Food Policy 46 (2014) 1–12

Contents lists available at ScienceDirect

Food Policy

journal homepage: www.elsevier.com/locate/foodpol

Farm production diversity is associated with greater household dietary diversity in Malawi: Findings from nationally representative data

Andrew D. Jones [a,*], Aditya Shrinivas [b], Rachel Bezner-Kerr [c]

[a] University of Michigan, School of Public Health, Ann Arbor, MI 48109, USA
[b] University of Illinois at Urbana-Champaign, Department of Agricultural and Consumer Economics, Urbana, IL 61801, USA
[c] Cornell University, Department of Development Sociology, Ithaca, NY 14853, USA

ARTICLE INFO

Article history:
Received 25 June 2013
Received in revised form 29 January 2014
Accepted 4 February 2014

Keywords:
Farm diversity
Crop diversity
Dietary diversity
Child anthropometry
Agriculture
Nutrition

ABSTRACT

Farm production diversity has the potential to influence the diversity of household diets, an important nutrition outcome associated with the nutrient adequacy of diets and the nutritional status of individuals. Yet, little empirical research has assessed the relationship between farm diversity and diet diversity or the plausible causal mechanisms that may operate between these two constructs. This research examines cross-sectional data from the Malawi Third Integrated Household Survey (IHS3), a nationally representative sample of farming households in Malawi, implemented from March 2010–March 2011 as part of the World Bank Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA). These data were used to determine the relationship between farm production diversity and household dietary diversity, and to identify determinants of this relationship. Two indicators of dietary diversity, a modified Household Dietary Diversity Score (HDDS), and the Food Consumption Score (FCS), were calculated along with three indicators of farm production diversity including the Simpson's Index, a metric accounting for both species richness and evenness. In multiple regression analyses, adjusting standard errors for the complex survey design of the IHS3 and controlling for the effects of several covariates on household dietary diversity, farm production diversity was consistently positively associated with dietary diversity ($P < 0.0001$). The association of increased farm diversity as measured by a combined crop and livestock measure on dietary diversity was significantly greater in woman-headed households compared to those headed by men (HDDS: $P = 0.008$; FCS: $P = 0.076$). The positive association of farm diversity with dietary diversity was also greater in wealthier households ($P < 0.05$). Consumption of legumes, vegetables and fruits was especially strongly associated with greater farm diversity. More diverse production systems may contribute to more diverse household diets. However, this relationship is complex; it may be influenced by gender, wealth, control of household decisions, the relative market-orientation of a household's agricultural production, and the specific nature of farm diversity.

1. Introduction

Agriculture produces much of the world's food, fiber, materials for shelter, and medicinal plants (Hawkes and Ruel, 2006), all of which serve as the primary foundation for sustaining human communities. In particular, for the nearly three-quarters of the world's poor people who live in rural areas of low-income countries, agricultural production and livelihoods may be especially influential on diets (Haddad, 2000; Pinstrup-Andersen, 2007).

Agriculture may influence the quality of diets of smallholder farming households in primarily two ways: (1) through production of subsistence food crops or animals that households then consume directly, or (2) through the sale of agricultural goods that affect household incomes and therefore food purchases and consumption (World Bank, 2007). Other pathways from agriculture to nutrition operate to affect the diets and nutritional status of *individuals* within households—for example: (1) household income may be spent to purchase healthcare for individuals, (2) a woman's time and workload may affect her energy expenditure and health as well as her capacity to feed and care for young children (Jones et al., 2012), and (3) a woman's control of household income, affected in part by her ownership of farm output and the kind of income generated from that output (Kennedy and Cogill, 1987), affects the kinds of purchases made with the income and the allocation of resources within households (Gillespie et al., 2012). Despite the importance of understanding if and how these

* Corresponding author. Address: 6642 SPH I, 1415 Washington Heights, Ann Arbor, MI 48109, USA. Tel.: +1 734 647 1881; fax: +1 734 763 5455.
E-mail address: jonesand@umich.edu (A.D. Jones).

http://dx.doi.org/10.1016/j.foodpol.2014.02.001
0306-9192/

pathways operate to impact nutrition outcomes, surprisingly few empirical studies have examined these relationships. In particular, the relationship between the production diversity of farms and the quality of the diets of the households managing those farms has not been well established.

Agricultural systems have traditionally been measured based on their productivity and economic output. Maximizing yields was the chief aim of Green Revolution technologies that combined high-yielding cereal varieties with the expanded use of fertilizers, chemical inputs and irrigation. While this approach resulted in an unprecedented increase in yields of rice and wheat (Hazell and Ramasamy, 1991), displacing millets and pulses with cereal grain production may have contributed to declines in the nutritional quality of diets (Bamji, 2007; Graham et al., 2007). These yield-driven agricultural systems tend to emphasize production of food energy, fiber and fuel while de-emphasizing production of diverse macro- and micronutrients for human consumption. These emphasized outputs are often produced at the expense of ecosystem services that support and sustain the natural environment (e.g. soil and water conservation, biodiversity or regeneration of organic materials) (World Resources Institute, 2003).

Given the enormous global burden of micronutrient deficiencies borne by vulnerable populations (Micronutrient Initiative, 2009), the seemingly intractable problem of child growth stunting that is in part due to poor quality diets (Bhutta et al., 2008), and emerging trends in overweight and obesity even in rural areas of low-income countries where overnutrition was not previously a concern (Popkin et al., 2011), understanding the capacity of farming systems to meet human nutritional needs is paramount.

One simple, commonly used measure that serves as a proxy for diet quality, or the extent to which nutritional needs are being met, is dietary diversity. Diets with a greater variety of foods or food groups are associated with greater energy and nutrient intakes (Kant, 2004; Rose et al., 2002; Tarini et al., 1999), more adequate nutrient intakes (Hatløy et al., 1998; Steyn et al., 2006), and more positive anthropometric outcomes for adults and children (Arimond and Ruel, 2004; Rah et al., 2010; Ruel and Menon, 2002). Usual household diets in low-income countries are often limited to one or two starchy staple foods and may be especially lacking in micronutrient-rich fruits, vegetables and animal-source foods. For farming households that consume primarily what they themselves produce, it seems reasonable that diversified agricultural production would lead to more diverse diets. However, most farming households throughout the globe in fact practice some mix of subsistence and market-oriented production, thus adding complexity to the relationship between farm production diversity and dietary diversity.

Herforth (2010) examined the relationship between farm diversity and dietary diversity among households in central Kenya and northern Tanzania (Herforth, 2010). In both Kenya and Tanzania, the number of crops grown by a household was positively associated with the dietary variety of the household (i.e. the number of unique foods in the diet) and in Tanzania, crop diversity was associated with the diversity of food groups in household and individual child diets. In both countries, crop diversity was also positively associated with the diversity of home-produced fruits and vegetables consumed. In the rural highlands of Ecuador, on-farm species diversity and family-level dietary diversity were also positively correlated (Oyarzun et al., 2013). Families with low agrobiodiverse farms in this setting consumed more off-farm food items. In western Mali, the number of crops cultivated by a household was positively associated with adult nutrient adequacy (i.e. mean adequacy ratio) (Torheim et al., 2004). Similarly, in rural areas of Malawi, Kenya and Uganda, the richness or diversity of plant species on farms was positively associated with a metric of nutritional functional diversity of farms, or the diversity of nutrients provided by farms based on the nutritional composition of their plant species (Remans et al., 2011). A similar analysis in western Kenya found no relationship between species richness and adult hemoglobin levels, though nutritional functional diversity was positively associated with hemoglobin (DeClerk et al., 2011).

The few studies that have examined the relationship between farm diversity and the diversity or quality of household diets have done so in relatively small population samples. The study presented here seeks to build from the limited evidence to date regarding the association between household farm diversity and household diet diversity by examining cross-sectional data from a large, nationally representative sample of farming households in Malawi. Examining these questions in the context of Sub-Saharan Africa (SSA) is particularly important given the widespread food insecurity and malnutrition seen across the continent, the kinds of agricultural policies currently promoted in response to this poor nutrition, as well as the fact that more than two-thirds of the population depends on agriculture as a source of livelihood (Pinstrup-Andersen, 2010). We use data on the diversity of household cropping systems, livestock production, and diets to determine the relationship between the production diversity of household farms and household dietary diversity, and to identify determinants of this relationship.

2. Methods

2.1 Setting

Malawi is a landlocked country in southeastern Africa of nearly 15 million people bordered by Zambia, Tanzania and Mozambique and to the east by the 587 km long Lake Malawi. The country is divided into 28 districts, located in three regions: north, central and south. Households in Malawi are highly dependent on agriculture. Thirty percent of GDP comes from the agriculture sector (World Bank, 2013a,b) with 94% of rural residents and 38% of urban residents engaged in agriculture to some extent (National Statistical Office Malawi, 2012a). Maize is the main staple for 90% of the population of Malawi, though cassava is also a dominant staple crop with greater than 4 million metric tons produced in 2011 (FAOSTAT, 2013). Almost all agricultural production is rainfed and occurs during the single rainy season from October to April on small plots of land (approximately one hectare) (Denning et al., 2009). In the last decade, maize production has been strongly supported by the Agricultural Input Subsidy Program which provides eligible households with fertilizer and hybrid maize vouchers that reduce fertilizer and seed costs to approximately one-third of the market price (Dorward et al., 2008; Zerfu Gurara and Salami, 2012). While this policy has been effective at increasing national maize production, undernutrition and food insecurity have remained high. Nearly half of all children under five years of age are undernourished (47.1% prevalence of stunting) (National Statistical Office Malawi, 2011) with 60% of preschool-aged children deficient in vitamin A (World Health Organization, 2009) and nearly three-quarters anemic (World Health Organization, 2008).

2.2 Data

We use data from the Malawi Third Integrated Household Survey (IHS3), a nationally representative survey implemented from March 2010–March 2011 as part of the World Bank Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) (World Bank, 2013a,b).

The IHS3 employed a stratified two-stage sample design wherein the primary sampling units were enumeration areas (EA) defined for the 2008 Malawi Population and Housing Census

(National Statistical Office Malawi, 2012b). These EAs were sampled from the three major rural regions of Malawi—North, Central and South—with a separate stratification for urban regions including Lilongwe City, Blantyre City, Mzuzu City, and the Municipality of Zomba. The EAs were selected with probability proportional to size within each district of the country and households were selected using random systematic sampling within each EA. A total of 12,271 households were surveyed over the one-year survey period. Households were excluded from the sample if they were not involved in agriculture ($n = 1870$) or if they did not report data on the 2009–2010 agricultural season ($n = 3649$). Inclusion of only households for which data were available for the full, one-year agricultural cycle beginning in the 2009–2010 rainy season (i.e. November 2009–April 2010) through the 2010 dry season (May–November 2010) helped to minimize potential seasonal bias and ensure comparability in the relationships observed across households. We further excluded households for which cropped area data were not available ($n = 127$) or were of questionable accuracy ($n = 2$). The final sample used in analyses then was 6623 households.

Food consumption data were collected in an evenly spread manner across the one-year survey period and across all regions of the country such that these data were collected in approximately 64 EAs each month.

2.3 Measurement of farm diversity

Because so few studies have examined the influence of farm production diversity on the diversity of household diets, and because dietary diversity in particular may be highly context specific (Ruel, 2003), we used more than one metric of each diversity measure. Using multiple measures allowed us to assess the consistency of the relationship between farm production diversity and dietary diversity.

We used three different measures of farm diversity in our analyses. First, a simple crop count variable was created that sums the total number of different crop species cultivated by the household over the 2009–2010 rainy season and 2010 dry season. Though few households cultivate crops during the dry season, between-household variability in the diversity of farm production throughout the entire year was identified *a priori* as a potentially important characteristic to capture. A crop and livestock count variable was also constructed that added to the crop count variable the number of different animal species reared by the household. These count indicators or variations of them have been used previously to assess farm genetic diversity and biodiversity (Herforth, 2010; Meng et al., 2010; Hawksworth, 1995; Smale et al., 1998). We also used the Simpson's Index (Simpson, 1949), an index used in the ecological literature to measure species diversity or biodiversity (Baumg, 2006; Lande, 1996; Whittaker, 1972), and in some cases, crop diversity (Kshirsagar et al., 2002; Shahidullah et al., 2008).

The Simpson's Index accounts for both richness (number of crops) and evenness (distribution of area cultivated). The index is defined as $\textit{Simpson's Index}_i = 1 - \sum s_j^2$. Here, s_j is the share of the crop j in the total area cultivated by the household i and is given by $s_j = a_{ij}/A_i$, where a_{ij} is the area cultivated on the jth crop by the ith household and A_i is the total area cultivated under all crops. Tree crops and permanent crops grown in monocropped fields were included in this total area measure. The Simpson's Index is bounded between 0 and 1. A value of zero indicates that a household grows only one crop and a value of one indicates that the acreage of all the cultivated crops is equally distributed. The index is interpreted as the probability that any two crops selected at random from a household will be of different types. A farm that devotes 90% of its cultivated area to maize and 10% to pigeon pea, for example, would receive a lower score on the Simpson's Index as compared to a farm that devotes equal acreage to the two crops.

2.4 Measurement of dietary diversity

Dietary diversity was calculated in two ways. A modified Household Dietary Diversity Score (HDDS) (Swindale and Bilinsky, 2006) was calculated for each household using data on consumption of 113 food items. The HDDS is normally constructed using data on dietary intake in the previous 24 h. No dietary data were available in the IHS3 data set based on 24-h diet recalls. We therefore use a modified HDDS based on consumption of foods over the previous 7 d. Food items were categorized into 12 different food groups with each food group counting toward the household score if a food item from the group was consumed by anyone in the household in the previous seven days. The modified HDDS, then, is a continuous score from 0 to 12. The food groups used to calculate the modified HDDS included: cereals, roots and tubers, vegetables, fruits, meat, eggs, fish and seafood, pulses and nuts, milk and milk products, oils and fats, sugar, and condiments.

The second dietary diversity variable calculated was the household's Food Consumption Score (FCS) (World Food Programme, 2008). The FCS combines data on dietary diversity and food frequency using 7-d recall data. The consumption frequency of eight food groups (i.e. staple grains and tubers, pulses, vegetables, fruits, meat and fish, dairy products, sugar and oil) is multiplied by an assigned weight, and the resulting values are summed to obtain the FCS. This score can then be recoded to a three-level categorical variable using standard cut-off values. The assigned weights for each food group are based on the energy, protein and micronutrient densities of each food group. The Malawi IHS3 included data on the consumption of specific food items in the previous 7 days as well as the frequency of consumption of food items from ten food groups in the previous 7 days. We used the latter food frequency data to calculate the FCS. We also used the continuous FCS variable rather than the three-level categorical variable to prevent the loss of data.

For some analyses, we also present results using raw counts of the number of food items consumed in the previous 7 d (FI) and food group frequency (FGF), that is, the number of days in the past 7 d that specific food groups were consumed by any household member.

2.5 Measurement of other variables

We assessed the production orientation of farming households (i.e. subsistence or market) by calculating the proportion of food consumed in the previous week that came from own production based on a quantitative assessment of the total amount of each food item consumed by the household. Assessing the production orientation of farming households is important for understanding the relative importance of subsistence vs. market-oriented production in influencing household diets—two of the principle pathways through which agricultural production is hypothesized to influence nutrition outcomes (Gillespie et al., 2012). Ideally, we would have assessed household agricultural production orientation by calculating the exact quantity of harvested crops that were kept for own consumption, sold to market, or used for other purposes. No conversion factors were provided in the IHS3, however, to translate into kilograms the units provided by respondents for the quantity of crops produced, sold, or kept for consumption. Therefore, we were unable to calculate the quantity of crops produced by households for different purposes. We did assess the proportion of cropped land area devoted to crops that were sold to market by assuming that if any amount of a crop was sold to market, this crop was a market crop. Because the IHS3 did not include questions on whether a crop was kept for own consumption, and because we lacked the conversion data to standardize units of quantity, we could not calculate this same proportion for subsistence crops or ascertain if a crop was both sold and kept for own consumption. Therefore, because the "proportion of land area devoted to market crops" indicator includes a strong assumption, we did not include it in our principal analyses, but rather included it in sub-analyses to inform interpretation of regression results.

Only a partial list of conversion factors were provided for the food consumption data. Therefore, in assessing food consumption from own production, the quantities of foods consumed were not able to be compared between households. However, the proportion of foods consumed in the previous one week that came from a household's own agricultural production was able to be calculated because standardized units were available within households for the quantity of specific food items consumed in total and the quantity consumed that came from own production.

We include in our multiple regression models several other measures that could potentially influence household diets and confound the relationship between farm diversity and diet diversity. We use quantitative cropped land area data based on GPS measurement of the area of farmers' plots to control for farm size which may explain much of the underlying diversity of farms and therefore confound the relationship between farm diversity measures and diet diversity. Farm size may also be independently associated with household diet diversity (Oyarzun et al., 2013).

Household food expenditures per capita in the previous one week (based on the total value of all purchased food items in the previous 7 days), and non-food expenditures per capita in the previous one month (e.g. soap, personal products, petrol, home repairs, soap, milling fees, etc.) are included in our models to control for household-level behaviors associated with the use of productive resources. Food-related expenditures may directly influence the quantity and quality of household diets, while non-food expenditures, through substitution effects, may indirectly influence the amount of resources available for diversifying diets. Population-weighted national consumption per-person quintiles were derived by the LSMS-ISA team from data on consumption of durable goods, services, education, and other welfare-related consumption, either through market and non-market transactions (National Statistical Office Malawi, 2012a). These data were converted into annual figures and population-weighted quintiles. We include these quintiles in our models as a proxy for household wealth.

We also include in our models the number of non-agricultural, income-generating enterprises in which the household has been involved in the previous 12 months. These enterprises could include a trading business, professional services, cottage industry activities, or other skilled labor activities. We include these data in our models to control for the extent to which households are engaged in agriculture as their primary source of livelihood. We also control for intrahousehold control of agricultural earning decisions. As noted earlier, control of income within households may have a strong influence on household diets and health outcomes. Respondents were asked to report the household member or members who controlled decisions regarding how to use income generated from the sale of agricultural goods. Finally, though we do not include it in our principal regression analyses, in sub-analyses, we examined the proportion of household plots that were intercropped. We used data on the proportion of each plot dedicated to specific crops and whether the plot was a "pure stand" or "mixed stand" (in the language of the questionnaire) to assess the extent of intercropping.

Anthropometric indices including height-for-age *Z*-score (HAZ) and weight-for-age *Z*-score (WAZ) were calculated for children aged 6–59 months of age from height, weight and age data on these children in the IHS3 using macros provided by the World Health Organization based on data from the Multicentre Growth Reference Study (World Health Organization, 2006). These indices were calculated to inform the characterization of children of the households in the sample. In households with more than one child in this age range, only the youngest child in the household was included.

2.6 Analytical methodology

We constructed multiple linear regression models using as response variables the two measures of dietary diversity and as independent variables the three measures of farm diversity, each in separate regression models. We specified our models using an *a priori* assessment of the potential causal determinants of household dietary adequacy based on findings from the peer-reviewed literature (Thorne-Lyman et al., 2010; Clausen et al., 2005; Torheim et al., 2004). Factors that may have confounded the relationship between farm diversity and dietary diversity were adjusted for including: household size, age of household head, education level of household head, sex of household head, total cropped area of the household in the previous rainy and dry seasons combined, household food and non-food expenditures, number of different non-agricultural income sources for the household, proportion of food consumed that came from own production, intrahousehold control of agricultural earnings decisions, population weighted national consumption-per-person quintile, and regional dummy variables that were calculated using effect coding. We first estimated coefficients for the regional dummies by excluding one of the zones at random from the regression, and re-ran regressions using a different combination of dummies that included the initially excluded dummy to obtain the coefficient for this dummy variable. In sensitivity analyses using different combinations of regional dummies, coefficient estimates and significance levels for model variables were stable.

Covariates were selected *a priori* based on existing theory regarding determinants of household dietary diversity and potential confounding factors of the relationship between farm diversity and diet diversity. We entered all covariates into the model simultaneously to prevent bias in estimation that might result from *post hoc* model manipulation. We used a partial sums of squares approach such that the order of variables did not influence the coefficient estimates.

Pearson product-moment correlation coefficients were also calculated to examine associations between measures of dietary diversity and farm diversity. ANOVA was used to assess differences in household characteristics across regions of Malawi and across national consumption quintiles. Pearson's chi-squared test statistic was also used to assess differences in percentage characteristics across these same strata.

We carried out diagnostic analyses to assess the potential for collinearity among the independent variables in the models. We observed variance inflation factors ranging from 1.1 to 2.2 which were below suggested cut-offs above which collinearity may be considered a problem (Kutner et al., 2004). We also present coefficient of determination values and the Akaike Information Criterion (AIC) for each model as reference model fit statistics.

All analyses were carried out using the Stata statistical software package version 12.1 (2013; StataCorp, College Station, TX, USA). We used the "svyset" command to identify sampling weights, cluster and strata variables. The primary sampling units in the IHS3, or clusters, were census enumerator areas. These were selected with probability proportional to size based on the number of households in the 2008 Malawi Census frame (National Statistical Office, 2012b). Sampling strata were defined as rural and urban strata. We used the "svy" command in Stata to estimate Taylor-linearized standard errors that adjust for the multistage sampling frame of the IHS3. Relationships were considered significant at $P < 0.05$ and for interaction terms, $P < 0.1$.

Table 1
Household- and child-level sample characteristics, disaggregated by region of Malawi.

Household and child characteristics	Regions of Malawi (disaggregated by IHS3 sampling strata)					
	Urban	Rural north	Rural central	Rural south	All regions	F-statistic[§]
Sample size (n)	627	1206	2104	2686	6623	
Demographic and socioeconomic characteristics						
Household size	5.08 (2.32)	4.88 (2.44)	4.90 (2.16)	4.41 (2.06)	4.72 (2.20)	14.0[**]
Percentage of household heads acquiring no education (%)	40.7	66.5	80.7	82.9	75.2	784[**]
Percentage of mothers acquiring no education (%)	80.5	92.7	96.3	98.6	95.4	118[**]
Food expenditures per capita in past 7 d (MK)	895 (1080)	316 (325)	288 (378)	294 (324)	353 (498)	28.6[**]
Non-food expenditures per capita in past 1 mo (MK)	1290 (5890)	290 (701)	267 (482)	227 (745)	352 (1939)	5.1[**]
Percentage of households in lowest two national consumption per person quintiles (%)	13.1	39.9	32.2	44.8	36.9	456[**]
Diet and diet diversity						
Household Dietary Diversity Score (HDDS)	10.3 (1.91)	8.66 (2.21)	8.17 (2.48)	7.94 (2.22)	8.37 (2.38)	46.4[**]
Food Consumption Score (FCS)	65.6 (21.0)	54.1 (19.0)	49.3 (18.2)	48.3 (16.4)	51.3 (18.6)	30.9[**]
Proportion of food consumed over the previous one week that came from own production	0.10 (0.10)	0.27 (0.17)	0.32 (0.18)	0.25 (0.17)	0.26 (0.18)	120[**]
Agricultural characteristics						
Cropped area (ha)	0.67 (0.81)	0.91 (0.64)	1.06 (0.87)	1.19 (1.19)	1.05 (0.99)	35.7[**]
Number of cultivated plots	1.42 (0.71)	1.87 (1.1)	2.10 (1.1)	1.70 (0.86)	1.83 (0.98)	38.6[**]
Proportion of cultivated plots that are intercropped	0.31 (0.45)	0.18 (0.34)	0.17 (0.34)	0.62 (0.44)	0.37 (0.45)	112[**]
Percentage of households growing crops in the dry season (%)	3.67	8.96	14.4	10.1	10.6	66.9[**]
Proportion of cropped land area devoted to market crops	0.13 (0.30)	0.29 (0.36)	0.37 (0.38)	0.15 (0.26)	0.25 (0.34)	59.9[**]
Number of fruit trees	0.69 (3.05)	2.08 (8.44)	2.51 (9.94)	4.84 (28.8)	3.2 (19.6)	10.9[**]
Livestock ownership (LUs)	0.25 (1.24)	0.60 (1.65)	0.35 (0.90)	0.27 (1.77)	0.35 (1.47)	8.3[**]
Farm diversity						
Crop count	1.71 (0.94)	2.45 (1.24)	2.37 (1.17)	2.55 (1.25)	2.39 (1.22)	99.2[**]
Crop and livestock count	2.21 (1.34)	3.58 (1.82)	3.23 (1.73)	3.21 (1.66)	3.19 (1.72)	54.2[**]
Simpson's Index	0.23 (0.27)	0.36 (0.25)	0.38 (0.26)	0.45 (0.25)	0.39 (0.26)	53.4[**]
Child characteristics						
Sample size (n)	321	584	1125	1401	3431	
Age (mo)	29.1 (14.8)	28.2 (13.9)	29.2 (14.4)	29.1 (14.3)	30.0 (14.3)	0.54
Height-for-age (Z-score)	−1.29 (1.89)	−0.41 (1.45)	−1.54 (1.79)	−1.39 (1.59)	−1.26 (1.71)	22.5[**]
Weight-for-age (Z-score)	−0.24 (1.25)	0.02 (1.16)	−0.53 (1.20)	−0.53 (1.16)	−0.41 (1.20)	11.7[**]

Data on mean (SD) are presented.
MK: Malawian kwacha; 1 MK = 0.0026 U.S. dollars.
[*] $P < 0.05$.
[**] $P < 0.01$.
[§] The F-statistic shown tests for differences across the regional means. The Pearson's chi-squared test statistic is shown for characteristics that are percentages.

3. Results

3.1 Sample characteristics

Table 1 presents household- and child-level characteristics for the sample disaggregated by region of Malawi. Both measures of dietary diversity were higher in urban areas as compared to rural regions, and rural areas of the northern region showed higher dietary diversity than other rural regions of Malawi. Compared to urban areas and the other rural regions, rural households in the northern region also demonstrated higher farm production diversity, especially when considering livestock ownership in the measure. Rural households in the central region devoted the largest area of cultivated land to market crops with rural households in the southern region dedicating the most amount of cropped land to subsistence crops. These differences were observed despite few differences across the rural regions in food and non-food expenditures and household size. Heads of rural households in the northern region were better educated than in other rural regions, though the proportion of mothers lacking formal education was similarly high across all rural regions. All of these measures of expenditures and education were consistently higher in urban areas as compared to rural regions. Child HAZ and WAZ were also lower in rural areas of the northern region compared to other rural regions and even urban areas.

Rural households in the northern region grew a significantly lower proportion of maize as a total of all cultivated land area compared to the overall mean of all regions and in rural areas of the southern region of Malawi, households dedicated more cultivated land to legumes, vegetables, millets and mangoes (Table 2). Urban areas showed significantly higher consumption of meat, dairy products, fruits, vegetables and cooked foods from vendors compared to the overall mean for all regions of Malawi (Table 3). Consumption of legumes and vegetables was especially high in rural areas of the central region and consumption of meat and dairy was high in rural areas of the northern region.

3.2 Correlations across measures of farm diversity and dietary diversity

The modified HDDS and FCS were strongly correlated with one another ($P < 0.0001$). The Pearson product-moment correlation coefficient was 0.72. The three measures of farm diversity were also strongly correlated with one another ($P < 0.0001$). Correlation coefficients for these measures were 0.85 (crop count and crop/livestock count), 0.79 (crop count and Simpson's Index), and 0.67 (crop/livestock count and Simpson's Index).

3.3 Associations between farm diversity and dietary diversity

In bivariate regressions models (data not shown), all measures of farm diversity were strongly positively correlated with all measures of dietary diversity ($P < 0.0001$) except for the relationship between the Simpson's Index and the FCS ($P = 0.126$).

In multiple regression analyses controlling for the effects of several covariates on household dietary diversity, farm diversity

Table 2
Percentage of cultivated land area dedicated to specific crops and proportion of households growing specific fruit trees, disaggregated by region of Malawi.

	Regions of Malawi					
	Urban	Rural north	Rural central	Rural south	All regions	*F*-statistic[§]
Cultivated land area devoted to select crops						
Maize	75.7 (28.7)	51.3 (31.8)	65.6 (25.7)	55 (26.8)	59.7(28.6)	18.9[**]
Tobacco	1.13 (7.60)	6.31 (15.7)	8.20 (16.1)	1.23 (6.46)	4.36 (12.6)	12.1[**]
Legumes	15.1 (23.1)	8.92 (16.4)	17.9 (20.5)	24.9 (22.9)	18.8 (21.9)	91.6[**]
Rice	2.30 (11.9)	4.34 (14.7)	1.23 (7.08)	1.24 (7.25)	1.90 (9.55)	2.17
Potato	1.28 (7.81)	1.51 (7.87)	1.64 (6.85)	0.83 (5.24)	1.25 (6.57)	7.81[**]
Wheat	0	0	0.05 (1.26)	0.04 (1.19)	0.03 (1.04)	0.83
Millets	0.54 (5.19)	0.41 (3.26)	0.43 (3.75)	6.89 (18.2)	3.05 (12.4)	52.2[**]
Cotton	0	0.07 (1.62)	0.38 (3.56)	1.81 (8.69)	0.87 (5.98)	23.9[**]
Sunflower	0.032 (0.82)	0.321 (3.47)	0.002 (0.10)	0.473 (4.28)	0.25 (3.12)	0.62
Sugarcane	0	0.01 (0.20)	0.02 (0.55)	0.06 (0.92)	0.03 (0.67)	4.21[*]
Vegetable	2.79 (9.86)	4.35 (12.4)	2.55 (8.92)	6.18 (13.6)	4.37 (11.8)	4.94[*]
Proportion of households growing fruit trees						
Mango	5.58	17.7	17.4	25.7	19.7	149[**]
Papaya	2.71	2.32	2.71	5.47	3.76	37.0[**]
Banana	0.80	13.9	6.7	7.26	7.69	112[**]
Avocado	2.07	1.00	0.86	3.09	1.90	38.1[**]

Data on mean (SD) are presented.
[*] $P < 0.05$.
[**] $P < 0.01$.
[§] The *F*-statistic shown tests for differences across the regional means. The Pearson's chi-squared test statistic is shown for characteristics that are percentages.

Table 3
Number of food items consumed in the previous 7 d (FI) and frequency of food group consumption (number of days) in the previous 7 d (FGF) by food group, disaggregated by region of Malawi.

	Regions of Malawi											
	Urban		Rural north		Rural central		Rural south		All regions		*F*-statistic[§]	
	FI	FGF	FI	FGF	FI	FGF	FI	FGF	FI	FGF	FI	FGF
Food groups consumed by Malawian households												
Meat and fish	2.18 (1.23)	3.77 (1.89)	1.47 (1.03)	3.07 (2.15)	1.53 (1.23)	2.59 (1.98)	1.33 (0.95)	2.61 (1.85)	1.50 (1.11)	2.80 (1.99)	31.5[**]	11.95[**]
Dairy products	0.78 (1.01)	2.36 (2.89)	0.24 (0.51)	0.88 (1.95)	0.14 (0.39)	0.51 (1.55)	0.07 (0.30)	0.41 (1.45)	0.19 (0.52)	0.71 (1.85)	91.7[**]	67.4[**]
Legumes	1.61 (1.14)	2.42 (1.72)	1.37 (1.09)	2.48 (1.92)	1.67 (1.34)	2.60 (2.10)	1.40 (1.11)	2.38 (1.95)	1.50 (1.19)	2.47 (1.98)	5.41[*]	4.33[*]
Millets	0.04 (0.20)	N/A	0.01 (0.09)	N/A	0.03 (0.19)	N/A	0.09 (0.32)	N/A	0.05	N/A	26.1[**]	N/A
Vegetables	4.16 (1.33)	6.36 (1.30)	3.07 (1.25)	5.88 (1.68)	3.58 (1.43)	6.21 (1.41)	3.12 (1.43)	5.79 (1.79)	3.36 (1.43)	5.99 (1.63)	27.2[**]	12.2[**]
Fruits	1.34 (1.08)	2.69 (2.30)	0.85 (0.87)	2.33 (2.65)	0.92 (0.90)	2.21 (2.49)	1.03 (0.96)	2.65 (2.68)	0.99 (0.94)	2.46 (2.59)	2.58	3.92[*]
Sugars	1.24 (0.63)	6.18 (1.95)	0.84 (0.59)	4.5 (3.01)	0.79 (0.70)	3.21 (3.02)	0.76 (0.74)	3.14 (3.11)	0.83 (0.70)	3.70 (3.12)	14.2[**]	60.3[**]
Cooked foods from vendors	0.68 (0.93)	N/A	0.37 (0.65)	N/A	0.50 (0.81)	N/A	0.37 (0.66)	N/A	0.44 (0.75)	N/A	7.87[**]	N/A

Data on mean (SD) are presented.
N/A: Data on frequency of food consumption were collected by food group and did not include millets or cooked foods from vendors.
[*] $P < 0.05$.
[**] $P < 0.01$.
[§] The *F*-statistic shown tests for differences across the regional means. The Pearson's chi-squared test statistic is shown for characteristics that are percentages.

remained strongly positively associated with dietary diversity (Table 4). The crop count and crop and livestock count measures were significantly positively associated with both the modified HDDS and FCS ($P < 0.0001$). The Simpson's Index was similarly associated with the modified HDDS ($P < 0.0001$), but was not associated with the FCS ($P = 0.16$).

3.4 Covariate relationships with dietary diversity

Several covariates in these models showed consistent relationships with measures of dietary diversity. For example, age of household head and the proportion of food consumed in the previous one week that came from household's own production were negatively associated with dietary diversity in all models ($P = 0.003$ or less in all models) (Table 4). Non-food expenditures per capita in the previous month were also negatively associated with dietary diversity in nearly all models (e.g. $P = 0.008$ in models using the modified HDDS). On the other hand, food expenditures per capita in the previous week, household size, and population weighted national quintiles of consumption per person were all positively associated with dietary diversity ($P < 0.0001$). The number of different non-agricultural income sources variable was also positively associated with the modified HDDS ($P < 0.0001$). Maximum education level attained by the household head was positively associated with the FCS ($P < 0.0001$) and households in which control of agricultural earnings was shared by the household head and spouse showed higher dietary diversity compared to households in which only the household head controlled these

Table 4
Multiple regression results of determinants of household dietary diversity using the modified Household Dietary Diversity Score (HDDS) and Food Consumption Score (FCS) as dependent variables.

Independent variables	Farm diversity measure					
	Crop count		Crop and livestock count		Simpson's Index	
	HDDS	FCS	HDDS	FCS	HDDS	FCS
Farm diversity	0.23**	0.81**	0.20**	0.71**	0.68**	1.65
Household demographics						
Household size	0.33**	2.2**	0.31**	2.1**	0.33**	2.2**
Sex of household head (male)	−0.06	−0.16	−0.05	−0.11	−0.07	−0.16
Age of household head	−0.01**	−0.04**	−0.02**	−0.04**	−0.02**	−0.04**
Education, expenditures, and wealth						
Education level of household head	0.07^{+}	1.6**	0.08^{+}	1.6**	0.07^{+}	1.6**
Food expenditures per capita in the past 7 d (1000 MK)	0.85**	11**	0.87**	11**	0.83**	11**
Non-food expenditures per capita in the past 1 mo (1000 MK)	−0.04**	−0.21^{+}	−0.04**	−0.22*	−0.03**	−0.20^{+}
National quintile, consumption per person, population weighted (low)						
Low-mid	1.5**	6.4**	1.5**	6.3**	1.5**	6.5**
Mid	2.5**	12**	2.4**	12**	2.5**	12**
High-mid	3.3**	18**	3.2**	18**	3.4**	18**
High	4.0**	23**	3.9**	23**	4.1**	23**
Farm size, production orientation, other livelihoods, and earnings decisions						
Total cropped area (ha)	0.04	0.42	0.03	0.35	0.10**	0.72**
Proportion of food consumed in previous one week from household's own production	−2.64**	−6.9**	−2.8**	−7.3**	−2.5**	−6.4**
Number of different non-agricultural income sources	0.22**	0.37	0.21**	0.35	0.23**	0.44
Control of agricultural earnings decisions: household head only vs. shared decisionmaking (household head only)	0.27**	2.6**	0.24*	2.5**	0.27**	2.6**
Region (grand mean)						
Urban	0.09	0.81	0.11	0.86	0.07	0.65
North rural	0.21**	1.4	0.16*	1.2	0.25**	1.7
Central rural	−0.18**	−2.2**	−0.17**	−2.2**	−0.19**	−2.3**
South rural	−0.12*	−0.02	−0.10^{+}	0.07	−0.13*	0.01
Intercept	4.5**	21**	4.6**	21**	4.6**	21**
R^2	0.56	0.43	0.56	0.43	0.56	0.43
Akaike Information Criterion (AIC)	25,007	53,723	24,959	53,717	25,070	53,736

Values shown are partial regression coefficients from multiple regression analyses including all variables shown as independent variables.
Reference categories are shown in parentheses next to independent variables.
$^{+}$ $P < 0.1$.
* $P < 0.05$.
** $P < 0.01$.

earnings (range of P-values from $P = 0.016$ to $P = 0.001$). Regional differences in dietary diversity were not consistent across the models, though rural areas of the central region tended to show lower dietary diversity compared to the overall mean for all regions and rural areas of the northern region demonstrated the opposite trend.

3.5 Model interactions

We also examined the interaction of farm diversity with select covariates on the diversity of household diets in separate multiple regression models controlling for the same covariates as those included in non-interaction models (data not shown). The association of farm diversity on dietary diversity using the crop and livestock count was significantly greater in woman-headed households compared to those headed by men (HDDS: $P = 0.008$; FCS: $P = 0.076$). This same statistically significant relationship was not observed for the other measures of farm diversity. Farm diversity was also more strongly positively associated with dietary diversity in wealthier households (using national quintiles of per person consumption as a proxy wealth measure) for all farm diversity variables using the FCS as a measure of dietary diversity ($P < 0.05$).

Further analysis of this interaction with household wealth showed that wealthier households were more likely to consume a greater number of different food items within food groups and to consume food groups with greater frequency (Table 5). In examining crop production, wealthier households cropped larger total areas, practiced less intercropping, and were more likely to devote a greater proportion of cultivated land to tobacco, a market crop, but also to legumes (Table 5). They also raised significantly more livestock ($P < 0.001$). Proportion of cultivated land devoted to maize declined with increasing consumption quintile, with the exception of the highest quintile in which households devoted a similar proportion of land to maize as those in the lowest quintile. Cultivation of cotton and millets showed similar trends. Importantly, proportion of land devoted to vegetable production did not differ across consumption quintiles.

No consistent statistically significant regional differences were observed in the relationship between farm diversity and dietary diversity in multiple regression models that controlled for the same covariates as those included in non-interaction models.

3.6 Associations between farm diversity and consumption of specific food groups

Farm production diversity was positively associated with the frequency of consumption of legumes in the previous 7 d as well as the number of different kinds of legumes consumed ($P < 0.0001$) in multiple regression models (Table 6). Consumption of vegetables and fruits also showed positive associations with the crop count and combined crop and livestock count measures ($P < 0.05$) (Table 6). Farm diversity did not show strong relationships with consumption of cereal grains or animal-source foods.

Table 5
Household consumption of specific food groups and farm characteristics, disaggregated by national quintiles of per person consumption.

	National quintile, consumption per person, population weighted					
	Low	Low-mid	Mid	High-mid	High	*F*-statistic§
Food consumption (FI)						
Cereals	1.43 (0.67)	1.77 (0.89)	2.09 (1.03)	2.59 (1.27)	3.24 (1.52)	286**
Meat and fish	0.72 (0.69)	1.10 (0.85)	1.37 (0.93)	1.71 (1.05)	2.25 (1.29)	227**
Dairy products	0.01 (0.08)	0.04 (0.19)	0.06 (0.24)	0.17 (0.41)	0.49 (0.79)	101**
Legumes	0.96 (0.92)	1.28 (1.11)	1.55 (1.19)	1.82 (1.27)	1.95 (1.30)	77.9**
Vegetables	2.59 (1.06)	3.07 (1.21)	3.32 (1.31)	3.62 (1.37)	4.03 (1.57)	132**
Fruits	0.51 (0.66)	0.72 (0.78)	0.95 (0.87)	1.17 (0.97)	1.36 (1.07)	84.1**
Food consumption (FGF)						
Cereals	6.79 (0.97)	6.82 (0.92)	6.81 (0.91)	6.83 (0.82)	6.83 (0.89)	1.31
Meat and fish	1.64 (1.65)	2.12 (1.74)	2.56 (1.81)	3.09 (1.86)	3.83 (1.99)	5.54**
Dairy products	0.05 (0.38)	0.18 (0.89)	0.36 (1.30)	0.76 (1.84)	1.86 (2.83)	293**
Legumes	1.79 (1.83)	2.08 (1.87)	2.46 (1.97)	2.83 (1.98)	2.97 (2.03)	154**
Vegetables	5.84 (1.67)	5.86 (1.69)	5.92 (1.65)	6.04 (1.57)	6.20 (1.53)	21.5**
Fruits	1.58 (2.41)	1.96 (2.44)	2.30 (2.48)	2.65 (2.51)	3.05 (2.60)	104**
Proportion of cultivated land devoted to specific crops						
Maize	64.1 (28.4)	62.3 (28.7)	60.4 (26.7)	59.8 (27.1)	63.6 (29.2)	3.62**
Tobacco	3.59 (11.7)	4.20 (11.9)	5.14 (13.0)	5.73 (14.5)	5.35 (14.4)	2.53*
Legumes	17.1 (21.0)	18.6 (21.4)	19.9 (21.5)	20.9 (22.2)	19.4 (23.1)	3.04*
Rice	1.34 (7.38)	2.15 (10.9)	1.65 (9.21)	1.27 (7.27)	1.14 (7.53)	2.21
Potato	1.11 (5.24)	1.32 (7.68)	1.08 (5.64)	1.42 (6.47)	1.35 (7.54)	0.47
Millets	4.76 (15.5)	3.24 (12.1)	2.54 (10.3)	1.84 (9.16)	1.66 (8.91)	6.02**
Cotton	1.05 (5.95)	0.81 (6.38)	0.60 (4.56)	0.60 (5.31)	0.35 (3.99)	2.63*
Sunflower	0.32 (3.35)	0.24 (2.72)	0.19 (2.31)	0.20 (3.60)	0.25 (3.39)	0.28
Sugarcane	0.04 (0.73)	0.02 (0.40)	0.04 (0.76)	0.03 (0.68)	0.04 (0.68)	0.71
Vegetable	3.99 (11.2)	4.02 (11.3)	4.53 (12.0)	4.90 (12.6)	3.73 (11.7)	1.01
Livestock	0.50 (0.71)	0.68 (0.86)	0.82 (0.90)	0.91 (0.99)	0.82 (1.04)	35.2**
Total cropped area and intercropping						
Cropped area (ha)	0.96 (0.84)	0.93 (0.79)	1.02 (0.90)	1.08 (0.88)	1.14 (1.29)	19.5**
Proportion of cultivated land area devoted to market crops	0.18 (0.30)	0.22 (0.32)	0.24 (0.34)	0.28 (0.36)	0.26 (0.37)	23.6**
Proportion of cultivated plots that are intercropped	0.36 (0.43)	0.36 (0.45)	0.38 (0.45)	0.34 (0.44)	0.31 (0.45)	3.78*

Data on mean (SD) are presented.
FI: household food consumption using the number of different food items from specific food groups consumed in the previous 7 d; FGF: frequency of food group consumption (number of days) in the previous 7 d.
"Livestock" refers to the number of animals owned by the household.
P-values are for *F*-tests in unadjusted ANOVA models assessing differences of means across consumption quintiles. Standard errors are adjusted for the complex survey design of the IHS3.
\+ $P < 0.1$.
* $P < 0.05$.
** $P < 0.01$.

Table 6
Multiple regression results of the associations between farm diversity and food consumption using as response variables the number of different food items from specific food groups consumed in the previous 7 d (FI) and the frequency of food group consumption (number of days) in the previous 7 d (FGF).

	Farm diversity measure					
	Crop count		Crop and livestock count		Simpson's Index	
	FI	FGF	FI	FGF	FI	FGF
Food groups consumed by Malawian households						
Cereals	0.02	−0.02	0.02	−0.002	−0.11	−0.16**
Meat and fish	0.03+	−0.02	0.03*	0.002	0.04	−0.15
Dairy products	−0.007	−0.005	0.0007	0.02	−0.06*	−0.02
Legumes	0.16**	0.20**	0.12**	0.15**	0.47**	0.78**
Vegetables	0.10**	0.01	0.06**	−0.009	0.08	0.04
Fruits	0.03*	−0.02	0.03*	−0.008	−0.04	−0.18

Models are adjusted for the same covariates as those shown in Table 4.
\+ $P < 0.1$.
* $P < 0.05$.
** $P < 0.01$.

4. Discussion

4.1 Summary of results

The production diversity of farms in Malawi was consistently positively associated with the diversity of household diets. Farm diversity demonstrated a consistent positive association with household dietary diversity independent of differences in household wealth and social standing. This relationship was significantly greater in wealthier households as well as in households headed by women. Farm diversity was especially strongly associated with consumption of legumes, vegetables and fruits.

The pathway from farm production diversity to household dietary diversity for households growing crops primarily for sale will likely operate mainly through income and food purchases while farm diversity in subsistence-oriented farming households may have a more direct influence on the diversity of household diets. However, many households in Malawi, as in other low-income African countries, are not strictly market-oriented or subsistence-oriented, but rather produce agricultural goods for both sale and own consumption. Previous studies cited earlier that have examined the relationship between farm diversity, diet and health have been limited in their assessment of the relative subsistence vs. market orientation of farm production. Future research that rigorously examines these dynamics is essential for furthering our understanding of agriculture and nutrition linkages.

4.2 Market-oriented production and dietary diversity

We observed a consistent negative association in multiple regression models between the proportion of food consumed from own production and household dietary diversity. In sub-analyses, we also observed that households dedicating a larger share of cultivated land to market crops had greater dietary diversity and more diverse farm production overall using any measure of farm production diversity ($P < 0.0001$; data not shown). Households that are less reliant on subsistence production then, and are in turn more market-oriented in their agricultural production, may have quite diverse diets if income is used to purchase nutrient-dense foods that diversify households diets (e.g. vegetables, fruits, pulses, animal-source foods). The potential to earn income from a new crop may in fact motivate production diversification which could have spin-off benefits for diet diversity if a portion of the harvested crop is also consumed by the household (Herforth, 2010).

Unfortunately, from the available production data, it is not possible to discern the extent to which crops were being sold to market, kept for home consumption, or serving multiple purposes. The data in Table 6 demonstrate that household production of legumes, vegetables and fruits made strong contributions to the diversity of household diets, in contrast to animal-source foods. This is supported in the consumption data showing that consumed legumes (e.g. pigeon pea, ground beans, and peas), millets, and green leafy vegetables (e.g. nkhwani, tanaposi) more commonly came from own production (data not shown). Therefore, displacing these subsistence crops with market-oriented crops or shifting their productive use to sale for market could have deleterious impacts on dietary diversity if efforts are not made to ensure equally or even more nutritious foods are purchased and consumed by the households. Previous evidence in other contexts also suggests that protecting household subsistence production of nutrient-dense crops and valorizing the nutritional importance of these foods may be important for household diets amidst commercialization efforts (Kennedy and Cogill, 1987; Shack et al., 1990).

It is also important to note that few households were strongly engaged in market-oriented agricultural production at all. Even in those regions with the highest proportion of cultivated land dedicated to market crops, that proportion did not account for a majority (or even two-fifths) of all cultivated land (Table 1). Therefore, the differences described here in the relationship between farm production and dietary diversity may more rightly be described as differences in the relative extent of subsistence production rather than differences between subsistence and market-oriented farming households. In this way, the data tend to suggest that diversity in farm production, as well as diversity in the orientation of farm production, are positive for the diversity of household diets.

4.3 Dietary diversity and household wealth

Dietary diversity and household wealth (assessed using consumption and expenditure data as proxy measures) have been shown to be positively associated in many contexts (Hoddinott and Yohannes, 2002; Thorne-Lyman et al., 2010). In Malawi, wealth as measured by population weighted national quintiles of consumption per person was positively associated with dietary diversity, that is, dietary diversity was consistently greater with increasing consumption quintiles (Table 4). Farm diversity remained positively associated with dietary diversity even adjusting for wealth. In fact, this positive association was significantly greater in wealthier households.

Though, as mentioned above, wealthier households dedicated a larger proportion of cultivated land to market crops, notably tobacco (Table 5), they also devoted a greater proportion of land to legume production, less to maize, and raised more animals. This suggests that the cultivation of legumes and livestock by wealthier households may be especially important for explaining the differences in the relationship between farm diversity and dietary diversity observed across consumption quintiles.

Wealthier households who were able to devote more land to legumes and less land to subsistence maize production were likely able to leverage this more diverse production to diversity their diets. Furthermore, the difference in average land holdings between households in the highest and lowest wealth quintiles was less than one-fifth of a hectare. This, and the fact that even wealthier households tended to practice intercropping in approximately one-third of their cultivated plots (Table 5), suggests that more diversified production among wealthier households was not accomplished by expanding cultivated land area, but rather by diversifying production on similar cultivated land areas as less wealthy households. This finding supports previous studies which show that increasing biodiversity through intercropping legumes has multiple benefits, including increased farm profitability and improved ecosystem services (Snapp et al., 2010).

4.4 Control of income within households

Evidence from many contexts suggests that income improvements alone are not sufficient to improve household diets or the nutrition of vulnerable groups within households (DeWalt, 1993). Control over household income may be more important than the extent of the income itself (Kennedy and Cogill, 1987; Quisumbing et al., 1995). In Malawi, dietary diversity was significantly greater in households in which decisions over what to do with agricultural earnings were shared between the household head and spouse as compared to being exclusively controlled by the head of household (Table 4). This finding is supported by evidence from several different contexts demonstrating that income controlled by women has a significantly greater positive effect on child nutrition and household food security than income controlled by men (Hoddinott and Haddad, 1994; Katz, 1994). Control of income, however, did not modify the association of farm production diversity with household dietary diversity.

4.5 The nature of farm diversity and its influence on dietary diversity

Significant variation exists in dietary patterns across contexts (Ruel, 2003) and the contribution of dietary diversity to nutrition depends on several factors including: the number of different kinds of foods available in a given region, the variation in the nutrient density of these foods, the bioavailability of nutrients within these foods, the prevalence of nutrient deficiencies or overnutrition in a population, and the age-, sex- and lifestage-specific needs of individuals. As a result, depending on how it is measured, the same level of farm production diversity could provide different nutritional benefits even if the production ended up contributing directly to the diversity of diets (Remans et al., 2011). Inter-species diversity on farms, for example, will likely be more nutritionally meaningful than intra-species diversity (i.e. different varieties of a species) (Berti and Jones, 2013). The distribution of nutrient contents within species are commonly log-normally distributed (i.e. right skewed with the mean greater than the median), and therefore varieties chosen at random from the distribution are likely to have nutrient contents less than the mean (Berti and Jones, 2013). However, crops are rarely selected solely for nutrient content. They are much more likely to be chosen based on a mix of agronomic, nutritional, social or economic considerations (Berti and Jones, 2013). Therefore, efforts to diversify farm production to benefit nutrition (Bezner Kerr et al., 2010; Hotz et al., 2012; Low et al., 2007) face the challenge of balancing the potential for improved nutrient intakes with the many other characteristics of crops and animals that farmers value.

Accounting for livestock in addition to crops in farm diversity measures may also lead to different associations with dietary diversity. For example, in unadjusted models, regional differences were observed across Malawi with respect to the relationship between farm diversity and dietary diversity. Rural areas of the northern region actually showed a negative association between the diversity of farms and diets when excluding livestock from the farm diversity measure. When including livestock, the relationship was significantly positive. Probing this relationship further revealed that three districts in the northern region (i.e. Karonga, Nkhata Bay, and Rumphi) were driving this negative association. Households in all three districts raised especially large amounts of livestock and consumed especially large amounts of meat and dairy products. For these districts, livestock production was a key contributor to overall farm diversity and animal-source foods contributed strongly to the diversity of diets. Excluding animals from the analysis then, masked the true relationship between farm and dietary diversity.

The Simpson's Index is unique among the farm diversity measures assessed in that it accounts not only for the diversity of farm production, but also the evenness of that diversity. The proportion of cultivated plots that are intercropped was strongly positively correlated with the Simpson's Index ($P < 0.0001$; data not shown). This metric of evenness may be agronomically significant. Intercropping may minimize soil runoff, help to economize water use, provide structural support to lodge-prone plants, suppress weeds, provide protection and shade, and encourage biodiversity and pest control (Szumigalski and Van Acker, 2005; Zobisch et al., 1995). Indeed, in Malawi, more diverse farming systems have been shown to support a variety of ecological services (Snapp et al., 2010). Intercropping could also be potentially beneficial to diets as it showed consistent positive associations with dietary diversity. These associations were independent of farm size, proportion of cultivated land area devoted to market crops, or household wealth. Another study in Malawi has shown that smallholder households using intercropped legumes had improved child growth compared to control households who did not use this cropping strategy (Bezner Kerr et al., 2010). These findings suggest perhaps that intercropping itself has some positive influence on the diversity of diets in Malawi either because species that are intercropped are more likely to directly influence diets (e.g. legumes) or that households that intercrop have a greater propensity to have diverse diets for reasons beyond wealth that are not captured in this analysis.

4.6 Limitations

The IHS3 dataset included both cross-sectional and panel surveys. This analysis drew only from the cross-sectional sample of households so as to take advantage of the larger sample size and ensure that all households were responding to questions on the same cropping cycle inclusive of the rainy and dry seasons. The cross-sectional nature of the data means that it is not possible to discern the directionality of the observed relationships or attribute causality to them. Furthermore, because these are observational data, unmeasured confounding may bias the model estimates. We thoroughly control for potentially confounding domains within our models including household demographics, education, wealth, farm size, purchasing behaviors, production orientation, livelihood, and household decisionmaking. However, the potential for unmeasured confounding remains a potential limitation of this work.

Another potential limitation of this study is that the timing of respondents' recall of food consumption varied based on the date of the interview. However, date of interview and farm diversity did not significantly interact in models using the modified HDDS or FCS as the response (data not shown). Farm diversity also remained consistently positively associated with dietary diversity while controlling for other determinants of dietary diversity that were drawn from theory and previous evidence. These findings lend support to the veracity of the observed relationships and their directions.

The lack of comparable information between households on the quantities of crops harvested and the quantities of food consumed was another limitation of the analysis. This limited the extent to which the orientation of production systems (i.e. subsistence, market-oriented, or mixed) and total consumption could be analyzed and compared across households. The analysis instead relies on the proportion of food consumed that came from a household's own production. This metric does, however, show important relationships with the variables of principal interest in our analyses.

5. Conclusion and policy considerations

Agricultural production is not an end in and of itself, but rather a means to multiple ends (Pinstrup-Andersen, 2006). While advances in agricultural technologies have tended to emphasize only increases in yields and incomes, agriculture may also be important for shaping nutrition outcomes. More diverse production systems, which have been shown to have multiple environmental benefits, may also contribute to more diverse household diets that in turn could positively influence the nutritional status of household members. Yet, this relationship is complex—it may be influenced by gender, wealth, control of household decisions, the relative market-orientation of a household's agricultural production, and the specific nature of farm diversity.

We observed in Malawi, that the diversity of farm production was consistently positively associated with the diversity of household diets. Furthermore, households whose diets relied less on subsistence production had more diverse diets even controlling for household wealth. Diverse, market-oriented production then may yield nutritional benefits if income from that production is translated into nutrient-dense, diverse foods. This, of course, requires accessible markets that provide such foods at an affordable price, and that are culturally valued or sufficiently marketed to compete with highly-processed, nutrient-poor foods and drinks that may be equally accessible, and heavily marketed. It is also important to recognize that the diversification of both crop production and the orientation of crop production may be equally beneficial. We observed that foods such as legumes, green leafy vegetables and millets that principally came from a household's own production, made important contributions to the diversity of household diets. Therefore, maintaining subsistence production of these foods may be important in the absence of economic, physical or cultural barriers to accessing these foods through markets. While the Government of Malawi's support of increased staple food crop productivity through its Agricultural Input Subsidy Program is important for maintaining production and stabilizing food prices, too narrow a focus on a single crop, or targeting a single market, may leave smallholder farms and farming families vulnerable.

The pathways leading from agriculture to improved nutrition are not all straightforward and may have unintended consequences (Babu and Mthindi, 1994). More research is required to clearly elucidate these pathways, especially with regard to identifying trade-offs and win-wins for agriculture's multiple ends (e.g. soil conservation, carbon sequestration, time and labor savings, yield, income and nutrition) (Remans et al., 2011) in the face of increasingly volatile climatic conditions and market prices for agricultural inputs and commodities (Barrios et al., 2008). It is clear though that policies that seek to cultivate food system resilience for improved nutrition, must explicitly consider nutritional outcomes and safeguards in policy formulation. Doing so may in fact help to ensure that agricultural policies achieve multiple wins.

Acknowledgements

We are grateful to Gina Kennedy and Carlo Cafiero for their thoughtful comments on earlier drafts of this manuscript.

References

Arimond, M., Ruel, M.T., 2004. Dietary diversity is associated with child nutritional status: evidence from 11 demographic and health surveys. J. Nutr. 134, 2579–2585.

Babu, S.C., Mthindi, G.B., 1994. Household food security and nutrition monitoring: the Malawi approach to development planning and policy interventions. Food Policy 19, 272–284.

Bamji, M.S., 2007. Nutrition-secure India-How do we get there? Nutrition conclave discusses the way forward. Curr. Sci. 93, 1473–1475.

Barrios, S., Ouattara, B., Strobl, E., 2008. The impact of climatic change on agricultural production: is it different for Africa? Food Policy 33, 287–298.

Baumg, S., 2006. Measuring the diversity of what? And for what purpose? A conceptual comparison of ecological and economic biodiversity indices. Ver. Gesell. Ökol. 33, 1–33.

Berti, P.R., Jones, A.D., 2013. Biodiversity's contribution to dietary diversity: magnitude, meaning and measurement. In: Fanzo, J., Hunter, D., Borelli, T., Mattei, F. (Eds.), Diversifying Food and Diets: Using Agricultural Biodiversity to Improve Nutrition and Health. Earthscan, Routledge, UK, pp. 186–206.

Bezner Kerr, R., Berti, P.R., Shumba, L., 2010. Effects of a participatory agriculture and nutrition education project on child growth in northern Malawi. Public Health Nutr. 14, 1466–1472.

Bhutta, Z.A., Ahmed, T., Black, R.E., Cousens, S., Dewey, K., Giugliani, E., Haider, B.A., Kirkwood, B., Morris, S.S., Sachdev, H.P.S., Shekar, M., 2008. What works? Interventions for maternal and child undernutrition and survival. Lancet 371, 417–440.

Clausen, T., Charleton, K.E., Gobotswang, K., Holmboe-Ottesen, G., 2005. Predictors of food variety and dietary diversity among older persons in Botswana. Nutrition 21, 86–95.

DeClerk, F., Fanzo, J., Palm, C., Remans, R., 2011. Ecological approaches to human nutrition. Food Nutr. Bull. 32, S41–S50.

Denning, G., Kabambe, P., Sanchez, P., Mali, A., Flor, R., Harawa, R., Nkhoma, P., Zamba, C., Banda, C., Magombo, C., Keating, M., Wangila, J., Sachs, J., 2009. Input subsidies to improve smallholder maize productivity in Malawi: toward an African Green revolution. PLoS Biol. 7, e1000023.

DeWalt, K.M., 1993. Nutrition and the commercialization of agriculture: ten years later. Soc. Sci. Med. 36, 1407–1416.

Dorward, A., Chirwa, E., Boughton, D., Crawford, E., Jayne, T., Slater, R., Kelly, V., Tsoka, M., 2008. Towards "smart" Subsidies in Agriculture? Lessons from Recent Experience in Malawi, Natural Resource Perspectives. Overseas Development Institute.

FAOSTAT, 2013. FAOSTAT Data. Food and Agriculture Organization of the United Nations. <http://faostat3.fao.org/home/index.html#VISUALIZE_BY_AREA> (accessed 11.04.13).

Gillespie, S., Harris, J., Kadiyala, S., 2012. The Agriculture-Nutrition Disconnect in India What Do We Know? International Food Policy Research Institute, Washington, DC.

Graham, R.D., Welch, R.M., Saunders, D.A., Ortiz-Monasterio, I., Bouis, H.E., Bonierbale, M., de Haan, S., Burgos, G., Thiele, G., Liria, R., Meisner, C.A., Beebe, S.E., Potts, M.J., Kadian, M., Hobbs, P.R., Gupta, R.K., Twomlow, S., 2007. Nutritious subsistence food systems. Adv. Agron. 92, 1–72.

Haddad, L., 2000. A conceptual framework for assessing agriculture-nutrition linkages. Food Nutr. Bull. 21, 367–373.

Hatløy, A., Torheim, L.E., Oshaug, A., 1998. Food variety—a good indicator of nutritional adequacy of the diet? A case study from an urban area in Mali, West Africa. Eur. J. Clin. Nutr. 52, 891–898.

Hawkes, C., Ruel, M.T., 2006. Understanding the Links between Agriculture and Health. International Food Policy Research Institute.

Hawksworth, D.L., 1995. In: Hawksworth, D.L. (Ed.), Biodiversity Measurement and Estimation. The Royal Society and Chapman and Hall, London.

Hazell, P., Ramasamy, C. (Eds.), 1991. The Green Revolution Reconsidered: The Impact of High-Yielding Rice Varieties in South India. International Food Policy Research Institute, Baltimore.

Herforth, A., 2010. Promotion of Traditional African Vegetables in Kenya and Tanzania: A Case Study of an Intervention Representing Emerging Imperatives in Global Nutrition. Cornell University, Ithaca, NY.

Hoddinott, J., Haddad, L.J., 1994. Women's income and boy–girl anthropometric status in the Côte d'Ivoire. World Dev. 22, 543–553.

Hoddinott, J., Yohannes, Y., 2002. Dietary Diversity as a Food Security Indicator. Discussion Paper, No. 136. Food Consumption and Nutrition Division. International Food Policy Research Institute, Washingon, DC.

Hotz, C., Loechl, C., Lubowa, A., Tumwine, J.K., Ndeezi, G., Masawi, A.N., Baingana, R., Carriquiry, A., de Brauw, A., Meenakshi, J.V., Gilligan, D.O., 2012. Introduction of B-Carotene-rich orange sweet potato in rural Uganda results in increased vitamin A intakes among children and women and improved vitamin A status among children. J. Nutr. 142, 1871–1880.

Jones, A., Agudo, Y.C., Galway, L., Bentley, J., Pinstrup-Andersen, P., 2012. Heavy agricultural workloads and low crop diversity are strong barriers to improving child feeding practices in the Bolivian Andes. Soc. Sci. Med. 75, 1673–1684.

Kant, A.K., 2004. Dietary patterns and health outcomes. J. Am. Diet. Assoc. 104, 615–635.

Katz, E., 1994. The impact of non-traditional export agriculture on income and food availability in Guatemala: an intra-household perspective. Food Nutr. Bull. 15, 295–302.

Kennedy, E., Cogill, B., 1987. Income and Nutritional Effects of the Commercialization of Agriculture in Southwestern Kenya. Research Report No. 63. International Food Policy Research Institute, Washington, DC.

Kshirsagar, K.G., Pandey, S., Bellon, M.R., 2002. Farmer perceptions, varietal characteristics and technology adoption: a rainfed Rice Village in Orissa. Econ. Polit. Weekly 37, 1239–1246.

Kutner, M.H., Nachtsheim, C.J., Neter, J., 2004. Applied Linear Regression Models, fourth ed. McGraw-Hill Irwin.

Lande, R., 1996. Statistics and partitioning of species diversity, and similarity among multiple communities. Oikos 76, 5–13.

Low, J.W., Arimond, M., Osman, N., Cunguara, B., Zano, F., Tschirley, D., 2007. A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. J. Nutr. 137, 1320–1327.

Meng, E.C.H., Smale, M., Bellon, M., Grimanelli, D., 2010. Farmer gene banks and crop breeding: economic analyses of diversity in wheat, maize and rice. In: Smale, M. (Ed.), Definition and Measurement of Crop Diversity for Economic Analysis. Kluwer Academic Publishers, The Netherlands, pp. 19–32.

Micronutrient Initiative, 2009. Investing in the Future: A United call to Action on Vitamin and Mineral Deficiencies. Global Report 2009. Micronutrient Initiative.

National Statistical Office Malawi, 2011. Malawi Demographic and Health Survey 2010. ICF Macro, Calverton, MD.

National Statistical Office Malawi, 2012a. Integrated Household Survey 2010–2011: Household Socio-economic Characteristics Report. National Statistical Office, Malawi.

National Statistical Office, 2012b. Malawi Third Integrated Household Survey (IHS3) 2010–2011 Basic Information Document. National Statistical Office, Malawi, Zomba, Malawi.

Oyarzun, P.J., Borja, R.M., Sherwood, S., Parra, V., 2013. Making sense of agrobiodiversity, diet, and intensification of smallholder family farming in the highland Andes of Ecuador. Ecol. Food Nutr. 52 (6), 515–541.

Pinstrup-Andersen, P., 2006. Focus the global food system on health and nutrition goals. Int. J. Agric. Sust. 4, 2–4.

Pinstrup-Andersen, P., 2007. Agricultural research and policy for better health and nutrition in developing countries: a food systems approach. Agric. Econ. 37, 187–198.

Pinstrup-Andersen, P., 2010. The African food system and human health and nutrition: a conceptual and empirical overview. In: Pinstrup-Andersen, P. (Ed.), The African Food System and Its Interaction with Human Health and Nutrition. Cornell University, pp. 1–13.

Popkin, B.M., Adair, L.S., Ng, S.W., 2011. Global nutrition transition and the pandemic of obesity in developing countries. Nutr. Rev. 70, 3–21.

Quisumbing, A.R., Brown, L., Feldstein, H., Haddad, L.J., Pena, C., 1995. Women: The Key to Food Security. International Food Policy Research Institute, Washington, DC.

Rah, J.H., Akhter, N., Semba, R.D., de Pee, S., Bloem, M.W., Campbell, A.A., Moench-Pfanner, R., Sun, K., Badham, J., Kraemer, K., 2010. Low dietary diversity is a predictor of child stunting in rural Bangladesh. Eur. J. Clin. Nutr. 64, 1393–1398.

Remans, R., Flynn, D.F.B., F, D., Diru, W., Fanzo, J., Gaynor, K., Lambrecht, I., Mudiope, J., Mutuo, P.K., Nkhoma, P., Siriri, D., Sullivan, C., Palm, C., 2011. Assessing nutritional diversity of cropping systems in African villages. PLoS ONE 6, e21235.

Rose, D., Meershoek, S., Ismael, C., McEwan, M., 2002. Evaluation of a rapid field tool for assessing household diet quality in Mozambique. Food Nutr. Bull. 23, 181–189.

Ruel, M.T., 2003. Operationalizing dietary diversity: a review of measurement issues and research priorities. J. Nutr. 133, 3911S–3926S.

Ruel, M.T., Menon, P., 2002. Child feeding practices are associated with child nutritional status in Latin America: innovative uses of the demographic and health surveys. J. Nutr. 132, 1180–1187.
Shack, K.W., Grivetti, L.E., Dewey, K.G., 1990. Cash cropping, subsistence agriculture, and nutritional status among mothers and children in Lowland Papua New Guinea. Soc. Sci. Med. 31, 61–68.
Shahidullah, S., Talukder, M., Kabir, M., Khan, A., Elahi, N., 2008. Cropping patterns in the South East Coastal Region of Bangladesh. J. Nutr. 4, 53–60.
Simpson, E.H., 1949. Measurement of diversity. Nature 163, 688.
Smale, M., Hartell, J., Heisey, P.W., Senauer, B., 1998. The contribution of genetic resources and diversity to wheat production in the Punjab of Pakistan. Am. J. Agric. Econ. 80 (3), 482–493.
Snapp, S.S., Blackie, M.J., Gilbert, R.A., Bezner Kerr, R., Kanyama-Phiri, G.Y., 2010. Biodiversity can support a greener revolution in Africa. In: Proceedings of the National Academy of Sciences.
Steyn, N.P., Nel, J.H., Nantel, G., Kennedy, G., Labadarios, D., 2006. Food variety and dietary diversity scores in children: are they good indicators of dietary adequacy? Public Health Nutr. 9, 644–650.
Swindale, A., Bilinsky, P., 2006. Household Dietary Diversity Score (HDDS) for Measurement of Household Food Access: Indicator Guide. Food and Nutrition Technical Assistance Project (FANTA), Academy for Educational Development, Washington, DC.
Szumigalski, A., Van Acker, R., 2005. Weed suppression and crop production in annual intercrops. Weed Sci. 53, 813–825.
Tarini, A., Bakari, S., Delisle, H., 1999. The overall nutritional quality of the diet is reflected in the growth of Nigerian children. Sante 9, 23–31.
Thorne-Lyman, A.L., Valpiani, N., Sun, K., Semba, R.D., Klotz, C.L., Kraemer, K., Akhter, N., de Pee, S., Moench-Pfanner, R., Sari, M., Bloem, M.W., 2010. Household dietary diversity and food expenditures are closely linked in rural Bangladesh, increasing the risk of malnutrition due to the financial crisis. J. Nutr. 140, 182S–188S.
Torheim, L.E., Ouattara, F., Diarra, M.M., Thiam, F.D., Barikmo, I., Hatløy, A., Oshaug, A., 2004. Nutrient adequacy and dietary diversity in rural Mali: association and determinants. Eur. J. Clin. Nutr. 58, 594–604.
Whittaker, R.H., 1972. Evolution and measurement of species diversity. Taxon 21, 213–251.
World Bank, 2007. From Agriculture to Nutrition: Pathways, Synergies, and Outcomes. Agriculture and Rural Development Department, World Bank, Washington, DC.
World Bank. World Bank Data. <http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS> (accessed 11.04.13).
World Bank. Living Standards Measurement Study: Integrated Surveys on Agriculture. World Bank. <http://web.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTLSMS/EXTSURAGRI/0,,contentMDK:22800726~menuPK:7420278~pagePK:64168445~piPK:64168309~theSitePK:7420261,00.html> (accessed 11.04.13).
World Food Programme, 2008. Food Consumption Analysis Technical Guidance Sheet: Calculation and Use of the Food Consumption Score in Food Security Analysis. World Food Programme, Rome, Italy.
World Health Organization, 2006. WHO Child Growth Standards: Length/Height for Age, Weight for Age, Weight for Length, Weight for Height and Body Mass Index for Age. Methods and Development. World Health Organization, Geneva, Switzerland.
World Health Organization, 2008. Worldwide Prevalence of Anemia 1993–2005: WHO Global Database on Anemia. World Health Organization.
World Health Organization, 2009. Global Prevalence of Vitamin A Deficiency in Populations at Risk 1995–2005. World Health Organization.
World Resources Institute, 2003. Ecosystems and Human Well-being: A Framework for Assessment. Island Press, Washington, DC.
Zerfu Gurara, D., Salami, A.O., 2012. Towards Sustaining Malawi's Farm Input Subsidy Program. Africa Economic Brief. African Development Bank.
Zobisch, M.A., Richter, C., Heiligtag, B., Schlott, R., 1995. Nutrient losses from cropland in the Central Highlands of Kenya due to surface runoff and soil erosion. Soil Till. Res. 33, 109–116.