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Subsistence production, markets, and dietary diversity in the Kenyan small farm sector

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Undernutrition and low dietary quality remain widespread problems in poor population segments, especially among smallholder farmers in sub-Saharan Africa. Hence, the question how smallholder systems can be made more nutrition-sensitive is of particular relevance for research and policy. Recent studies analyzed whether increasing farm production diversity may help to improve nutrition. Most existing studies found a positive but small effect on dietary diversity on average. The underlying mechanisms were not examined in detail. This article tests the hypothesis that the effect of farm diversity on nutrition is small because production diversity is positively associated with dietary diversity obtained from subsistence production but negatively associated with dietary diversity obtained from the market. This hypothesis is confirmed with data from Kenya, using different indicators of production diversity and dietary diversity scores at household and individual levels. The results underline the important role of markets for smallholder diets and nutrition. Hence, strengthening markets and improving market access should be a key strategy to make smallholder systems more nutrition-sensitive.

1. Introduction

Undernutrition is a widespread problem in many developing countries. While the proportion of undernourished people declined significantly during the last few decades, the number of people with insufficient access to food remains high and even increased recently in sub-Saharan Africa (FAO, 2019). Beyond food quantity, dietary diversity is important for healthy and balanced nutrition. Measures of dietary diversity consider the different types of foods consumed by households and individuals and have recently become popular indicators in the food security and nutrition literature (Fongar et al., 2019; Verger et al., 2019). At the household level, dietary diversity scores are easy-to-measure indicators of food security (Headey and Ecker, 2013). At the individual level, dietary diversity scores are proxies of dietary quality and nutrition, because they are significantly associated with micronutrient intakes and nutrition status (Fongar et al., 2019; Arimond and Ruel, 2004). Undernutrition and micronutrient malnutrition remain the leading risk factors for child mortality and other serious health issues in Africa (Gödecke et al., 2018; Development Initiatives, 2018).

Many of the people affected by undernutrition and micronutrient malnutrition are smallholder farmers. Hence, the question how smallholder systems can be made more nutrition-sensitive has received considerable attention in the recent literature (Ruel et al., 2018; Carletto et al., 2015). One common recommendation is to increase farm production diversity, meaning that farmers should be encouraged to produce a larger number of different crop and livestock species (Jones, 2017; Fanzo et al., 2013). As smallholder households typically consume large proportions of what they produce at home, higher farm production diversity may also lead to higher dietary diversity. Indeed, several recent studies found a positive relationship between farm production diversity and dietary diversity in the small farm sector of different developing countries (Ecker, 2018; Hirvonen and Hoddinott 2017; Koppmair et al., 2017; Bellon et al., 2016; Romeo et al., 2016; Sibhatu et al., 2015; Jones et al., 2014). However, the effect of increasing production diversity on dietary diversity was found to be small in many cases, which could mean that introducing additional species may not be the most effective strategy to improve diets and nutrition in smallholder households. A few authors argued that the small size of the effects might be due to measurement issues and that the picture could change if other indicators were used (Verger et al., 2017; Berti, 2015). But recent reviews showed that the mean effects of increased production diversity on diets and nutrition remain small even when alternative indicators are used (Sibhatu and Qaim, 2018a, 2018b).

Smallholder households obtain the food that they consume from different sources, the most important of which are (i) own production

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(subsistence pathway) and (ii) market purchases (market pathway). When smallholder households increase their production diversity, then both the subsistence and the market pathway may be affected. Here, we hypothesize that the association between farm production diversity and overall dietary diversity is small because production diversity may have a positive partial effect on diets through the subsistence pathway, but a negative partial effect through the market pathway. Even though smallholder farmers tend to be subsistence-oriented, recent research showed that a sizeable share of their diets is typically obtained from the market (Sibhatu and Qaim, 2017; Frelat et al., 2016; GLOPAN, 2016; Luckett et al., 2015). Increasing farm production diversity can lead to a substitution of home-produced food for market purchases, so that the total effect of production diversity on dietary diversity may be reduced. While the important role of markets for smallholder diets was highlighted in previous research (Ogutu et al., 2020; Hirvonen and Hoddinott, 2017; Koppmair et al., 2017; Barrett, 2008), we are not aware of studies that explicitly differentiated between subsistence and market pathways when analyzing the role of farm production diversity. We address this research gap with data from smallholder farm households in Kenya.

In particular, we examine the association between farm production diversity and overall dietary diversity, as other studies did, but then extend the analysis by separately looking at dietary diversity obtained through the subsistence pathway and dietary diversity obtained through the market pathway. This analysis can help to better understand the underlying mechanisms and develop effective strategies towards making smallholder systems more nutrition-sensitive. We also test the robustness of the results by using various indicators of production diversity and dietary diversity with household-level and individual-level data for women and children. We collected data in the Western parts of Kenya, where farms are mostly very small and subsistence-oriented. These are typical conditions for sub-Saharan Africa. Hence, the results may offer some broader lessons also beyond the concrete empirical setting.

2. Conceptual framework

Existing studies on farm production diversity and dietary diversity (Ecker, 2018; Hirvonen and Hoddinott 2017; Koppmair et al., 2017; Bellon et al., 2016; Romeo et al., 2016; Sibhatu et al., 2015; Jones et al., 2014) implicitly assumed a direct link between these two variables by estimating regression models of the following type:

$$DD = \alpha_0 + \alpha_1 PD + \alpha_2 \boldsymbol{X} + \varepsilon \quad (1)$$

where DD is an indicator of dietary diversity, PD is an indicator of farm production diversity, $\boldsymbol{X}$ is a vector of control variables, and ε is a random error term. However, in reality, the relationship is less direct because households obtain their food from different sources, including subsistence production and market purchases.[1] Hence, overall dietary diversity is a function of dietary diversity obtained from subsistence and dietary diversity obtained from the market, as shown in Fig. 1.

Farm production diversity has a direct partial effect on dietary diversity from subsistence, which is expected to be positive. But farm production diversity may also affect dietary diversity from the market, and this partial effect may be negative. Up to a certain extent, a negative partial effect may simply be due to dietary substitution: if a household produces certain food items itself, there may be no need to obtain the same foods also from the market. However, increasing farm production diversity may also affect household income and thus the ability to buy food in the market (Dzanku and Mawunyo, 2018). If production diversification is a response to market incentives, then it may result in increased household income, which could lead to higher dietary diversity through the market pathway. For instance, Hirvonen and Headey (2018) showed that rural households in Ethiopia are more likely to grow vegetables in home gardens when they are located close to the market, probably because market closeness allows these households to also sell some of the vegetables produced. Similarly, Bellon et al. (2016) found that better market opportunities were associated with higher levels of farm diversification in one region in Benin. More typically, however, the opposite is true: farms with poor market access are more diversified and subsistence-oriented (Ruel et al., 2018; Sibhatu and Qaim, 2017; GLOPAN, 2016; de Janvry et al., 1991).

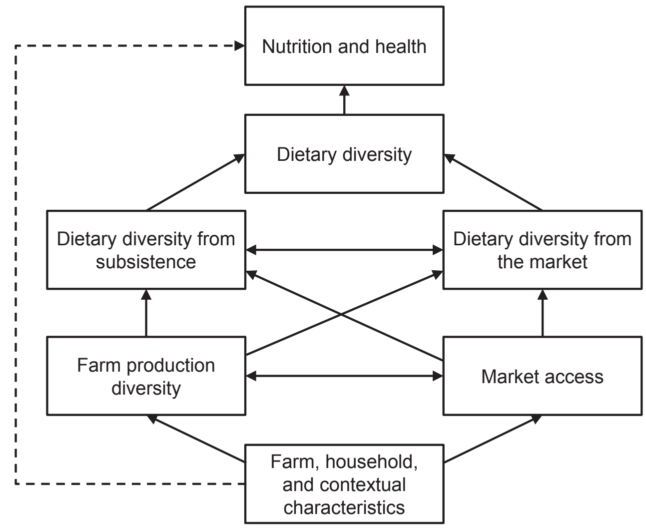

Fig. 1. Links between farm production diversity and dietary diversity through subsistence and market pathways.

Against this background, we hypothesize that farm production diversity is positively associated with dietary diversity from subsistence (DD_{sub}), but negatively associated with dietary diversity from the market (DD_{mar}). This hypothesis is tested using the following regression models:

$$DD_{sub} = \beta_0 + \beta_1 PD + \beta_2 \boldsymbol{X} + \varepsilon \quad (2)$$

$$DD_{mar} = \gamma_0 + \gamma_1 PD + \gamma_2 \boldsymbol{X} + \varepsilon \quad (3)$$

where β_1 is expected to be positive, and γ_1 is expected to be negative. A negative γ_1 might also explain why the combined effect of production diversity on total dietary diversity (DD_{tot}) is often smaller than expected. These partial effects were not analyzed in previous research. We will use Eq. (1) to estimate the combined effect and Eqs. (2) and (3) to estimate the partial effects, with appropriate control variables included. As shown in Fig. 1, control variables that may also affect dietary diversity include farm, household, and contextual characteristics.

3. Materials and methods

3.1. Household survey

Data for this study were collected from farm households in the counties of Kisii and Nyamira in Western Kenya through a survey that was implemented in November and December 2016. Kisii and Nyamira are characterized by high population density, very small farm sizes (mostly below 2 acres), and favorable agricultural potential (GoK, 2014). With over 1000 mm of annual rainfall spread over two extended rainy seasons, agricultural production takes place all the year around. As a result, there is relatively little seasonal variation in food production and consumption (Fongar et al., 2019), which is advantageous for

[1] Subsistence production represents foods obtained from the own farm, while market purchases represent foods that the household purchases from local markets. Other sources can include the collection of wild foods, gifts, and transfers, but subsistence production and market purchases are generally the most important ones (Sibhatu and Qaim, 2017).

our analysis, because data were only collected during a two-month period. In spite of the favorable agricultural conditions, undernutrition is widespread in the study region. According to official statistics, 25% of the children in Kisii and Nyamira are stunted (low height-for-age), which is the most common indicator of child undernutrition (KNBS, 2014).

To get a representative sample of farm households in the absence of recent census data, we exploited the fact that the majority of farm households in the study region are organized in farmer groups.[2] These groups are registered with the Ministry of Social Services. Based on the Ministry list of farmer groups and with the help of Africa Harvest, a local non-governmental organization active in the region, we identified the existing groups in Kisii and Nyamira and randomly sampled 48 groups that were spread over 8 different sub-counties. In each of these 48 groups, we randomly selected 15–20 households (depending on group size), resulting in a total sample of 755 farm households.

In addition to collecting household-level data, in the 755 households we also collected individual-level data from 550 women (either the household head or the spouse) and 205 children aged 6–59 months. We were not able to collect individual-level data in all of the households. Also, many of the households did not have small children. If a household had more than one child aged 6–59 months, we selected one of the children randomly.

The selected households were personally interviewed with a structured questionnaire, which was carefully designed and pre-tested. Households were interviewed on dietary patterns and farm production practices, including types of crops produced or livestock kept, and how the farm produce was utilized. The household-level dietary section of the questionnaire was answered by the person responsible for food preparation in the household. The individual-level dietary section for women was answered by the respective woman herself; for children the section was answered by the mother or caregiver. Food consumption at the household level was captured through a 7-day recall. Individual food intakes were captured through a 24-hour dietary recall.

3.2. Measurement of dietary diversity

We compute three types of dietary diversity scores, as shown in Table 1. Dietary diversity scores count the number of different food groups consumed over a certain period of time. The first score that we use is the household dietary diversity score (HDDS) with a total of 12 food groups (FAO, 2011). We calculate the HDDS based on data from the 7-day food consumption recall. HDDS is a good proxy of a household's economic access to food and food security, as households typically diversify their food consumption patterns with rising incomes and when they have achieved certain minimum levels of calorie sufficiency (Headey and Ecker, 2013). However, HDDS is not necessarily a good indicator of dietary quality for at least two reasons. First, HDDS also counts certain less healthy food groups that may contribute to diversity but not to dietary quality, such as sugar, sweets, and soft drinks (Table 1). Second, dietary diversity scores at the household level do not account for intra-household food distribution and may therefore not fully reflect what individual household members actually eat (Verger et al., 2019).

Dietary quality is better captured with individual-level data. Various studies showed that individual-level dietary diversity scores are significantly correlated with micronutrient intakes and nutritional status (Fongar et al., 2019; Arimond and Ruel, 2004). Therefore, the other two scores are calculated at the individual level for women and children aged 6–59 months, using the 24-hour dietary recall data. Women and children are of particular interest because they are typically most affected by undernutrition and micronutrient malnutrition (Development Initiatives, 2018). For women, we calculate the Women's Dietary Diversity Score (WDDS) using 9 food groups (FAO, 2011). For children, we calculate a Child Dietary Diversity Score (CDDS), using the 7 food groups recommended by WHO (2008) for assessing the minimum dietary diversity of small children.[3] The food group classifications for all three scores are shown in Table 1.

All three dietary diversity scores are first calculated considering all foods consumed by households and individuals, regardless of the particular food source. In a second step, we re-calculate two additional versions of all three dietary diversity scores by (i) only considering the foods obtained from subsistence production ($HDDS_{sub}$, $WDDS_{sub}$, $CDDS_{sub}$) and (ii) only considering the foods obtained from the market ($HDDS_{mar}$, $WDDS_{mar}$, $CDDS_{mar}$). Note that the total dietary diversity scores are not necessarily the sum of the scores from the two sources, because certain food groups may be obtained from subsistence and from markets (or other sources) simultaneously.

3.3. Measurement of farm production diversity

Farm production diversity can be measured in different ways. One common approach is to simply count all the different crop and animal species produced by the farm household, regardless of whether these are produced for food or other purposes (Sibhatu et al., 2015; Jones et al., 2014). We use such a species count of the crops grown in the previous planting season and the livestock kept as one measure of farm production diversity.

However, this simple species count also includes non-food cash crops that cannot contribute to dietary diversity through the subsistence pathway. Moreover, different crop species that belong to the same food group – such as different types of cereals – may not add to diets when these are assessed with dietary diversity scores (Berti, 2015). Therefore, as an alternative measure of production diversity, we also calculate so-called production diversity scores, which count the number of different food groups produced, using the same food group classification as for the HDDS. Production diversity scores were also calculated and used in other recent research analyzing the association between production diversity and dietary diversity (Sibhatu and Qaim, 2018b; Hirvonen and Hoddinott, 2017; Koppmair et al., 2017).

3.4. Measurement of other key variables

Dietary diversity in smallholder farm households cannot only be influenced by farm production diversity, but also by a number of other farm, household, and contextual characteristics. Some of these characteristics may be correlated with farm production diversity, so we need to control for them in the regression models to avoid estimation bias. We control for farm size, household size, as well as gender, age, and education of the household head. These are all variables that were shown to influence household diets and nutrition in previous studies (Ogutu et al., 2020; Sibhatu et al., 2015; Jones et al., 2014).

Household wealth or living standard is also expected to be an important determinant of diets and nutrition. In general, income or expenditures are commonly used indicators of living standard, but including income or expenditures in our models would be problematic because of endogeneity. Simultaneity may be an issue, because diets

[2] We sampled farm households from farmer groups, because complete lists of groups and – within each group – complete lists of members were available. This allowed us to sample randomly in a two-stage process. The alternative would have been to sample villages first, but complete household lists at the village level were mostly not available. As most farmers in the study region are organized in groups, our sample should be fairly representative of all farm households in this part of Kenya. This is supported by comparing data on farm sizes and a few other characteristics with official statistics and other recent publications (Ogutu et al., 2020; GoK, 2014).

[3] The CDDS was primarily developed and validated for young children aged 6–23 months, but recent research suggests that it can also be used for older children up to 59 months (Fongar et al., 2019), as we do here.

Table 1
Food group classification for different dietary diversity scores.

Number	Household dietary diversity score (HDDS)	Women's dietary diversity score (WDDS)	Child dietary diversity score (CDDS)
1	Cereals	Starchy staples	Grains, roots, and tubers
2	White roots and tubers	Dark green leafy vegetables	Legumes and nuts
3	Vegetables	Other vitamin A rich fruits and vegetables	Dairy products (milk, yoghurt, cheese)
4	Fruits	Other fruits and vegetables	Flesh foods (meat, fish, poultry, and liver/organ meats)
5	Meat	Organ meat	Eggs
6	Eggs	Meat and fish	Vitamin A rich fruits and vegetables
7	Fish	Eggs	Other fruits and vegetables
8	Legumes, nuts, and seeds	Legumes, nuts, and seeds	
9	Milk	Milk and milk products	
10	Oils and fat		
11	Sugar and sweets		
12	Spices, condiments, beverages		

and nutrition can influence people's labor productivity, and thus also income and expenditures. Also, income (and expenditures) may be affected by farm production diversity (Sibhatu and Qaim, 2018b). As income is likely one of the key mechanisms for the association between production diversity and dietary diversity from the market, including income as a control variable could lead to serious estimation bias. Finding an instrument for income in our models was not possible, because all variables that affect income also affect diets and nutrition. Instead, we control for the value of household assets (vehicles, television, other major appliances, etc.), which is another indicator of household wealth and much less prone to endogeneity than income or expenditures.

Market distance may also matter, as farm households use markets to sell farm produce and buy food items that they do not produce themselves (Hirvonen and Hoddinott, 2017; Koppmair et al., 2017; Parlasca et al., 2020). We include a variable that measures the distance from the household to the closest village market. These village markets are typically small and used frequently by farmers for regular transactions. Furthermore, recent research showed that informal social networks can be important channels for the flow of agricultural and nutrition information in rural communities (Jäckering et al., 2019). In our regression models, we control for farmers' social networks through a variable that counts the number of other persons within the group that the farmer interacts with on topics related to food and agriculture.

Finally, in the individual-level models for women and children we also control for a few individual characteristics. In the models for women's dietary diversity, we control for the women's age and education level. In the child models, we control for the child's age and the number of siblings living in the household, which may be an important factor for intra-household food distribution. For the siblings, we count all children up to the age of 14 years, as this is the age until which children in Kenya are expected to attend primary school.

3.5. Regression estimators

As explained above, we estimate the models shown in Eqs. (1)–(3) to analyze the association between farm production diversity and dietary diversity. In these models, the dependent variables are dietary diversity scores, which are count variables. Count data models are typically estimated with a Poisson estimator (Greene, 2007). The standard Poisson estimator assumes equidispersion in the data, implying that the variance of the outcome variable is equal to its mean. We tested the equidispersion assumption in our data and found that the variance of all dietary diversity scores is significantly lower than the mean, indicating the presence of under-dispersion. Against this background, instead of the standard Poisson estimator we use the generalized Poisson model, which is more suitable to analyze under-dispersed data (Harris et al., 2012). We use the generalized Poisson estimates to calculate marginal effects for all variables, which are straightforward to interpret. All models are estimated with clustered standard errors at the farmer group level to deal with possible heteroscedasticity (Cameron and Miller, 2015).

4. Results

4.1. Descriptive statistics

Descriptive statistics for the main variables used in this study are shown in Table 2. The farms are small in size (average land holding of 1.45 acres) and quite diverse in their production patterns. On average, farms produce 13.4 different crop and livestock species, including maize, sorghum, millet, beans, bananas, different types of vegetables, as

Table 2
Descriptive statistics for key variables.

Variable	Description	Mean	SD
Socioeconomic characteristics			
Farm size	Land area owned (acres)	1.45	1.19
Household size	Number of household members	5.49	2.04
Male head	Household head is male (dummy for male = 1)	0.76	0.43
Age head	Age of household head in years	50.31	12.43
Education head	Years of education of household head	8.74	3.60
Age woman	Age of woman interviewed in years	45.31	12.28
Education woman	Years of education of woman interviewed	8.16	3.62
Age of child	Age of child in months	46.85	12.54
Distance to market	Distance to closest village market (km)	1.90	2.02
Assets	Value of assets owned (thousand $)	2.80	7.16
Social network	Number of people farmer shares information with	6.54	4.36
Farm production diversity			
Species count	Number of crop and animal species produced	13.37	3.74
Crop count	Count of crop species grown on farm	11.31	3.41
Animal count	Count of animal species kept on farm	2.06	1.13
Production diversity score	Number of food groups produced	5.81	1.07
Dietary diversity			
HDDS	Household dietary diversity score	9.72	1.31
$HDDS_{sub}$	HDDS from subsistence	4.75	1.58
$HDDS_{mar}$	HDDS from the market	7.37	1.55
WDDS	Women's dietary diversity score	4.17	0.82
$WDDS_{sub}$	WDDS from subsistence	2.86	1.36
$WDDS_{mar}$	WDDS from the market	2.31	1.06
CDDS	Child dietary diversity score	4.13	0.73
$CDDS_{sub}$	CDDS from subsistence	2.95	1.28
$CDDS_{mar}$	CDDS from the market	2.34	1.05

Note: The sample contains observations from 755 households, 550 women, and 205 children.

well as cash crops such as tea and coffee. Many households also keep sheep, goats, chicken, and sometimes cattle. The average production diversity score is 5.8, meaning that households produce more than five different food groups on their farms.

The lower part of Table 2 shows the different dietary diversity scores. The HDDS is larger than the WDDS and the CDDS, which is plausible for three reasons. First, the HDDS includes a larger number of food groups than the other two scores. Second, the HDDS considers the foods consumed by all household members, whereas the WDDS and CDDS only include the foods consumed by individual women and children. Third, for the calculation of HDDS we used data from the 7-day food recall, meaning that all foods consumed over a 7-day period were considered, whereas the WDDS and CDDS were calculated using 24-hour dietary recall data.

Households obtain a larger part of their food diversity from the market than from subsistence production (Table 2). This is in line with recent results from other African contexts (Hirvonen and Hoddinott, 2017; Sibhatu and Qaim, 2017). The picture is somewhat different for the WDDS and CDDS disaggregation, where subsistence and market sources both account for about half of total dietary diversity. The larger role of markets for HDDS is due to the fact that the HDDS also includes food groups such as oils and fats, sweets, and other processed foods that are only purchased in the market.

Interesting to note is that the average number of food groups produced on the farms is larger than the number of food groups consumed from subsistence. Seasonality may potentially play a role here because the HDDS only considers foods consumed during the last 7 days. On the other hand, there are also certain foods that farms produce and sell without consuming them on a regular basis. This is especially true for certain types of vegetables, but also for eggs and other animal products. For instance, 80% of the sample households produced eggs, while only 34% of them consumed eggs from their own farm during the 7-day recall period.

In Table 3, we compare more specifically which of the food groups are produced by many farm households and what shares of total consumption are obtained from subsistence and from the market.[4] Almost all households produced cereals, especially maize, but at the same time almost all households also purchased cereal products from the market. Around 40% of all cereal foods consumed in the farm households were obtained from the market, which often involves semi-processed products such as maize and wheat flour. Similarly, almost all households grew vegetables and fruits, but the majority also purchased items from these food groups in the market. For instance, a household may grow kale and bananas, but may buy other items such as tomatoes and papaya. This means that most households specialize in producing certain species rather than trying to produce everything that they would like to consume. Most of the roots and tubers, meat, fish, and highly processed food products are obtained from the market, as one would expect.

Table 3
Food group production and consumption from different sources.

	Households producing (%)	Household consumption: Total quantity (kg)	From subsistence (%)	From the market (%)
Cereals	97	4.19 (4.78)	53	40
Roots and tubers	16	3.50 (3.36)	21	68
Vegetables	98	3.04 (4.07)	65	30
Fruits	95	10.27 (10.24)	61	31
Meat	97	1.04 (0.87)	31	68
Eggs	80	5.82 (4.06)	75	24
Fish	0.4	0.64 (0.58)	2	92
Legumes, nuts, seeds	31	1.4 (1.44)	78	19
Milk/milk products	67	6.8 (5.83)	77	22
Oils and fats	0	0.7 (0.46)	0	99
Sugar and sweets	0	1.44 (0.84)	0	97
Spices, condiments, beverages	0	0.29 (0.27)	0	97

Notes: The sample contains observations from 755 households. Consumption refers to mean quantities consumed by households over a 7-day recall period with standard deviations shown in parentheses. For fruits and eggs, quantity is measured in terms of pieces consumed.

4.2. Comparisons between different types of farms

In Table 4, we compare mean dietary diversity and farm production diversity for different types of farms to get a better understanding of the patterns observed. All farms in our sample are very small, fairly diversified, and produce to a large extent for subsistence. Nevertheless, they differ somewhat in terms of their market orientation. For comparative purposes, we subdivide the total sample into two subsamples of equal size according to their level of commercialization, using the proportion of farm output sold as the distinguishing variable. Households in the less commercialized subsample sell less than 40% of their farm output, meaning that more than 60% is kept for home consumption. Accordingly, households in the more commercialized subsample sell more than 40% of their output. A second typology we use is households with and without the production of cash crops, such as tea and coffee. Two-thirds of the households in our sample grow cash crops, whereas one-third does not (Table 4).

More commercialized households have higher HDDS and WDDS than less commercialized households (Table 4). Usually one would expect that more commercialized households are more specialized in their production patterns and obtain more of the foods consumed from the market. Strikingly, however, the more commercialized households in our sample have an even higher farm production diversity than the less commercialized households. The comparisons in Table 4 also suggest that farm commercialization is more strongly associated with dietary diversity from subsistence than with dietary diversity from the market. For CDDS, no significant differences can be observed between more and less commercialized households.

Comparing the households with and without cash crop production, no significant differences are observed in terms of HDDS (Table 4). Interestingly, however, WDDS and CDDS are somewhat higher in the households without cash crop production, and this is in spite of a lower production diversity score. This may possibly be related to the fact that the income from cash crops is primarily controlled by male household members, who are often less concerned about dietary quality and child nutrition than female household members (Malapit et al., 2015). In any case, the observed patterns underline the complex relationships between farm production, household and individual consumption, and market participation.

4.3. Regression results

The estimated associations between farm production diversity and dietary diversity at household and individual levels are summarized in Fig. 2. Details of the underlying regression models are shown in Tables 5–7. Table 5 presents the regression results for the household-level models, meaning that HDDS is the dependent variable. For each model, we estimated two versions; first, using the simple species count as the production diversity indicator (columns 1–3 in Table 5 and panel a in Fig. 2), and second, using the production diversity score (columns 4–6 in Table 5 and panel b in Fig. 2).

Farm production diversity is positively associated with total HDDS,

[4] For some of the food groups, the subsistence and market shares do not add up to 100%, because small quantities are also obtained from other sources, such as collection of wild foods, gifts, and transfers. However, subsistence and markets account for over 95% of the quantities consumed in most cases.

Table 4
Dietary diversity scores in different farming systems.

	Less commercialized (n = 377) [a]	More commercialized (n = 378) [a]	Without cash crops (n = 249) [a]	With cash crops (n = 506) [a]
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Dietary diversity scores				
HDDS	9.58 (1.36)	9.85** (1.24)	9.72 (1.28)	9.71 (1.32)
$HDDS_{sub}$	4.50 (1.59)	4.99*** (1.52)	4.62 (1.57)	4.80 (1.57)
$HDDS_{mar}$	7.27 (1.55)	7.46 (1.55)	7.58 (1.61)	7.25 (1.51)
WDDS	4.12 (0.83)	4.21* (0.78)	4.28* (0.84)	4.11 (0.78)
$WDDS_{sub}$	2.71 (1.34)	3.01** (1.33)	2.80 (1.45)	2.89 (1.29)
$WDDS_{mar}$	2.34 (1.09)	2.32 (1.02)	2.52*** (1.17)	2.24 (0.98)
CDDS	4.19 (0.74)	4.07 (0.72)	4.32*** (0.73)	4.02 (0.72)
$CDDS_{sub}$	2.90 (1.25)	2.99 (1.32)	2.87 (1.32)	2.99 (1.26)
$CDDS_{mar}$	2.36 (1.10)	2.32 (1.01)	2.51* (1.11)	2.24 (1.01)
Farm production diversity				
Species count	13.12 (3.80)	13.70* (3.61)	12.25 (3.54)	13.98*** (3.67)
Production diversity score	5.73 (1.05)	5.90* (1.06)	5.70 (1.09)	5.87* (1.03)

Notes: The total sample contains observations from 755 households, 550 women, and 205 children. [a] This sample size refers to the number of household observations in each category. Mean differences between categories were tested for statistical significance. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

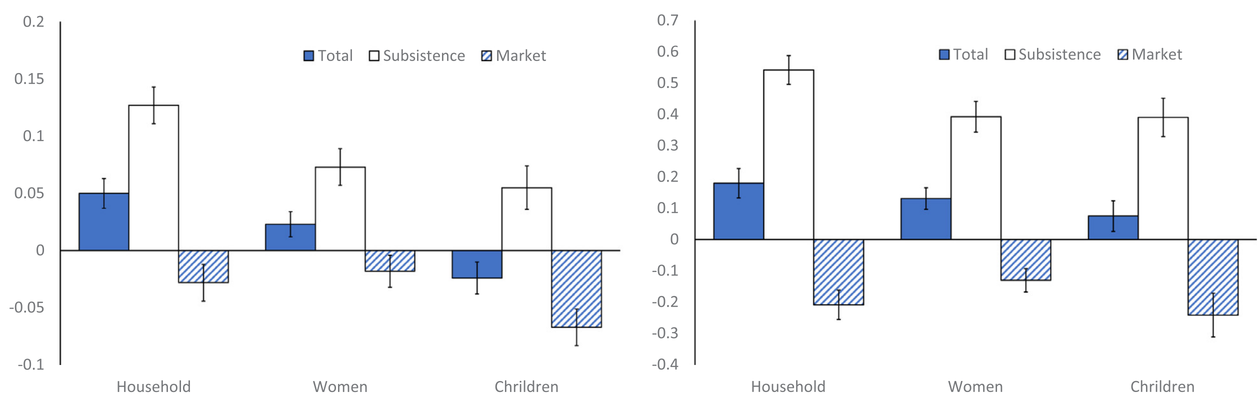

Fig. 2. Association between farm production diversity and dietary diversity (summary results). Notes: In the left panel, production diversity is measured with the species count. In the right panel, production diversity is measured with the production diversity score. Marginal effects of production diversity on household and individual dietary diversity scores are shown with standard error bars. Estimates are based on the regression models shown in Tables 5–7, controlling for confounding factors.

Table 5
Association between farm production diversity and household dietary diversity.

	(1) HDDS	(2) $HDDS_{sub}$	(3) $HDDS_{mar}$	(4) HDDS	(5) $HDDS_{sub}$	(6) $HDDS_{mar}$
	Species count			Production diversity score		
Farm production diversity	0.050***	0.127***	−0.028*	0.180***	0.541***	−0.208***
	(0.013)	(0.016)	(0.016)	(0.047)	(0.046)	(0.047)
Farm size (acres)	0.078*	0.114***	−0.013	0.084**	0.117***	0.000
	(0.042)	(0.039)	(0.050)	(0.042)	(0.034)	(0.052)
Household size	0.049**	0.011	0.040	0.046**	0.005	0.049*
	(0.022)	(0.025)	(0.030)	(0.022)	(0.024)	(0.029)
Male head (dummy for male = 1)	0.323**	0.400***	0.207	0.305**	0.348***	0.244
	(0.132)	(0.126)	(0.158)	(0.140)	(0.133)	(0.149)
Age head (years)	−0.010**	0.003	−0.016***	−0.008*	0.008**	−0.017***
	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.005)
Education head (years)	−0.002	0.023	−0.001	0.001	0.030**	−0.001
	(0.014)	(0.015)	(0.016)	(0.013)	(0.013)	(0.016)
Distance to market (km)	0.053***	0.088***	0.011	0.046**	0.074***	0.015
	(0.020)	(0.026)	(0.029)	(0.019)	(0.027)	(0.029)
Assets (value)	0.001	0.002	−0.000	0.001	0.001	0.001
	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
Social network index	0.042***	0.060***	0.009	0.035**	0.044***	0.015
	(0.015)	(0.018)	(0.021)	(0.015)	(0.017)	(0.021)
Number of observations	755	755	755	755	755	755

Notes: Marginal effects of generalized Poisson models are shown with cluster corrected standard errors in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 6
Association between farm production diversity and women's dietary diversity.

	(1) WDDS	(2) $WDDS_{sub}$	(3) $WDDS_{mar}$	(4) WDDS	(5) $WDDS_{sub}$	(6) $WDDS_{mar}$
	Species count			Production diversity score		
Farm production diversity	0.023**	0.073***	−0.018	0.131***	0.392***	−0.130***
	(0.011)	(0.016)	(0.014)	(0.035)	(0.049)	(0.037)
Farm size (acres)	0.019	0.086**	−0.096***	0.016	0.085**	−0.096***
	(0.032)	(0.044)	(0.033)	(0.030)	(0.036)	(0.033)
Household size	0.022	−0.006	0.040	0.019	−0.019	0.040
	(0.017)	(0.028)	(0.027)	(0.017)	(0.027)	(0.026)
Male head (dummy for male = 1)	0.119	0.288**	0.039	0.095	0.233	0.092
	(0.074)	(0.147)	(0.117)	(0.075)	(0.147)	(0.106)
Age head (years)	−0.010*	−0.007	−0.000	−0.009	−0.002	−0.004
	(0.006)	(0.011)	(0.008)	(0.006)	(0.011)	(0.008)
Education head (years)	0.005	−0.001	0.006	0.007	0.003	0.002
	(0.011)	(0.022)	(0.018)	(0.011)	(0.023)	(0.018)
Age woman (years)	0.004	0.012	−0.009	0.003	0.008	−0.006
	(0.007)	(0.010)	(0.008)	(0.006)	(0.011)	(0.008)
Education woman (years)	0.013	0.053**	−0.024	0.011	0.050**	−0.021
	(0.013)	(0.027)	(0.018)	(0.013)	(0.023)	(0.017)
Distance to market (km)	0.031**	0.054**	0.001	0.028*	0.041*	0.004
	(0.015)	(0.024)	(0.021)	(0.015)	(0.022)	(0.021)
Assets (value)	0.001	0.003	0.000	0.001	0.002	0.001
	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
Social network index	0.012	0.040**	−0.014	0.008	0.029	−0.011
	(0.014)	(0.020)	(0.020)	(0.014)	(0.019)	(0.020)
Number of observations	550	550	550	550	550	550

Notes: Marginal effects of generalized Poisson models are shown with cluster corrected standard errors in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 7
Association between farm production diversity and child dietary diversity.

	(1) CDDS	(2) $CDDS_{sub}$	(3) $CDDS_{mar}$	(4) CDDS	(5) $CDDS_{sub}$	(6) $CDDS_{mar}$
	Species count			Production diversity score		
Farm production diversity	−0.024*	0.055***	−0.067***	0.075	0.390***	−0.242***
	(0.014)	(0.019)	(0.016)	(0.049)	(0.061)	(0.070)
Farm size (acres)	−0.043	0.072	−0.084	−0.063*	0.053	−0.089
	(0.031)	(0.051)	(0.059)	(0.034)	(0.047)	(0.058)
Household size	0.020	−0.024	0.064	0.014	0.000	0.048
	(0.031)	(0.068)	(0.058)	(0.031)	(0.068)	(0.054)
Male head (dummy for male = 1)	0.268**	0.264	0.069	0.233*	0.197	0.150
	(0.120)	(0.167)	(0.156)	(0.125)	(0.174)	(0.152)
Age head (years)	0.004	0.009	−0.007	0.001	0.005	−0.009*
	(0.005)	(0.006)	(0.005)	(0.005)	(0.006)	(0.005)
Education head (years)	0.030*	0.037	0.021	0.025*	0.036*	0.010
	(0.016)	(0.024)	(0.018)	(0.015)	(0.021)	(0.017)
Age child (months)	0.011**	0.007	−0.000	0.011**	0.006	−0.000
	(0.004)	(0.008)	(0.004)	(0.005)	(0.007)	(0.004)
Number of siblings	−0.093	−0.041	−0.161**	−0.093	−0.070	−0.158*
	(0.061)	(0.082)	(0.081)	(0.063)	(0.085)	(0.083)
Distance to market (km)	0.009	0.070*	0.008	0.017	0.062*	0.032
	(0.021)	(0.036)	(0.024)	(0.021)	(0.034)	(0.025)
Assets (value)	−0.001	−0.001	0.001	−0.001	−0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
Social network index	−0.010	0.043	−0.040	−0.017	0.023	−0.032
	(0.020)	(0.028)	(0.026)	(0.020)	(0.027)	(0.024)
Number of observations	205	205	205	205	205	205

Notes: Marginal effects of generalized Poisson models are shown with cluster corrected standard errors in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

but the magnitude of the association is relatively small. The marginal effect of 0.05 in column (1) of Table 5 suggests that each additional species produced on the farm is associated with a 0.05 increase in the number of food groups consumed. In other words, households would have to produce 20 additional species in order to increase HDDS by one food group. The association is larger when the production diversity score is used (column 4), as was also demonstrated in previous research (Sibhatu and Qaim, 2018b). But the marginal effect remains relatively small: the value of 0.18 implies that more than five additional food groups would have to be produced in order to increase HDDS by one food group.

The results for $HDDS_{sub}$ and $HDDS_{mar}$ in Table 5 reveal the pathways that were outlined in the conceptual framework. The estimates confirm our main hypothesis, namely that farm production diversity is positively associated with dietary diversity obtained from subsistence, but negatively associated with dietary diversity obtained from the market (also see Fig. 2). As expected the partial effects through the subsistence pathway are larger than the total effects. Interesting to note, however, is that even when the production diversity score is used, the effect on dietary diversity from subsistence remains significantly smaller than one (0.54 in column 5 of Table 5). Hence, the production of one additional food group on the farm does not necessarily mean that this additional food group is also consumed by the farm household. This is in line with the above-mentioned finding that certain foods are produced primarily for the market and not consumed by the farm households on a regular basis.

Results for women's dietary diversity, with WDDS as dependent variable, are presented in Table 6. They are generally similar to what we also found at the household level: farm production diversity is positively associated with dietary diversity obtained from subsistence but negatively associated with dietary diversity obtained from the market. The combined effect is positive and relatively small, regardless of how exactly farm production diversity is measured. The marginal effects on WDDS are smaller than those on HDDS in absolute terms, which is due to the smaller number of food groups considered in calculating the WDDS.

Results for children's dietary diversity, with CDDS as dependent variable, are shown in Table 7. Here, we also find positive effects of production diversity on dietary diversity obtained from subsistence, and negative effects on dietary diversity from the market. But as both these partial effects are similar in terms of their absolute magnitude, they balance out so the combined effect is not significantly different from zero (column 4 of Table 7). When production diversity is measured with the simple species count, the combined effect is even negative (column 1), meaning that producing additional species on the farm tends to reduce child dietary diversity.

Beyond the effects of farm production diversity, the estimates for the control variables in Tables 5–7 are also of interest, as they help to better understand dietary diversity outcomes. Farm size is positively associated with dietary diversity at the household level (HDDS in Table 5), which is unsurprising given that a larger farm size allows more production for home consumption and for markets. The effect of farm size on HDDS is particularly channeled through the subsistence pathway. Interestingly, the combined effect of farm size on women's dietary diversity is not significant (Table 6), and it is even negative for children's dietary diversity (column 4 of Table 7).

The results in Table 5 further show that male-headed households have a higher dietary diversity than female-headed households. These gendered effects are probably driven by households with male household heads having higher incomes on average. Female-headed households are often those where the male household head died or left, which tends to reduce the income-earning opportunities for the rest of the family.

Education of the household head has positive marginal effects in several of the models. This is unsurprising, because diets are also determined by nutrition knowledge, and nutrition knowledge tends to increase with rising educational levels. The important role of knowledge and access to information is also stressed by the positive marginal effects of the social network indicator, especially in the household-level models in Table 5. As was shown in recent research, informal social networks can play an important role for the spread of agricultural and nutrition information in rural communities of Africa (Jäckering et al., 2019).

Distance to market has positive marginal effects on dietary diversity in many of the models, which is surprising on first sight, because longer distances are normally expected to worsen access to diverse foods from the market. However, as can be seen, the positive effects of market distance are primarily channeled through the subsistence pathway. This is plausible, since households with limited market access are often more oriented towards subsistence production (Hirvonen and Hoddinott, 2017; de Janvry et al., 1991).

In a final analysis, we test whether the role of farm production diversity for household and individual dietary diversity differs between households at different levels of market orientation. For this analysis we return to the commercialization typology introduced above and re-estimate all models for two subsamples, namely the less commercialized and the more commercialized households. The estimation results are summarized in Table 8.

We observe the same patterns for both subsamples. The overall effect of production diversity on dietary diversity is small, and it combines a positive partial effect through the subsistence pathway and a negative partial effect through the market pathway. In the household-level estimates, the total effect of production diversity on dietary diversity is somewhat larger in the less commercialized households than in the more commercialized ones, which is plausible because in the less commercialized households the subsistence pathway plays a more important role. Also in the individual-level models for women and children, we observe that the effects of production diversity on dietary diversity through the subsistence pathway are somewhat larger in the less commercialized households. But overall, the differences between the two subsamples are small, suggesting that the main findings hold for all types of smallholder farm households in the study region.

5. Conclusions and policy implications

Smallholder farmers in sub-Saharan Africa remain one of the population groups most affected by undernutrition and low dietary quality. Hence, there is an urgent need to make smallholder production systems more nutrition-sensitive. Several recent studies analyzed whether further increasing farm production diversity might be a useful strategy to improve diets and nutrition. Most of these studies identified a positive relationship between production diversity and dietary diversity, even though the average magnitude of the effect was found to be small. Reasons for the small effect were hardly examined in detail, a research gap which we addressed in this article with data from smallholder farmers in Western Kenya.

Farm production can affect smallholder diets through different pathways, especially the subsistence pathway and the market pathway. We tested the hypothesis that farm production diversity is positively associated with dietary diversity obtained from subsistence and negatively associated with dietary diversity obtained from the market. This hypothesis was confirmed, using various indicators of production diversity and dietary diversity, also after controlling for possible confounding factors. In addition to household-level dietary diversity scores, we also calculated individual-level dietary diversity scores for women and children with the same overall conclusions.

To some extent, the negative partial effect through the market pathway can be explained by a simple substitution of own-produced foods for foods purchased in the market. However, high farm production diversity and a focus on subsistence can also be associated with lower household income and thus lower economic ability to access higher-value and more nutritious foods from the market. In any case, the negative partial effect through the market pathway counteracts the positive effect through the subsistence pathway, so that the combined overall effect of production diversity on dietary diversity is small.

The results underline the important role of markets for the diets of smallholder farmers, even in subsistence-oriented settings. Overall, about half of all the foods consumed in the sample households were purchased in the market. While the role of food sources varies by food group, for 9 out of the 12 food groups used to calculate household dietary diversity scores the market-derived quantities were found to be 30% or more. These numbers are in line with previous studies carried out in other parts of sub-Saharan Africa (Hirvonen and Hoddinott, 2017; Koppmair et al., 2017; Sibhatu and Qaim, 2017; GLOPAN, 2016).

One important policy implication is that promoting farm diversification may not be the most effective strategy to improve diets and nutrition in smallholder farm households. African smallholder farms are often quite diverse anyway. In our study region, the average farm produces more than 13 different species on less than 1.5 acres of land. Further diversification may foster subsistence and reduce the

Table 8
Association between farm production diversity and dietary diversity in more and less commercialized households.

	(1) DDS	(2) DDS_{sub}	(3) DDS_{mar}	(4) DDS	(5) DDS_{sub}	(6) DDS_{mar}
	Less commercialized households (n = 377)			More commercialized households (n = 378)		
Production diversity (effects at household level)	0.060***(0.020)	0.137***(0.023)	−0.026(0.023)	0.041**(0.016)	0.119***(0.021)	−0.026(0.019)
Production diversity (effects for women)	0.020(0.014)	0.084***(0.024)	−0.017(0.019)	0.029**(0.013)	0.068***(0.020)	−0.018(1.02)
Production diversity (effects for children)	−0.032(0.020)	0.070*(0.036)	−0.089***(0.021)	−0.011(0.018)	0.052**(0.025)	−0.036*(0.022)

Notes: Marginal effects of production diversity (measured with the simple species count) on dietary diversity scores (DDS) estimated with generalized Poisson models are shown with cluster corrected standard errors in parentheses. The same control variables as shown in Tables 5–7 were included in estimation but are not shown here for brevity. The total sample contains observations from 755 households, 550 women, and 205 children. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

opportunities to participate in markets as sellers and buyers. Strengthening markets and improving market access for smallholders seems to be a more promising strategy.

Strengthening markets and improving market access requires improved roads as well as storage and market infrastructure. Higher-value nutritious foods, such as fruits, vegetables, and animal-source products, are more perishable than grains and most other staple foods, so that good infrastructure and efficient logistics are especially important. Obviously, these higher-value foods are of particular relevance to improve dietary quality and nutrition and should receive particular policy attention. In addition to general infrastructure improvements, the establishment of nutrient-preserving processing facilities could also help to improve market functioning for perishable foods. This plea for strengthening markets does not mean that certain forms of production diversification in the small farm sector may not be useful in particular contexts. But, unless markets are completely absent, diversification should build on market incentives rather than focusing on subsistence alone.

The results presented here on subsistence and market pathways refer to farm households in Western Kenya. However, the situation in Western Kenya is quite typical for the African small farm sector, so that the general findings may also apply to other contexts. Of course, follow-up research in different settings will be useful to better understand the complex linkages between agricultural production patterns, markets, diets, and nutrition in smallholder farm households.

CRediT authorship contribution statement

Davis Muthini: Conceptualization, Methodology, Writing - original draft, Investigation, Formal analysis, Writing - review & editing, Visualization. **Jonathan Nzuma:** Conceptualization, Supervision, Investigation, Writing - review & editing, Project administration. **Matin Qaim:** Conceptualization, Methodology, Supervision, Writing - review & editing, Validation, Visualization, Funding acquisition, Project administration.

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