in most cases, except in the Ethiopian case that a positive and significant effect is observed (Table A3). The estimated positive effects provide evidence for the widespread perception that the farm diversity has important role in augmenting farm-households' dietary diversity. Besides, this analysis indicates that the relationship need not always be linear. However, due to existence of factors that would shape the relation between farm diversity and dietary diversity, further analyses are carried out.

4.3. Role of market access and other confounding factors in defining the link

As the second step in the analysis, we examine how the effect of farm diversity on dietary diversity changes when the regression models are expanded with additional variables depicting market access. The estimation results are shown in Table 3. The effect of farm diversity on dietary diversity remained positive and significant in Indonesia, Malawi and in the pooled sample. Distance to the nearest market is found negatively and significantly affecting the dietary diversity in Ethiopia, Malawi and in the pooled model. This implies that farm-households located nearer to the markets enjoy greater dietary diversity – denoting the prominence of income effect from increased trade opportunities. More importantly, the interaction between farm diversity and distance to market is statistically insignificant in these models, except in Malawi. Hence we cannot prove the hypothesis that effect of farm diversity on dietary diversity is higher in the remote areas. Off-farm income generating activities have positive impact on dietary diversity in Kenya, Ethiopia, Malawi, as well as in the pooled sample. However, its interaction effect with farm diversity is negative in Malawi and the pooled sample and positive in Indonesia, limiting the scope for generalization.

[Table 3 about here]

Since the "distance to the market" variable yielded only insignificant coefficients, an examination of the dietary diversity of food items obtained from purchases gains significant relevance. In Ethiopia and Malawi, most of the sample farmers produce mainly for subsistence consumption (*cf.* Table 1). The regression estimates with dietary diversity of food items from purchases are provided in Table 4. Interesting patterns are revealed from the estimates, when the food is partitioned based on source of production. A negative effect is obtained for food production diversity in all the models with the food items consumed from purchases. This reflects that with increasing species diversity on the subsistence farms, households rely less and less on purchased foods for dietary diversity. Further, the farm diversity negatively interacts with the distance to the market, indicating that the contribution of farm diversity to dietary diversity of purchased foods is higher for farm-households with better access to the market.

[Table 4 about here]

As the next step, a number of socio-demographic variables are added in the regression models to test whether the marginal effect of farm diversity changes. Some of them are directly related to the market access, viz. percentage of harvest sold. This variable is included only for Ethiopia and Malawi, as most of the farm output is sold in Indonesia and Kenya. The factor is interacted with farm diversity variable to obtain the differential effects of farm diversity. The estimated coefficients for all confounding factors are provided in the Appendix, Table A4. When the estimates from inclusion of the socio-economic factors with those from Tables 2 and 3 for Malawi are compared, the effect of farm diversity on dietary is not changing much in most of the models. The farmers' dietary diversity seems relying very much on the farm diversity. However, it is seen in Table 4, the market access could reduce the magnitude or even alter the direction of the effect.

Particularly, inclusion of socio-economic factors does not drastically affect the marginal impact of farm diversity in Indonesia. But, the Indonesian case is rather unique with farmers cultivating perennial cash crops for the international markets. On the other hand, the impact of farm diversity remained insignificant in Kenyan and Ethiopian models even after the inclusion of confounding variables. Kenyan farmers focus on cultivation of vegetable crops for the market, and when the farmers have better market access their dependency on farm diversity to augment dietary diversity naturally reduces. The insignificant effect of farm diversity in Kenya could be also due to the general proximity to the market, and that the sample farmers are already enjoying a high dietary diversity, increasing which might be beyond the scope of farm diversity. With the Ethiopian case, although most of the farmers are subsistence still farm diversity has only an insignificant effect, possibly due to very high concentration of crop-livestock species on a small farmland. The contribution of farm diversity to dietary diversity of purchased foods is higher for farm-households with better access to the market.

In sum, irrespective of the degree of market access, farm diversity could affect for dietary diversity of farming households. Only the effect pathway changes – in the subsistence systems, it is seems through increased consumption of farm-produced goods, and in the market-oriented systems through increasing and stabilizing the farm income across seasons and/or direct consumption of farm products.

5. Discussion and Conclusion

The study examined the role of farm production diversity in ensuring dietary diversity among smallholder farmers of developing countries. Farm diversity is found to have a positive implication for dietary diversity of Indonesian and Malawian farming households, but not necessarily through ensuring subsistence consumption. The farm income impact of diverse farming system could be more pronounced. On the other hand, farm diversity does not affect dietary diversity in Kenya and

Ethiopia, even after controlling market access and other confounding factors.

We found out that the sub-samples of farmers with market-oriented production (Indonesia and Kenya) consume more diversified diet than those from subsistence systems (Ethiopia and Malawi). Among the subsistence farmers also, the market access weakens the household's dependability on farm diversity to ensure dietary diversity of purchased food items. Nevertheless, higher farm diversity and better market access need not be substitutes in ensuring food security in the global South, especially in areas where farmers own bigger farmlands and specialize on tree crops which is an advantage for intercropping of food crops and animal feed for home consumption. The seasonal nature of the agricultural industry should also be considered. Diversifying diets through diversified farms need not require that the production system should be subsistence in nature. In systems with cash crops in the species portfolio, market access and farm diversity could together yield significant income effects that would lead to increased consumption of diverse food items. However, it is not universally true that a positive link exists between farm diversity and dietary divers. Further research is necessary to delineate the pathways through which farm production diversification affect dietary diversity.

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7. Tables

Table 1. Descriptive statistics, disaggregated by country.

Household characteristics	Indonesia	Kenya	Ethiopia	Malawi	Pooled
Cultivated land area per household (hectare)	4.50 (7.42)	0.71 (0.94)	1.63 (1.91)	0.74 (0.60)	1.23 (2.16)
Farm production diversity (number of species)	1.74 (0.91)	7.82 (2.58)	10.19 (5.81)	4.80 (3.08)	6.13 (4.75)
Margalef species richness diversity index	0.16 (0.10)	0.79 (0.28)	0.85 (0.65)	0.28 (0.25)	0.44 (0.47)
Food variety score: all food (number of items)	29.58 (8.11)	24.68 (4.64)	7.91 (2.31)	16.68 (6.72)	15.94 (8.43)
Food variety score: purchased food (number of items)	--	--	4.50 (2.27)	12.13 (5.82)	--
Dietary diversity score: all food items (number of groups)	10.02 (1.29)	11.40 (0.97)	5.42 (1.70)	8.48 (2.02)	7.99 (2.48)
Dietary diversity score: Purchased foods (number of groups)	--	--	3.47 (1.68)	7.37 (2.33)	--
Distance to the nearest market (km)	6.55 (7.41)	3.09 (3.58)	63.53 (47.50)	8.17 (5.71)	21.27 (33.37)
Off-farm income (1-yes & 0-no)	0.48	0.51	0.32	0.35	0.36
Food purchase from market (% of total food)	--	--	54.75 (21.11)	61.33 (19.68)	--
Harvest sold in the output market (1-yes & 0-no)	--	--	0.41	0.12	--
Sample size	674	397	2045	5114	8230

Notes: Figures in parentheses show standard deviation. For brevity not all variables are reported.

Table 2. Farm production diversity on household dietary diversity.

Explanatory variables	Indonesia	Kenya	Ethiopia	Malawi	Pooled
Farm production diversity	0.054*** (0.015)	0.003 (0.010)	0.002 (0.004)	0.015*** (0.002)	0.009*** (0.002)
Farm production diversity squared	-0.007*** (0.003)	1.4E-04 (5.7E-04)	1.3E-04 (1.5E-04)	-3.2E-04** (1.4E-04)	-1.4E-04* (8.6E-05)
Pseudo R^2	0.001	<0.001	0.001	0.002	0.121
Number of observations	674	397	2045	5114	8230
Estimated marginal effect of farm species diversity	0.544*** (0.154)	0.031 (0.111)	0.010 (0.023)	0.131*** (0.021)	0.081*** (0.017)

Notes: Dependent variable is dietary diversity scores of farm-households. All models are Poisson regressions. In the pooled model country dummies and sample weights are included. Figures in parentheses show the robust standard errors of coefficient or marginal effect. *, **, ***: p<0.1, p<0.05, and p<0.01 respectively.

Table 3. Farm production diversity and market access on household dietary diversity.

Explanatory variables	Indonesia	Kenya	Ethiopia	Malawi	Pooled
Farm production diversity	0.048***	0.001	0.006	0.011***	0.010***
	(0.016)	(0.010)	(0.004)	(0.003)	(0.002)
Farm production diversity squared	-0.008***	2.0E-04	1.1E-04	-1.5E-04	-1.5E-04
	(0.003)	(0.001)	(1.5E-04)	(1.5E-04)	(9.7E-05)
Distance to the nearest market	-0.002	-0.006	-0.001*	-0.014***	-0.001***
	(0.002)	(0.005)	(3.1E-04)	(0.002)	(2.6E-04)
[Farm production diversity] x	-6.9E-05	5.0E-04	-2.0E-05	4.3E-04*	1.6E-05
[Distance to market]	(0.001)	(5.5E-04)	(2.6E-05)	(2.2E-04)	(2.0E-05)
Off-farm income	-0.009	0.059**	0.073**	0.083***	0.039***
	(0.020)	(0.029)	(0.029)	(0.013)	(0.008)
[Farm production diversity] x [Off-	0.020**	-0.002	-3.5E-04	-0.004*	-0.002*
farm income]	(0.010)	(0.003)	(0.002)	(0.002)	(0.001)
Pseudo R^2	0.002	0.001	0.009	0.020	0.122
Number of observations	674	397	2045	5114	8230
Estimated marginal effect of farm	0.571***	0.005	0.027	0.078***	0.080***
species diversity	(0.150)	(0.111)	(0.023)	(0.027)	(0.017)

Notes: Dependent variable is dietary diversity scores of farm-households. All models are Poisson regressions. In the pooled model country dummies are included. Figures in parentheses show the robust standard errors of coefficient or marginal effect. *, **, ***: p<0.1, p<0.05, and p<0.01 respectively.

Table 4. Farm production diversity and market access on household dietary diversity of food obtained from the purchases in Ethiopia and Malawi.

Explanatory variables	All Food			Purchased Food		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Farm production diversity	0.011***	0.011***	0.010***	-0.013***	-0.012***	-0.013***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
Farm production diversity	-1.6E-04*	-1.0E-04	6.2E-06	3.8E-04***	0.001***	0.001***
squared	(9.1E-05)	(1.0E-04)	(1.1E-04)	(1.4E-04)	(1.5E-04)	(1.5E-04)
Distance to the nearest	--	-4.3E-04	-4.4E-04*	--	-0.002***	-0.002***
market		(2.7E-04)	(2.7E-04)		(4.7E-04)	(4.7E-04)
[Farm production diversity]	--	-3.2E-05	-2.6E-05	--	-1.1E-04***	-9.1E-05**
x [Distance to market]		(2.2E-05)	(2.2E-05)		(3.8E-05)	(3.8E-05)
Harvest sold in to the	--	--	0.045***	--	--	0.020
market			(0.016)			(0.021)
[Farm production diversity]	--	--	-0.005***	--	--	-0.007***
x [Harvest sold]			(0.002)			(0.002)
Off-farm income	--	--	0.075***	--	--	0.099***
			(0.011)			(0.015)
[Farm production diversity]	--	--	-0.001	--	--	0.001
x Off-farm income]			(0.001)			(0.002)
Malawi (country dummy)	0.489***	0.454***	0.479***	0.724***	0.583***	0.572***
	(0.009)	(0.011)	(0.011)	(0.013)	(0.017)	(0.017)
Pseudo R^2	0.075	0.076	0.078	0.131	na	na
Number of observations	7159	7159	7159	7159	7159	7159
Estimated marginal effect of	0.074***	0.078***	0.061***	-0.071***	-0.064***	-0.076***
farm species diversity	(0.014)	(0.014)	(0.014)	(0.016)	(0.015)	(0.016)

Notes: Dependent variables are dietary diversity scores of farm-households. All models are Poisson regressions. Figures in parentheses show the robust standard errors of coefficient or marginal effect. Some variables are dropped for brevity. *, **, ***: p<0.1, p<0.05, and p<0.01 respectively. na – not applicable because of the distribution of the dependent variable.

8. Appendix

Table A1. Correlation between farm production diversity (species count) and Margalef crop species richness index

	Indonesia	Kenya	Ethiopia	Malawi	Pooled
Correlation coefficient	+0.80***	+0.86***	+0.82***	+0.90***	+0.90***

Note: ***: p<0.01.

Table A2. Farm production diversity on food variety score

Explanatory variables	Indonesia	Kenya	Ethiopia	Malawi
Farm production diversity	0.128***	-0.006	0.008**	0.023***
	(0.031)	(0.020)	(0.004)	(0.004)
Farm production diversity	-0.013**	0.001	4.3E-05	--4.1E-04*
squared	(0.005)	(0.001)	(1.4E-04)	(2.3E-04))
Pseudo R^2	0.015	0.003	0.005	0.007
Number of observations	674	397	2045	5114
Estimated marginal effect of	3.794***	-0.148	0.062***	0.383***
farm species diversity	(0.928)	(0.485)	(0.031)	(0.069)

Notes: Dependent variable is food variety score. All models are Poisson regressions. Figures in parentheses show the robust standard errors of coefficient or marginal effect. *, **, ***: p<0.1, p<0.05, and p<0.01 respectively.

Table A3. Farm production diversity on household dietary diversity.

Explanatory variables	Indonesia	Kenya	Ethiopia	Malawi	Pooled
Margalef species diversity	0.310**	-0.024	0.038**	0.094***	0.049***
index (Margalef index)	(0.158)	(0.080)	(0.018)	(0.027)	(0.011)
Margalef index squared	-0.321	0.029	0.004	-0.013	0.001
	(0.320)	(0.047)	(0.005)	(0.021)	(0.003)
Pseudo R^2	0.001	0.0001	0.002	0.001	0.121
Number of observations	674	397	2,045	5,114	8,230
Estimated marginal effect of	2.078***	0.256	0.251***	0.736***	0.447***
farm species diversity	(0.668)	(0.171)	(0.050)	(0.175)	(0.078)

Notes: Dependent variable is dietary diversity scores of farm-households. All models are Poisson regressions. In the pooled model country dummies and sample weights are included. Figures in parentheses show the robust standard errors of coefficient or marginal effect. *, **, ***: p<0.1, p<0.05, and p<0.01 respectively.

Table A4. Farm production diversity on dietary diversity, with all confounding factors

Explanatory variables	Indonesia	Kenya	Ethiopia	Malawi	Pooled
Farm production diversity	0.044***	0.008	0.004	0.012***	0.008***
	(0.014)	(0.009)	(0.004)	(0.003)	(0.002)
Farm production diversity squared	-0.007***	-2.0E-04	1.7E-04	-3.4E-04**	-1.3E-04
	(0.003)	(0.001)	(1.5E-04)	(1.4E-04)	(9.4E-05)
Distance to the nearest market	-0.001	-0.005	-3.9E-04	-0.004***	-0.001***
	(0.002)	(0.004)	(2.9E-04)	(0.002)	(2.5E-04)
[Farm production diversity] x [Distance to market]	1.7E-04	3.5E-04	-3.9E-05	1.4E-04	3.1E-06
	(0.001)	(4.4E-04)	(2.4E-05)	(1.8E-04)	(1.9E-05)
Harvest sold in to the market	--	--	-0.001	2.0E-04***	--
			(0.002)	(4.9E-05)	
[Farm production diversity] x [Harvest sold]	--	--	-0.002	-0.005**	--
			(0.002)	(0.002)	
Off-farm income	-0.003	0.011	0.083***	0.051***	0.037***
	(0.020)	(0.023)	(0.028)	(0.010)	(0.008)
[Farm production diversity] x [Off-farm income]	0.013	-0.003	-0.002	-0.002	-0.001
	(0.009)	(0.003)	(0.002)	(0.002)	(0.001)
Cultivated land area	0.001**	0.013***	-2.7E-03	0.003	0.006***
	(4.6E-04)	(0.004)	(0.003)	(0.003)	(0.001)
Age of household head: (years)	8.8E-05	-0.001*	-0.002***	-0.002***	-0.001***
	(4.4E-04)	(3.3E-04)	(4.8E-04)	(2.1E-04)	(1.9E-04)
Gender of household head: (1-male & 0-female)	0.022	0.027**	0.025	0.022***	0.029***
	(0.020)	(0.013)	(0.019)	(0.008)	(0.007)
Education level of household head: (years)	0.006***	0.003**	0.017***	0.005***	0.009***
	(0.002)	(0.001)	(0.002)	(0.001)	(0.001)
Household size: (count)	0.008**	-0.001	0.013***	0.021***	0.007***
	(0.004)	(0.003)	(0.003)	(0.001)	(0.001)
Ownership of vehicles: (1-yes & 0-no)	0.046***	--	--	--	--
	(0.012)				
Household is transmigrant: (1-yes & 0-no)	-0.016	--	--	--	--
	(0.011)				
Ethnicity: (1-Javanese & 0-othters)	0.011	--	--	--	--
	(0.011)				
Nutritional training: (1-yes & 0-no)	--	0.018*	--	--	--
		(0.010)			
Electricity access: (1-yes & 0-no)	--	0.025**	--	0.030***	--
		(0.012)		(0.011)	
Use irrigation on farm: (1-yes & 0-no)	--	0.035**	--	--	--
		(0.017)			
Female involved in production decision: (1-yes & 0-no)	--	0.007	--	--	--
		(0.009)			
Animal product sold: (1-yes & 0-no)	--	--	0.075***	--	--
			(0.014)		

Notes: Dependent variable is dietary diversity score of farm-households. Poisson regression is used in all models. In the pooled model country dummies and sample weights are included. Figures in parentheses show the robust standard errors of coefficients or marginal effects. *, **, ***: p<0.1, p<0.05, and p<0.01 respectively.

Table A4. Continuation

Explanatory variables	Indonesia	Kenya	Ethiopia	Malawi	Pooled
Rural or urban: (Rural=1 & Urban=0)	--	--	--	-0.061***	--
				(0.009)	
Household income is above the poverty line (1-above & 0-below)	--	--	--	0.224***	--
				(0.006)	
Religion: (1-christian & 0-others)	--	--	--	-0.019**	--
				(0.009)	
Credit access: (1-yes & 0-no y)	--	--	--	0.013*	--
				(0.007)	
Energy for cooking: (1-electricity and others & 0-firewood)	--	--	--	0.066***	--
				(0.008)	
Mother educated: (1-yes & 0-no)	--	--	--	0.029***	--
				(0.008)	
Region dummy in reference to North: Central	--	--	--	-0.043***	--
				(0.008)	
Region dummy in reference to North: South	--	--	--	-0.013*	--
				(0.007)	
Country dummy in reference to Ethiopia: Indonesia	--	--	--	--	0.545***
					(0.014)
Country dummy in reference to Ethiopia: Kenya	--	--	--	--	0.623***
					(0.013)
Country dummy in reference to Ethiopia: Malawi	--	--	--	--	0.386***
					(0.011)
Model intercept	2.139***	2.304***	1.582***	1.943***	1.615***
	(0.044)	(0.053)	(0.042)	(0.021)	(0.017)
Pseudo/Adjusted R^2	0.005	0.003	0.014	0.040	0.126
Number of observations	674	397	2,045	5,114	8,230
Estimated marginal effect of farm species diversity	0.497***	0.071	0.014	0.090***	0.0692***
	(0.141)	(0.103)	(0.023)	(0.024)	(0.016)

Notes: Dependent variable is dietary diversity score of farm-households. Poisson regression is used in all models. In the pooled model country dummies and sample weights are included. Figures in parentheses show the robust standard errors of coefficients or marginal effects. *, **, ***: p<0.1, p<0.05, and p<0.01 respectively.