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Farm production diversity and dietary quality: linkages and measurement issues

Kibrom T. Sibhatu[1] · Matin Qaim[1]

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Abstract

Recent research has analyzed whether higher levels of farm production diversity contribute to improved diets in smallholder farm households. We add to this literature by using and comparing different indicators, thus helping to better understand some of the underlying linkages. The analysis builds on data from Indonesia, Kenya, and Uganda. On the consumption side, we used 7-day food recall data to calculate various dietary indicators, such as dietary diversity scores, consumed quantities of fruits and vegetables, calories and micronutrients, and measures of nutritional adequacy. On the production side, we used a simple farm species count in addition to looking at the number of different food groups produced. Regression models showed that production diversity measured through simple species count is positively associated with most dietary indicators. However, when measuring production diversity in terms of the number of food groups produced, the association turns insignificant in many cases. Further analysis revealed that diverse subsistence production often contributes less to dietary diversity than cash income generated through market sales. If farm diversification responds to market incentives and builds on comparative advantage, it can contribute to improved income and nutrition. Yet, increasing the number of food groups produced on the farm independent of market incentives may foster subsistence, reduce income, and thus rather worsen dietary quality. The results suggest that improving the functioning of agricultural markets and smallholder market access are key strategies to enhance nutrition.

Keywords Dietary diversity · Micronutrients · Nutrition-sensitive agriculture · Smallholder farm households · Developing countries

1 Introduction

Agricultural modernization over the last few decades has primarily focused on a few crop species, especially cereals. The resulting production increases have contributed considerably to reducing hunger and improving peoples' access to calorie-dense staple foods (Godfray et al. 2010; Khoury et al. 2014; Pingali 2015). However, in addition to calories, healthy nutrition requires access to a wide range of nutrients. Micronutrient deficiencies in particular are still widespread, causing multiple serious health problems and significant economic and humanitarian costs (Horton and Steckel 2013; IFPRI 2017). To improve nutrition more broadly, stronger emphasis needs to be on promoting dietary quality and diversity.

Many of those people globally affected by nutritional deficiencies live in smallholder farm households in developing countries (Muller 2009; Barrett 2010). These households largely depend on agriculture for their livelihoods. Against this background, the question as to how to make smallholder agriculture more nutrition-sensitive has recently gained significant interest among researchers and policymakers (Remans et al. 2011; Keding et al. 2012; Pinstrup-Andersen 2013; Ruel and Alderman 2013; Fanzo 2017; Qaim 2017). Often, the promotion of production diversity on smallholder farms is seen as a promising strategy (Burlingame and Dernini 2012; Fanzo et al. 2013; Powell et al. 2015). As small farm

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✉ Kibrom T. Sibhatu
ksibhat@uni-goettingen.de

Matin Qaim
mqaim@uni-goettingen.de

[1] Department of Agricultural Economics and Rural Development, University of Goettingen, 37073 Goettingen, Germany

households typically consume a substantial share of what they produce, production diversity could directly translate into consumption diversity and thus improve dietary quality through this subsistence pathway. Several recent studies have empirically analyzed the relationship between farm production and dietary diversity (Oyarzun et al. 2013; Pellegrini and Tasciotti 2014; Jones et al. 2014; Sibhatu et al. 2015; Snapp and Fisher 2015; Koppmair et al. 2017; Jones 2017). Most of these studies suggest that farm production diversity has a positive influence on people's diets, although the magnitude of the estimated effect varies. Sibhatu et al. (2015) used data from various countries and showed that the production diversity effect tends to be small, and sometimes insignificant. Results from Sibhatu et al. (2015), Snapp and Fisher (2015), Hirvonen and Hoddinott (2017), and Koppmair et al. (2017) suggest that access to markets may sometimes be more important for nutrition than increasing farm production diversity. Loos and Zeller (2014) also documented that income generated through sales of farm produce contributes strongly to dietary quality. However, various questions remain, especially concerning the indicators used to measure production diversity and dietary quality. The choice of indicators may possibly affect the relationship in important ways (Luckett et al. 2015; Berti 2015; Verger et al. 2017).

In order to design policies towards more nutrition-sensitive agriculture, it is important to better understand the role of production diversity for farm household diets and nutrition. Should further diversification of smallholder production systems be promoted, and – if so – what kind of diversification and under what conditions? Here, we contribute to this research direction by using data from different countries and comparing alternative indicators.

On the consumption side, previous studies used household dietary diversity scores as dietary indicators (Jones et al. 2014; Sibhatu et al. 2015; Snapp and Fisher 2015). Dietary diversity scores count the number of different food groups consumed by the household over a certain period of time. These scores are generally accepted as good and easy-to-measure proxies for the household's economic access to food (Ruel 2003; Swindale and Bilinsky 2006; Headey and Ecker 2013). However, eventually it is not the number of food groups that matters for healthy nutrition, but the supply of all essential nutrients in sufficient quantities. Hence, in addition to using dietary diversity scores with different food group classifications, we also examine how production diversity relates to other dietary indicators, such as the consumption of fruits and vegetables, micronutrients, and measures of nutritional adequacy.

On the production side, previous studies used a simple count of all crop and livestock species produced on a farm as the main indicator of production diversity (Jones et al. 2014; Sibhatu et al. 2015; Snapp and Fisher 2015). However, different species have different nutritional functions, so that the type of farm diversification can matter for effects on household diets (DeClerck et al. 2011; Remans et al. 2014; Berti 2015). For instance, the dietary quality effect of growing sorghum in addition to maize may be smaller than that of adding a pulse or vegetable crop to a cereal-dominated production system. Hence, in addition to using a simple species count, we also employ an indicator that explicitly considers the nutritional functions of the different commodities produced on a farm. Comparison of results across the different indicators also helps to shed more light on the mechanisms underlying the production and dietary quality link.

The empirical research builds on survey data from Indonesia, Kenya, and Uganda.[1] The data from all three countries were collected in specific regions and are not nationally representative. Nevertheless, comparing these cases can help to gain insights into the linkages between farm production diversity and household diets under different conditions. For the comparisons it is advantageous that the relevant data on farm production and household food consumption in all three countries were collected using the same survey format.

2 Materials and methods

The main research objective pursued in this study is to better understand the relationship between production diversity and dietary quality in smallholder farm households and the underlying mechanisms. We start this section by giving a short description of the surveys conducted in Indonesia, Kenya, and Uganda and the regional settings. After that, we explain the different indicators used to characterize household diets and farm production diversity, before introducing the statistical approaches.

2.1 Data sources

We use data from surveys of smallholder farm households in Indonesia, Kenya, and Uganda. We planned and conducted all three surveys in 2012 for different research projects (Euler et al. 2017; Chege et al. 2015; Chiputwa and Qaim 2016). However, as the relevant questionnaire sections on farm production and household diets were almost identical, using and comparing the data from all three countries for the purpose of this analysis can be instructive. In all three countries, the surveys are not nationally representative but focus on specific regions in which smallholders produce food and cash crops to varying degrees. Within the selected regions, a multistage sampling procedure was used, with random selection of

[1] The data from Indonesia and Kenya were also used by Sibhatu et al. (2015) to analyze the relationship between production diversity and dietary diversity. However, Sibhatu et al. (2015) did not employ and compare different indicators of production diversity and dietary quality, as we do here.

individual farm households at the last stage. The data in all three countries were collected right after the main harvest season.

In Indonesia, we surveyed 672 farm households in Jambi Province on Sumatra Island. Farmers in Jambi are often specialized in plantation cash crops, notably rubber and oil palm (Euler et al. 2016). Some of the sample farmers do not produce any food themselves, others have small plots with maize, rice, and horticultural crops, sometimes supplemented with livestock and aquaculture production (Euler et al. 2017). In Kenya, the sample comprised 393 farm households from Kiambu County, an important vegetable-growing area in Central Kenya (Chege et al. 2015). Sample farms grow different types of green leafy vegetables (e.g., kale, spinach, black nightshade) in addition to other food crops such as maize and banana and non-food cash crops such as coffee and tea. Some of the farmers are also involved in small-scale livestock production. The data from Uganda were collected in Luwero and Masaka, two districts in the Central Region where a lot of coffee is grown (Chiputwa et al. 2015; Chiputwa and Qaim 2016). The sample comprises 417 farm households that grow coffee in addition to food crops such as plantains, cassava, sweet potatoes, different types of cereals, vegetables, and legumes such as beans and groundnuts. Some fodder crops are grown as well for the households' small-scale livestock enterprises.

In all three surveys, a wide range of socioeconomic data was captured, including all income sources of the household and details of agricultural production over the past 12 months. To capture dietary patterns, we used 7-day consumption recalls, recording the quantities of all food items consumed by households during the recall period. Respondents were asked to report the total quantities consumed regardless of the source. Thus, in addition to own production and market purchase, also foods received as gifts or collected from the natural environment were included. Rowland et al. (2016) showed that collected foods can make important contributions to dietary quality for rural households in some settings. An explicit breakdown of consumed food quantities by source was not included in the questionnaires.

2.2 Dietary indicators

Dietary diversity scores are frequently used as simple indicators of access to food and dietary quality from survey data (Ruel 2003; Headey and Ecker 2013). Dietary diversity scores are categorical measures of the number of different food groups consumed. Depending on the type of data available, dietary diversity scores can be calculated for individuals or for households. The exact interpretation varies. Koppmair et al. (2017) and Koppmair and Qaim (2017) showed in recent studies with data from Malawi that dietary diversity scores at household and individual levels are significantly correlated. Here, we calculate household dietary diversity scores, because the food consumption data in Indonesia, Kenya, and Uganda were collected at the household level.

There are also differences in the literature with respect to the recall period used in the survey. Many recent studies have calculated dietary diversity scores based on 24-h recall data (Oyarzun et al. 2013; M'Kaibi et al. 2015; Koppmair 2017), while others have used 7-day recalls (Jones et al. 2014; Snapp and Fisher 2015; Sibhatu et al. 2015; Jones 2017). Dietary diversity scores from 7-day recall data are systematically higher, as more of the day-to-day variation in food consumption is captured. Certain food groups that a household only consumes once or twice a week are recorded in a 7-day recall but not necessarily in a 24-h recall. Differences may be especially relevant for livestock products, which poor households rarely consume on a daily basis. Hence, the magnitude of results from studies with different survey formats is not directly comparable. As mentioned, all three surveys used here had a 7-day recall period.

We calculated two different types of dietary diversity scores at the household level. The first is the household dietary diversity score (HDDS) with 12 food groups that has emerged as a widely used indicator of access to food (Swindale and Bilinsky 2006; FAO 2011). The 12 food groups considered are: cereals; white tubers and roots; legumes, legume products, nuts, and seeds; vegetables and vegetable products; fruits; meat; eggs; fish and fish products; milk and milk products; sweets, sugars, and syrups; oils and fats; and spices, condiments, and beverages. The second score we calculated uses a different food group classification that better accounts for micronutrient supply. We used the following 10 food groups that were also proposed for calculation of the minimum dietary diversity for women of reproductive age (FAO 2016): starchy staple foods; beans and peas; nuts and seeds; dairy; flesh foods; eggs; vitamin A-rich dark green leafy vegetables; other vitamin A-rich vegetables and fruits; other vegetables; and other fruits. Table A1 in the Online Resource shows frequencies of the number of food groups consumed by sample households in the three study countries.

Regardless of the food group classification used, dietary diversity scores have certain drawbacks in terms of measuring dietary quality (Torheim et al. 2004; Coates 2013; Maxwell et al. 2014; Hirvonen et al. 2015). One major drawback is that food groups are counted irrespective of the actual quantities consumed. Very small quantities of certain foods consumed increase the dietary diversity score, even though they may add little to nutritional adequacy. To address this shortcoming, other dietary indicators that account for food quantities consumed should be used (de Haen et al. 2011). Our survey data includes information on the quantities consumed during the 7-day recall period with a detailed breakdown of food items. The survey questionnaire used in Indonesia and Uganda listed around 100 different food items tailored to the local context, whereas the questionnaire used in Kenya included 139 different foods. Based on these data, we calculated the daily quantities of fruits and vegetables consumed, as fruits and vegetables are important sources of micronutrients. In addition, using data from all food items consumed and local and international food composition tables (USDA 2005; FAO 2010; SMILING 2013), we calculated the daily quantities of calories and various micronutrients consumed by each household. To make the consumption values comparable across households of different size, these indicators are expressed as per adult equivalent (AE). In terms of micronutrients, we concentrated on iron, zinc, and vitamin A. Deficiencies in these three micronutrients are responsible for the most important nutritional disorders in large parts of the developing world (Barrett and Bevis 2015; IFPRI 2017). Recent studies have used calorie and micronutrient consumption levels to assess nutritional impacts of innovations in African food supply chains (Chege et al. 2015; Chiputwa and Qaim 2016). A few studies have also used quantity-based indicators to analyze linkages between farm production diversity and diets (Oyarzun et al. 2013; M'Kaibi et al. 2015; Jones 2017).

Based on the consumption levels of calories and micronutrients and internationally recommended quantities, we also calculated indicators of nutritional adequacy for each household. Recommended consumption levels are 2400 kcal for calories, 18 mg for iron, 15 mg for zinc, and 625 μg retinol equivalents for vitamin A per AE per day (FAO, WHO, and UNO 2004). Following Hatloy et al. (1998), we express nutritional adequacy for each nutrient in terms of a dummy variable, which takes a value of one if actual consumption is equal to or above the recommended level, and zero otherwise. Furthermore, we calculated mean micronutrient adequacy for each household by averaging over the adequacy indicators for iron, zinc, and vitamin A.

It should be noted that calorie and micronutrient consumption levels calculated from 7-day food recalls are less precise than from 24-h recalls (de Haen et al. 2011). Seven-day recalls tend to overestimate actual food and nutrient intakes, which is why we use the term "consumption" rather than "intake" in this study.

2.3 Production diversity indicators

A common indicator of production diversity on a farm is a simple count of the different species produced (Sibhatu et al. 2015). This indicator is taken from the agrobiodiversity literature. Sometimes the area under a crop is used for weighting purposes, although a common weighting scheme is more difficult when livestock production is also involved. We use an unweighted count of all crop and livestock species produced on a farm as one measure of production diversity. However, different species have different nutritional functions (DeClerck et al. 2011; Remans et al. 2014; Luckett et al. 2015), which is important to consider when analyzing the production-consumption diversity link. When non-food cash crops are grown, the nutritional value is zero regardless of the number of different species produced. But also when food crops are grown, increasing the number of species within the same food group (e.g., different types of cereals) may have smaller nutritional benefits than when species of a different food group are added to the production portfolio (e.g., adding pulses, vegetables, or fruits). The reason is that products within the same food group tend to provide a similar range of nutrients.

To better account for the nutritional function of production diversity, we calculated the so-called production diversity score as an alternative measure to the simple species count. The production diversity score counts the number of different food groups produced on a farm (Berti 2015; Koppmair et al. 2017). We used the same 10 food groups that were already discussed above for one of the dietary diversity scores on the consumption side (FAO 2016). In contrast to the simple species count, the production diversity score counts different species produced on the farm as one when they all belong to the same food group (e.g., maize, wheat, sorghum, potato, cassava that all belong to the group of starchy staples). On the other hand, the same species can count as two when it delivers products that belong to different food groups (e.g., chicken that deliver eggs and meat).[2]

2.4 Statistical methods

We wanted to estimate the relationship between farm production diversity and household diets by estimating regression models of the following type:

$$D_i = \beta_0 + \beta_1 P_i + \beta_2 x_i + \varepsilon_i$$

where D_i is a dietary indicator, P_i is a production diversity indicator, and X_i is a vector of other covariates that may also influence diets, all referring to farm household i. Variables in vector X_i include farm characteristics such as land area, market access, and sociodemographic characteristics such as household size, age, gender, and education. β_0, β_1, and β_2 are coefficients to be estimated, and ε_i is a random error term.

We estimated different specifications of this model, using the various dietary and production diversity indicators discussed above. All models were estimated with robust standard errors to account for heteroscedasticity. A comparison of the estimates of β_1 across the specifications helps to test how sensitive the results are to issues of measurement. Comparing

[2] Further research is needed to develop indicators that properly account for the nutritional value of the different foods produced. The nutrition functional diversity metric (DeClerck et al. 2011; Remans et al. 2014; Luckett et al. 2015) and the nutritional yield metric (DeFries et al. 2015) are interesting approaches in this direction.

the coefficients for the two production diversity indicators can also provide insights into the potential mechanisms underlying the relationship in different situations. For instance, in subsistence settings the coefficient of the production diversity score is expected to be larger than that of the simple species count, because the number of food groups produced will translate more directly into the number of food groups consumed. In more market-oriented settings the comparison is less clear and may possibly be reversed: households that try to produce many of the food groups consumed themselves may forego cash income gains, because they would not focus primarily on those species for which they have a comparative advantage in the market.[3] In addition to the regression models, we also used correlation analysis to test direct associations between the production diversity indicators and household income.

3 Results and discussion

3.1 Descriptive statistics

Table 1 shows descriptive statistics of the variables used in this study. Considerable heterogeneity was found across the three study countries, and also within countries. The largest average farm size was observed in Indonesia (11.1 acres), the smallest in Kenya (2.2 acres). Sample farmers in Indonesia primarily grow non-food cash crops such as rubber and oil palm: on average only 6% of the farm area is cultivated with food crops. In contrast, 74% of the area of Kenyan sample farms is cultivated with food crops. This does not imply that farms in the Kenyan sample are primarily subsistence-oriented. Vegetables, which we count under food crops, are largely grown for commercial purposes in Kiambu County, as is also reflected in sizeable cash revenues for the sample farm households in Kenya (about 1020 US dollars per year per AE). Sample farms in Uganda are much more subsistence-oriented, on average their annual cash revenues only amount to 172 US dollars. Apart from coffee as the main source of agricultural cash revenues, Ugandan farm households produce food and feed crops primarily for domestic use.

In terms of production diversity, farmers in Kenya and Uganda have a much larger species count than their colleagues in Indonesia. Interestingly, farm households in Uganda produce the largest number of species and food groups, but have the lowest dietary diversity scores. The highest dietary diversity scores and also the highest rates of micronutrient adequacy are observed in Kenya.

[3] One could argue that subsistence-oriented households also need less cash income for the purchase of food and would therefore not be worse off. However, economic theory shows that using markets and building on comparative advantage leads to gains in total income (not only cash income) when markets function properly. That many farmers continue to be subsistence-oriented is their response to market failures, especially high transaction costs. Reducing market failures through appropriate policies is an important precondition for agricultural growth and development.

3.2 Production diversity and dietary quality

We now use the regression models described above to analyze the relationship between production diversity and diets more formally. As explained, we employed different dietary indicators as dependent variables, and different production diversity indicators as explanatory variables. The results are summarized in Table 2. In this summary table, we only show the estimates for the production diversity indicators, as these are the explanatory variables of primary interest. Full results of the different models with other covariates included are shown in Tables A2 to A7 in the Online Resource.

In columns (1) and (2) of Table 2, we used the two different dietary diversity scores (with 12 and 10 food groups) as dependent variables. Since these scores are count variables, the underlying models were estimated with a Poisson estimator. In columns (3) to (7), we used fruit and vegetable quantities, and calorie and micronutrient consumption levels as dependent variables. These are continuous variables, so that an ordinary least squares (OLS) estimator was used. All estimates in Table 2 can be interpreted as marginal effects.

In the upper part of Table 2, we used the simple species count as the indicator of production diversity. The positive and significant coefficients in columns (1) and (2) suggest that household dietary diversity increases with the number of different species produced on the farm. Yet the effects are relatively small. After controlling for other factors, producing one additional crop or livestock species increases the number of food groups consumed by 0.16 in the Indonesian sample (column 1). Extrapolating this result implies that more than six additional species would have to be produced on the farm, in order to increase dietary diversity by one food group. Comparison with the other country models reveal that the estimates vary. The effect is smaller in Kenya and larger in Uganda. But even the 0.2 coefficient for Uganda in column (1) is relatively small. Small positive effects of production diversity on dietary diversity are consistent with findings by Sibhatu et al. (2015) and Koppmair et al. (2017).

For Kenya and Uganda, the coefficients in columns (1) and (2) are similar. For Indonesia, the coefficient in column (2) is smaller than in column (1) and statistically insignificant. These comparisons suggest that the finding of relatively small effects of production diversity are not driven by the food group classification used in the calculation of dietary diversity scores.

In columns (3) to (7) of Table 2, where we use other dietary indicators as dependent variables, we also see mostly positive effects. For Indonesia and Uganda, many of these effects are statistically significant. We infer that the number of species produced on the farm contributes to higher consumption of

Table 1 Descriptive statistics

Variables	Indonesia	Kenya	Uganda
Farm characteristics			
Cultivated land area (acres)	11.13	2.17	4.30
	(18.38)	(2.93)	(3.06)
Share of land under food crops (%)	5.99	74.23	48.04
	(19.71)	(30.09)	(23.67)
Agricultural cash revenues per year (US$/AE)	2537.74	1020.09	172.03
	(5208.99)	(2171.39)	(264.82)
Production diversity indicators			
Species count on farm (crop + livestock)	1.74	7.82	7.99
	(0.94)	(2.60)	(2.01)
Production diversity score (10 food groups)	0.64	3.71	4.26
	(1.06)	(1.61)	(1.00)
Dietary indicators			
Household dietary diversity score (HDDS; 12 food groups)	10.01	11.39	9.33
	(1.29)	(0.97)	(1.63)
Household dietary diversity score (10 food groups)	7.87	8.31	6.43
	(1.13)	(0.84)	(1.45)
Fruit and vegetable consumption per day (grams/AE)	591.04	480.99	667.39
	(383.308)	(460.72)	(723.72)
Calorie consumption per day (kcal/AE)	3124.15	3290.70	3047.28
	(1477.50)	(1169.74)	(1371.08)
Iron consumption per day (mg/AE)	19.61	16.84	22.33
	(12.29)	(7.40)	(11.14)
Zinc consumption per day (mg/AE)	11.07	21.15	11.69
	(5.52)	(8.08)	(6.29)
Vitamin A consumption per day (μg RE/AE)	1127.00	1392.52	1236.46
	(1633.52)	(966.99)	(1161.25)
Calorie adequacy (dummy)	0.66	0.79	0.62
Iron adequacy (dummy)	0.44	0.37	0.58
Zinc adequacy (dummy)	0.16	0.75	0.24
Vitamin A adequacy (dummy)	0.48	0.83	0.68
Mean adequacy of iron, zinc and vitamin A (dummy)	0.36	0.65	0.50
Other household characteristics			
Total household income per year (US$/AE)	3460.11	2291.40	4302.89
	(6789.35)	(3550.24)	(9670.22)
Distance to market (km)	6.56	3.11	3.74
	(7.41)	(3.60)	(4.42)
Household size (number of members)	4.20	4.47	6.60
	(1.52)	(1.71)	(3.20)
Age of household head (years)	45.72	52.03	52.54
	(12.18)	(13.55)	(14.29)
Education level of household head (years)	7.50	9.65	6.57
	(3.63)	(3.69)	(3.63)
Male household head (dummy)	0.95	0.86	0.76
Number of observations	672	393	417

Mean values are shown with standard deviations in parentheses. *AE*, adult equivalent. *RE*, retinol equivalent

Table 2 Effect of farm production diversity on household diets

Explanatory variables	(1) DDS (12 FG)	(2) DDS (10 FG)	(3) F&V (g/AE)	(4) Calories (kcal/AE)	(5) Iron (mg/AE)	(6) Zinc (mg/AE)	(7) Vitamin A (μg/AE)
Species count (crop + livestock)							
Indonesia	0.155***	0.062	58.204***	300.402***	2.499***	1.006***	204.475**
	(0.046)	(0.043)	(15.610)	(66.202)	(0.546)	(0.249)	(84.544)
Kenya	0.045**	0.045**	−24.725	−4.671	0.020	0.032	−30.797
	(0.018)	(0.018)	(16.178)	(25.399)	(0.165)	(0.173)	(21.172)
Uganda	0.198***	0.194***	44.213***	83.035**	0.470*	0.301**	35.618
	(0.038)	(0.038)	(15.116)	(33.648)	(0.255)	(0.152)	(30.738)
Production diversity score (10 food groups)							
Indonesia	0.048	−0.011	4.342	67.897	0.730	0.212	18.672
	(0.049)	(0.056)	(11.962)	(54.883)	(0.464)	(0.201)	(45.682)
Kenya	0.067**	0.070**	−10.342	−0.490	−0.093	0.066	−73.757*
	(0.029)	(0.031)	(28.780)	(43.203)	(0.280)	(0.290)	(38.215)
Uganda	0.334***	0.316***	87.022***	74.930	0.500	0.274	71.107
	(0.082)	(0.083)	(27.056)	(66.806)	(0.540)	(0.321)	(57.506)

The marginal effects are based on regression models as shown in Tables A2 to A7 in the Online Resource. Robust standard errors are shown in parentheses. Models in columns (1) and (2) were estimated with a Poisson estimator. Models in columns (3) to (7) were estimated with ordinary least squares. *, **, *** denote significance at the 10%, 5%, and 1% level, respectively. *DDS*, dietary diversity score; *FG*, food groups; *F&V*, fruits and vegetables; *AE*, adult equivalent

fruits and vegetables, calories, and micronutrients. For instance, the estimates for Uganda suggest that one additional crop or livestock species produced on the farm is associated with a 44 g higher fruit and vegetable consumption per AE and day. Also for Uganda, the effect of one additional species produced on calorie consumption is 83 kcal, on iron consumption it is 0.47 mg, and on zinc consumption it is 0.30 mg. The effect on vitamin A consumption is statistically insignificant. For Kenya, all effects in columns (3) to (7) are statistically insignificant. From this analysis, we conclude that farm species diversity can contribute to improved dietary quality in some situations, but not in all.

The lower part of Table 2, where we measured farm diversity in terms of production diversity scores, helps to gain further insights. As explained, instead of a simple species count, production diversity scores count the number of different food groups produced. That is, the production of non-food crops or of several food crops within the same food group does not influence this measure. If subsistence production is an important source of food in the household, we would expect a strong association between the numbers of food groups produced and consumed. In that case, switching from the simple species count to production diversity scores should lead to larger coefficient estimates. The results in Table 2 indicate that this is not always the case. The effects on the dietary diversity scores are somewhat larger in Kenya and Uganda, but not in Indonesia. For Indonesia, all of the coefficient estimates in the lower part of Table 2 are insignificant, suggesting that the subsistence pathway is not of major importance. This is unsurprising in a setting where most farmers concentrate on the production of non-food cash crops. But also for Kenya and Uganda, most of the coefficients for the quantity-based dietary indicators are not statistically significant, implying that also in these settings diverse subsistence production is not the main determinant of household dietary quality. One exception is the consumption of fruits and vegetables in Uganda, where subsistence production seems to play a significant role.

Especially in Indonesia and Kenya, the cash income pathway seems to be more important than the subsistence pathway in explaining the positive association between production diversity and dietary quality. Farm diversification may add to cash incomes, when farmers respond to market price incentives. Rather than trying to maximize the number of food groups produced, it is economically more rational to diversify following the principles of comparative advantage. This may include diversifying into non-food cash crops. In Indonesia, many farmers increased their cash incomes by adding oil palm to their production portfolio (Euler et al. 2017; Krishna et al.

2017). Among other things, the higher cash income is used to improve dietary quality through the purchase of more diverse and nutritious foods from the market.[4] Adding additional food groups to the production portfolio instead would not have the same nutritional effect in Indonesia, which is why the significantly positive effects in the upper part of Table 2 turn insignificant in the lower part. For Kenya and Uganda, the situation is somewhat different, but even there market sales and purchases seem to play an important role.

The role of markets for household diets is also visible from some of the other covariates included in the different models, which are shown in Tables A2 to A7 in the Online Resource. Market distance has a negative association with the dietary indicators in several models, even though this is often not statistically significant. Interestingly, the share of land under food crops also has negative effects in some of the cases, implying that cash crop production and market sales are sometimes more important for household nutrition than food crop production. In other cases, the production of food crops plays a more important role. A case in point is vitamin A consumption in Uganda, where own production of foods plays a significantly positive role. Total farm size and educational levels mostly contribute to better diets, as one would expect.

3.3 Production diversity and nutritional adequacy

We now discuss the effect of production diversity on nutritional adequacy. Estimation results are summarized in Table 3 (full model results are shown in Tables A8 to A13 in the Online Resource). Since the dependent variables in these models are binary, we used a Probit estimator and report marginal effects. For instance, the coefficient of 0.078 for Indonesia in the upper part of column (1) suggests that increasing production diversity by one species is associated with a 0.078 higher likelihood of calorie adequacy. Overall, the results in Table 3 confirm the findings so far. When measured in terms of a simple species count, production diversity often has positive but relatively small effects on the probability of nutritional adequacy (upper part of Table 3). When measured in terms of production diversity scores, many of the coefficients are smaller and statistically insignificant (lower part of Table 3).

3.4 Role of agricultural cash revenues

The above analysis suggests that cash incomes may sometimes play a more important role for farm household diets than diverse subsistence production. This is now analyzed further by regressing the different dietary indicators on agricultural cash revenues. Cash revenues are endogenous, so the estimation results should not be interpreted as causal. We are primarily interested in the association, which is also why we do not control for other factors in these models. Several other factors are correlated with cash revenues, so their inclusion would make interpretation of the association less straightforward. Results are summarized in Table 4 (full results are shown in Table A14 in the Online Resource). Agricultural cash revenues are positively associated with all dietary quality indicators in the Indonesian sample, and most of these associations are statistically significant. Also for Uganda, most of the estimated coefficients are positive. The dependent and independent variables in these models are both log-transformed, so the coefficient estimates can be interpreted as elasticities. For instance, in Uganda, a 1% increase in cash revenues is associated with 0.03% higher calorie consumption and a 0.17% higher fruit and vegetable consumption. These results support our hypothesis that market transactions and cash revenues matter for household diets and nutrition. However, for Kenya the estimated coefficients in Table 4 are not statistically significant.

Farm diversification and increasing cash revenues are not necessarily contradictory strategies. As discussed, much depends on whether or not farm diversification is a response to market incentives. In Table 5, we correlate the two different production diversity indicators with agricultural cash revenues and total household income. For Uganda, the species count (upper part of Table 5) is positively correlated with total household income, but not with agricultural cash revenues. This suggests that in the Ugandan context diverse production systems are more associated with subsistence rather than higher market sales. However, for the Kenyan sample, the situation is different. Sample farmers in Kenya have diversified into different horticultural crops, which are in high demand in the market. Hence, in the Kenyan context farm diversification is associated with higher market sales and higher household incomes. For Uganda and Kenya, the correlation analysis leads to similar results with both production diversity indicators.

For Indonesia, the situation is again different. Agricultural cash revenues and income are positively correlated with the farm species count and negatively correlated with the production diversity score. The reason for this switch in the sign is that cash crop diversification helps to increase farm revenues and incomes, whereas growing additional food groups is against comparative advantage in this context and hence associated with income losses.

3.5 Further discussion

The analysis suggests that farm diversification is positively associated with household dietary quality, but that fostering market access and cash revenues are also promising avenues to improve nutrition in many situations. The important role of

[4] In this part of Indonesia, food markets function quite well. A high diversity of nutritious foods can be purchased all year round.

Table 3 Effect of farm production diversity on calorie and micronutrient adequacy

	(1) Calorie adequacy	(2) Iron adequacy	(3) Zinc adequacy	(4) Vitamin A adequacy	(5) Mean MN adequacy
Species count (crop + livestock)					
Indonesia	0.078***	0.065***	0.065***	0.071***	0.067***
	(0.020)	(0.020)	(0.013)	(0.020)	(0.020)
Kenya	0.009	−0.011	0.006	0.014*	0.008
	(0.009)	(0.011)	(0.009)	(0.008)	(0.006)
Uganda	0.030**	0.061*	0.024**	0.030**	0.025**
	(0.013)	(0.034)	(0.011)	(0.012)	(0.011)
Production diversity score (10 food groups)					
Indonesia	0.021	0.023	0.032**	0.017	0.024
	(0.020)	(0.020)	(0.013)	(0.020)	(0.021)
Kenya	0.002	−0.018	0.001	0.016	0.059
	(0.015)	(0.018)	(0.015)	(0.013)	(0.062)
Uganda	0.029	0.012	0.016	0.037	0.036*
	(0.026)	(0.027)	(0.021)	(0.024)	(0.021)

The marginal effects are based on regression models as shown in Tables A8 to A13 in the Online Resource. Robust standard errors are shown in parentheses. Models were estimated with a Probit estimator. *, **, *** denote significance at the 10%, 5%, and 1% level, respectively. *MN*, micronutrient

markets for household nutrition can be seen in Fig. 1, which compares mean dietary diversity scores (with 10 food groups) and production diversity scores for the sample households in the three study countries. In the Indonesian sample, households consume 7.9 food groups, while only producing 0.6 food groups on average. In other words, own farm production accounts for less than 8% of the dietary diversity consumed in the households.

To be sure, the sample in Indonesia is very specific, as farmers in the study region have specialized in cultivating cash crops such as rubber and oil palm, which are more profitable than most food crops. In this context, increasing the number of food groups produced on the farms would not make sense, neither economically nor nutritionally. The role of own food production for dietary diversity is higher in the farm household samples from Kenya and Uganda. In Kenya and Uganda, production diversity accounts for 45% and 66% of dietary diversity on average (Fig. 1). But even in these African settings, markets play an important role, so fostering market access and commercialization are important strategies to improve nutrition. Promoting the cultivation of additional food groups alone may not always be appropriate. In both African countries, farms are already quite diverse, producing around 8 different crop and livestock species and four different food groups on average (Table 1). Further increasing farm diversity can make sense in specific cases, for instance to improve household food availability where markets are basically nonexistent, or to increase cash incomes where new market

Table 4 Association between agricultural cash revenues and diets

	(1) DDS (12 FG)	(2) DDS (10 FG)	(3) Calories (kcal/AE)	(4) F&V (g/AE)	(5) Iron (mg/AE)	(6) Zinc (mg/AE)	(7) Vitamin A (μg/AE)
Indonesia	0.003***	1.1E-04	0.010***	0.010***	0.015***	0.009***	0.012**
	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)	(0.002)	(0.005)
Kenya	0.001	0.001	−0.002	−0.006	−0.004	−0.003	−0.006
	(0.001)	(0.001)	(0.003)	(0.004)	(0.003)	(0.003)	(0.005)
Uganda	0.024***	0.022***	0.032**	0.166***	0.014	0.023	−0.001
	(0.005)	(0.008)	(0.015)	(0.045)	(0.014)	(0.016)	(0.029)

Results are based on OLS regression models as shown in Table A14 in the Online Resource. Log transformations were applied to both dependent and independent variables. Robust standard errors are shown in parentheses. *, **, *** denote significance at the 10%, 5%, and 1% level, respectively. *DDS*, dietary diversity score; *FG*, food groups; *F&V*, fruits and vegetables; *AE*, adult equivalent

Table 5 Correlation between production diversity, agricultural cash revenues, and household income

	Indonesia	Kenya	Uganda
Species count (crop + livestock)			
Agricultural cash revenues (US$/AE)	0.132***	0.200***	−0.004
Total household income (US$/AE)	0.036	0.130**	0.091*
Production diversity score (10 food groups)			
Agricultural cash revenues (US$/AE)	−0.028	0.240***	0.077
Total household income (US$/AE)	−0.063*	0.196***	0.091*

*, **, and *** denote significance at the 10%, 5%, and 1% level, respectively. AE, adult equivalent

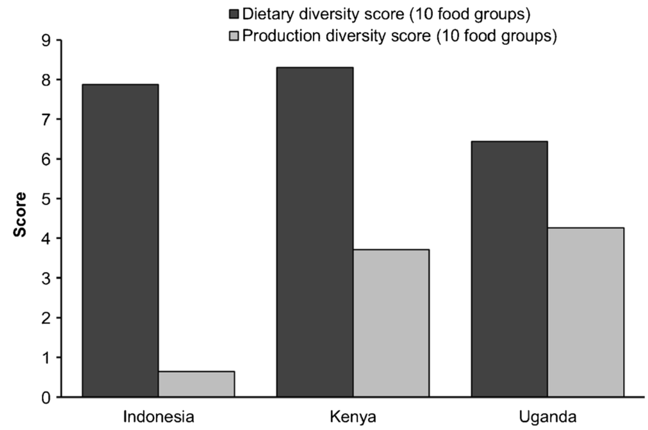

Fig. 1 Mean dietary diversity scores and production diversity scores in farm households

opportunities for specialty products emerge. Conversely, further increasing farm diversity may also be associated with losses in total income (in cash and in kind) due to foregone gains from specialization. Such income losses may be counterproductive for household diets and nutrition.

Two other aspects are worth some further reflection. The first aspect relates to the fact that markets can be quite different and often do not function well in rural areas of developing countries (Geertz 1978; Fafchamps and Hill 2005). Sales and purchases of farm households may occur in local, regional, or international value chains that can be governed by formal rules, traditional norms, different types of government interventions, and other mechanisms. Oftentimes, markets for calorie-dense staples and processed foods are better developed than markets for more perishable horticultural and livestock products, which is largely due to poor infrastructure, inefficient institutions, and different types of policy biases (Pingali 2015).[5] Market failures for fresh and perishable products mean that selling prices are low and buying prices are high in rural areas. In extreme cases, self-produced fruits and vegetables may be the only affordable nutritious foods for farm households in remote locations. Such market failures and policy biases towards calorie-dense foods need to be overcome. Well-functioning markets for diverse types of products are an important precondition for nutrition-sensitive food systems. Without this in mind, a push towards higher levels of market orientation can be counterproductive for improving dietary quality in smallholder farm households.

The second aspect relates to seasonality. As is well known, diets and food sources of rural households often vary considerably over the year, depending on fluctuations in food availability and income (Powell et al. 2013, Hirvonen et al. 2015). Our dietary analysis builds on single round 7-day food recall data, so that seasonality aspects could not be considered. It is possible that own farm production plays a larger role during other times of the year that we did not cover with our surveys. We do not expect this, because the surveys in all three study countries were conducted right after the main harvest season. A recent study with seasonal data from Ethiopia showed that own-produced foods plays the largest role in farm household diets during the harvest season and shortly thereafter (Sibhatu and Qaim 2017). However, this result on the seasonal role of different food sources in Ethiopia cannot necessarily be transferred to other countries. Hence, follow-up research with data that capture seasonal variation would certainly be useful to gain additional insights.

4 Conclusion

We have analyzed the relationship between farm production diversity and household diets using micro-level data from Indonesia, Kenya, and Uganda. We have contributed to the existing literature by using different indicators and comparing results, thus shedding light on the robustness of previous findings and also helping to better understand some of the underlying linkages. When measuring farm diversity in terms of a simple count of crop and livestock species produced, we found a positive relationship with household dietary diversity. This is consistent with previous findings (Keding et al. 2012; Jones et al. 2014; Pellegrini and Tasciotti 2014; Sibhatu et al. 2015; Jones 2017). However, as was also reported in recent studies (Sibhatu et al. 2015; Koppmair et al. 2017), this effect of production diversity on consumption diversity is relatively small.

In most cases, the small positive effect also remains when using other dietary indicators, such as consumption quantities of fruits and vegetables, calories, and micronutrients. We conclude that the results are not driven by the choice of dietary

[5] In urban areas of developing countries, the rising market share of supermarkets is also contributing to a shift in consumption towards processed foods that are high in sugar, fat, and salt (Hawkes 2008; Demmler et al. 2018). Supermarkets do not yet play a major role in rural areas of developing countries (Qaim 2017).

indicators.[6] For this type of analysis, dietary diversity scores seem to work well in terms of capturing various aspects of access to food and dietary quality in farm households. This is a welcome finding, because the calculation of dietary diversity scores requires less data than the calculation of nutrient consumption levels or other quantity-based indicators.

We also tested the sensitivity of results with respect to changes in the production diversity indicator. When using production diversity scores instead of a simple species count, the effect on dietary quality gets smaller and turns statistically insignificant in several cases. This is an interesting finding. The production diversity score measures the number of different food groups produced on a farm, so one could have expected the effect on the number of food groups consumed in the farm household to be stronger. The fact that this is not always the case reveals that the subsistence pathway is not the only mechanism underlying the production-consumption relationship. In some situations, cash income generated from agricultural sales is also an important pathway contributing to improved dietary quality. Additional model estimates confirmed a positive association between agricultural cash revenues and dietary quality in Indonesia and Uganda, but not in Kenya.

The results suggest that markets tend to be more important for farm household nutrition than production diversity in situations where markets function properly and are accessible to rural households. Our data show that own production often accounts for fewer than half of the different food groups consumed in farm households; the rest is mostly purchased from the market. Diversifying the farm production portfolio such that more food groups were produced may foster subsistence, reduce cash incomes, and thus rather worsen dietary quality in some situations. This does not mean that farm diversity is bad. But the type of diversification should follow market incentives, building on farmers' comparative advantage, rather than trying to maximize the number of food groups produced for subsistence. Especially the results from the Indonesian sample suggest that the production of non-food cash crops can play an important and positive role for household diets through the income pathway, when markets function efficiently.

It needs to be stressed that the data from Indonesia, Kenya, and Uganda used in this study are not nationally representative and mainly refer to situations where farmers have relatively good access to markets. Results for Uganda suggest that in less commercialized settings the subsistence pathway still plays a more important role. However, even in situations where farmers primarily produce for subsistence, a large share of the food consumed is typically purchased from the market (Luckett et al. 2015; Sibhatu et al. 2015; Jones 2017; Sibhatu and Qaim 2017). Hence, also in such situations policy initiatives should not only focus on subsistence but improve farmers' access to markets and market functioning through strengthening infrastructure and institutions. Farmers' subsistence orientation is primarily a response to risk and various other market failures. Reducing these failures and supporting closer market integration and higher levels of market efficiency can contribute to income gains and better nutrition in smallholder households.

We conclude that if farm diversification helps to increase household income, it will contribute to better nutrition. Otherwise, diversification can also be counterproductive from a dietary quality and nutrition perspective. It should be stressed that *in situ* preservation of agrobiodiversity (including species diversity and genetic diversity) can have long-term benefits for food security and nutrition well beyond what we analyzed here. Furthermore, species diversity has benefits for ecosystem processes and the environment more broadly, which we also did not analyze in this study. Finally, it should be stressed that our results refer to the individual farm level. At higher scales (villages, districts, provinces, countries etc.) sufficient diversity is important, because affordable access to diverse foods from the market certainly requires that somebody produces these foods. And affordability of foods is positively linked to consumption (Herforth and Ahmed 2015). Policy biases towards only a small number of staple foods – as often observed in the past – need to be rectified. If markets and technologies for a wide range of products exist, food systems will become more diverse, even without every farmer having to maximize diversity on her own farm.

[6] We used 7-day food recall data for the dietary analysis. Seven-day recall data lead to systematically higher dietary diversity scores than 24-h recall data. A recent study with 24-h recall data from Malawi also showed positive but small associations between production diversity and dietary diversity (Koppmair et al. 2017). However, further research comparing different dietary indicators could be useful.

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Compliance with ethical standards

Conflict of interest The authors declared that they have no conflict of interest.

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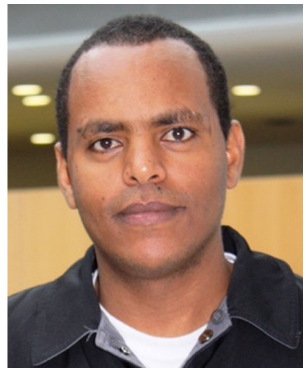

Kibrom T. Sibhatu is a postdoctoral researcher at the Department of Agricultural Economics and Rural Development, University of Goettingen, Germany. His research focuses on the link between agriculture and nutrition in smallholder farm households in Asia and Africa. His interests are agrobiodiversity, nutrition, food security, environmental issues, and development economics. He holds a Bachelor's degrees from the University of Asmara in Eritrea, a Master's degree in Agricultural Economics from Nagoya University in Japan, and a PhD degree in agricultural economics from the University of Goettingen. Previously, he was a graduate assistant and lectured several agricultural economics and economics courses at Hamelmalo Agricultural College in Eritrea.

Matin Qaim is Professor of International Food Economics and Rural Development at the University of Goettingen, Germany. Before, he was professor at the University of Hohenheim in Stuttgart, Senior Researcher at the Center for Development Research in Bonn, and Research Fellow at the University of California at Berkeley. He holds a doctoral degree in agricultural and development economics from the University of Bonn. Qaim has extensive research experience related to the economics of innovation in the small farm sector of Africa, Asia, and Latin America, including the analysis of impacts on poverty, food security, and nutrition.