Do Wealth and Market Access Explain Inconsistent Relationships Between Crop Diversity and Dietary Diversity? Evidence from 10 Sub-Saharan African Countries

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**Do Wealth and Market Access Explain Inconsistent Relationships between Crop Diversity and Dietary Diversity? Evidence from 10 Sub-Saharan African Countries**

Isabel Curtin  
The University of Vermont

**Abstract**

Despite a robust literature base that has explored links between household crop diversity and children’s dietary diversity, evidence continues to yield mixed results regarding the significance and efficacy of crop diversity to improve childhood dietary outcomes. Given wide variance in the association between agrobiodiversity and dietary diversity across contexts, identifying factors that influence the direction and significance of the relationship can help inform targeted and appropriate development policies and interventions to maximize beneficial impact on livelihoods. Household characteristics such as wealth and distance to markets may provide important insight into the linkages between crop diversity and dietary diversity, given that low-resource households are often more reliant on localized production (including their own) for nutritional needs as compared to wealthier households with the resources to purchase more diverse foods from markets. This study examines the associations between crop diversity and dietary diversity among farm households at different levels of wealth in 10 sub-Saharan African countries. Drawing on the Integrated Public Use Microdata Series (IPUMS)-Demographic and Health Surveys (DHS) system, we show that the significance and direction of the association between crop diversity (as proxied by the Simpsons Diversity Index (SDI)) and children’s dietary diversity (as measured by the Household Dietary Diversity Score (HDDS)) varies by wealth quintile across all study countries. We find that the significance and direction of the relationship between crop diversity and dietary diversity depends on the socioeconomic status of a household: in richer households, crop diversity has a negative effect on dietary diversity and in poorer households, there is no significant effect. Further, findings demonstrate the importance of considering contextual factors, such as wealth and distance to markets, in assessing how the presence of crop diversity may improve nutritional outcomes. This study indicates the need to better understand the factors that impact the relationship between agricultural diversity and dietary diversity in order to inform agricultural development strategies.
Introduction

Food insecurity affects over 30% of the world’s population and has been on the rise since 2014 (FAO, 2020). In Africa, 322 million people faced food insecurity in 2021 which is 21.5 million more than in 2020 and 58 million more than in 2019 – trending in the opposite direction of the goal of zero hunger by 2030 articulated by the Sustainable Development Goals (FAO 2021; FAO, 2022). These concerning trends are attributed to a variety of factors including climate change, the COVID-19 pandemic, conflict, market instability, and the expense of quality diets (FAO, 2021). Women and children face the highest rates of undernourishment in sub-Saharan Africa: the continent represents one-third of all stunted children in the world and experiences the highest percentages of food and nutrition insecurity globally per capita (FAO et al., 2019). As a result of chronic malnutrition, stunting (low height for age) affects nearly one-third of children in Africa with implications for both physical growth and cognitive development (UNICEF; FAO, 2019). This trend is particularly noticeable in rural areas, where an estimated 80% of food production in sub-Saharan Africa is provided by small-scale farmers (IFAD 2016; OECD/FAO 2016; Fanzo, 2017).

With an increase in the number of food insecure people globally, compounded by the growing threat of climate change (Thiede & Strube, 2020), strategies to build resilience among vulnerable groups are urgently needed. Crop productivity predictions show that climate change will reduce agricultural production in most places in sub-Saharan Africa and therefore increase the prevalence of hunger (Lenne & Wood, 2011; Furman et al., 2021). For example, Grace et al. (2012) found that climate change can increase childhood stunting rates in areas of sub-Saharan Africa that rely on rainfed agriculture.

To mitigate these effects, crop diversity has been identified as having a positive influence on food security by maintaining productivity and providing back-up food sources during unpredictable weather patterns (Brush, 2000; Frison et al., 2011). Growing diverse crops can buffer against the negative impacts that weather and climate variation have on agricultural productivity and caloric intake (Grace et al. 2014; Frison et al. 2011). Furthermore, crop diversity has also been shown to lessen the effects of market disruptions on yield stability (Kahane et al., 2013). Yield instability has been shown to negatively impact health outcomes. Given price fluctuations and other related shocks that impact the ability of a household to buy and sell agricultural products, it is possible that crop diversity can buffer against adverse health impacts that often emerge from market instability (Grace et al. 2014; Kahane et al., 2013). Indeed, greater crop diversity is often associated with improved dietary quality (Jones, 2017; Steyn et al., 2005; Jones, 2014).

Although research linking crop diversity with food security has found a positive association at the household level (Jones 2017), the strength of these relationships is often marginal and sometimes the direction is even negative (Sibhatu & Qaim, 2018). For example, although Jones (2017) found a small but positive association between crop diversity and dietary diversity among 19 out of 21 studies in a meta-review, he also concludes that an inverse U-shaped relationship best characterizes the relationship between household crop diversity and dietary diversity. This suggests that crop diversity promotes dietary diversity up to a certain degree before flipping into a negative relationship, perhaps due to a loss in income.
when households forgo specialization (Jones, 2017). Other studies also consider the relationships between crop diversity and childhood health outcomes, while assessing other variables that may impact the association. For example, Bakhtsiyarava & Grace (2021) found that an increase in on-farm crop diversity is associated with an increase in HAZ (height-for-age Z score; a common indicator of childhood nutritional status) among children and that the presence of a market had no significant impact on this relationship. Across the studies that Jones (2017) reviews, dietary diversity is the most common outcome variable, for it is considered a useful proxy for food access, dietary quality and nutritional adequacy (Kahane et al., 2013; Jones, 2017; Steyn et al., 2005). Food security and nutritional outcomes are commonly associated, although nutritional outcomes are only partially determined by diet quality. Hygiene, water access, food safety, and breastfeeding practices are also thought to influence nutritional outcomes, often observed anthropometrically through metrics like HAZ (Jones, 2017).

Despite a clear conceptual link between crop diversity and dietary diversity, studies at the household level have not presented a strong and consistent pattern that can definitively drive policy initiatives that seek to address food security and malnutrition. Other strategies to use crop diversity to benefit food security have been highlighted including improving market engagement to enhance the ability of a household to generate income and, in turn, enabling its members to buy more diverse foods in the market (Sibhatu et al., 2015; Furman et al., 2021; Koppmair et al, 2017). Sibhatu and Qaim (2018) found that market-oriented agricultural diversification has a greater impact on dietary diversity than diversification for subsistence due to the increases in income farmers experienced due to their crop sales. More research is thus needed to discern how the presence of crop diversity and market access converge in particular ways to influence household food and nutrition security (Jones, 2017).

Due to the mixed results that previous research has documented regarding the relationship between on-farm crop diversity and dietary diversity, recommendations point to the importance of investigating this complex relationship at scales beyond the household (Sibhatu & Qaim, 2018; Tobin et al., 2019; Bellon, 2016). Tobin et al. (2019) found a positive relationship between village-level SDI and dietary diversity as well as SDI and HAZ, though they also recommend that future studies verify their preliminary evidence. The authors argue that the presence of crop diversity at, for example, the village level may benefit the households who live in that locale, even if not all households are diversifying their crop production. However, much like the household level, initial evidence at the village level provides mixed results and vary significantly among countries in sub-Saharan Africa (Isbell et al., under review). According to Isbell et al., at the village level, some countries (Burkina Faso and Zimbabwe) show a positive relationship between crop diversity and household dietary diversity, others have a negative relationship (Ethiopia and Guinea), and still others show no relationships (Uganda, Benin, Cameroon, Ghana, Malawi, and Nigeria). Due to this variance (as seen in Figure 1), it is important to consider the conditions and factors that influence the relationship between crop diversity on a village scale and dietary diversity of the individuals who comprise that village.

Socioeconomic as well as geographic indicators are likely candidates to mediate the effects of crop diversity on dietary diversity. Frongillo et al. (1997) found that the variability for both stunting and wasting can be explained by geographic region, implying that there are various causes to nutritional deficiencies. Those who live in a rural setting may rely more heavily on subsistence-oriented production
and less on market-purchased food and therefore, rely more on their own production as the source of diet diversity (Jones, 2017; Koppmair et al., 2017). In Malawi, Koppmair et al. (2017) found that production diversity plays a greater role in dietary diversity in rural areas versus in more urban settings. Further, geographic isolation may inhibit households from using markets to sell agricultural products and therefore limit income used to purchase more diverse foods (Koppmair et al., 2017). In urban and more commercialized areas, increasing on-farm crop diversity may decrease revenue due to a loss in specialization (Sibhatu et al., 2015; Koppmair et al., 2017). Previous research also emphasizes the role that wealth has on the relationship between crop diversity and dietary diversity, leading us to believe that in subsistence-oriented and poorer areas, crop diversity has a greater effect on dietary diversity.

Despite existing literature that explores the relationship between agrobiodiversity and dietary diversity, wealth has yet to be properly interrogated within these analyses, even though studies indicate that wealth may be a determinant of child nutritional status and improved socioeconomic status can reduce the occurrence of childhood stunting. For example, Pongou et al. (2006) indicate that in Cameroon, household economic status generally has a positive effect on children’s HAZ but little impact on children aged 0-5 months due to the role of breastfeeding. Further, their study shows that regional variations in child nutritional status and HAZ are mediated by socioeconomic conditions (Pongou et al., 2006). This trend is similarly noted in the findings of Sahn & Alderman (1998), who found that in 8 out of 10 sub-Saharan African countries, stunting is more common in children from poorer households than from non-poor households (exceptions include Ethiopia and Guinea) and in all 10 countries, stunting is more common in rural than urban areas.

The wealth of a household also influences the dietary diversity of a household (Pongou et al., 2006; Sahn & Alderman 1998). In lower income countries, poorer households experience certain living conditions like poor sanitation that can cause childhood stunting (Rah et al., 2020; Berhane et al., 2020). The households that experience such conditions as a result of socioeconomic status may also be the ones that are more likely to rely on subsistence-based production, and therefore, benefit directly from agricultural diversification. Furthermore, wealthier households are thought to have the financial means to purchase more diverse foods, leading to a more diversified diet, which is sometimes used as an indicator of food access and nutritional adequacy (Codjoe et al., 2016; Berhane et al., 2020; Kahane et al., 2013). These households may be better positioned to benefit more from greater access and participation in markets, which provide households with the opportunity to generate money and purchase diverse foods. Households of lower socioeconomic status have less purchasing power and therefore, have a greater reliance on subsistence-based production. Accordingly, these households may experience greater benefits from on-farm crop diversity to increase dietary diversity and possibly, decrease childhood stunting. Further, these households may benefit more from markets because the exchange of diverse agricultural products for cash may have a more profound impact on household wellbeing as opposed to that of a wealthier household (Sibhatu et al., 2015; Islam et al., 2018). Therefore, based on previous research, there is reason to suspect that household wealth, a variable considered a determinant of food insecurity, may impact the significance and direction of the relationship between the presence of crop diversity and dietary diversity.
This study seeks to analyze the influence of socioeconomic status on the relationship between crop diversity and dietary diversity to understand the variance in the relationship, such that the relationship may vary in strength and even in direction depending on wealth status. Further, in countries where overall, there is no association between crop diversity and dietary diversity, this may indicate that the difference in association based on wealth group obscures a potentially significant association in poorer households. This study therefore analyzes the potential for wealth to explain variation in the estimated associations between crop diversity and household food security. Specifically, two hypotheses guide this study:

i. The association between crop diversity and dietary diversity varies according to household wealth.
   a. In poorer households, crop diversity has a positive association with dietary diversity.
   b. In richer households, crop diversity has a negative association with dietary diversity.

ii. The association between crop diversity and dietary diversity varies according to household market engagement.
   a. In households with low market engagement, crop diversity has a positive association with dietary diversity.
   b. In households with high market engagement, crop diversity has a negative association with dietary diversity.

Table 1. The Association Between SDI at 10km and HDDS in the Findings of Isbell et al. (forthcoming)

<table>
<thead>
<tr>
<th>Positive association between crop diversity and HDDS</th>
<th>Burkina Faso</th>
<th>Zimbabwe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative association between crop diversity and HDDS</td>
<td>Ethiopia</td>
<td>Guinea</td>
</tr>
<tr>
<td></td>
<td>Uganda</td>
<td>Benin</td>
</tr>
<tr>
<td>No association between crop diversity and HDDS</td>
<td>Cameroon</td>
<td>Ghana</td>
</tr>
<tr>
<td></td>
<td>Malawi</td>
<td></td>
</tr>
</tbody>
</table>
Materials and Methods

Measuring Dietary Diversity

Recent research has focused on crop diversity in the context of human nutrition and how the consumption of a greater number of food groups may foster food and nutrition security (Jones, 2017; Bakhtsiyarava & Grace, 2021). Arimond & Ruel (2004) found that dietary diversity and HAZ are significantly associated, suggesting that children’s dietary diversity proxies nutritional status (Mekonnen et al., 2020). Across many studies, dietary diversity is regarded as a good indicator of people’s broader nutritional status, as opposed to anthropometric measures which can be unreliable (Islam et al. 2018; Kumar et al. 2015; Sibhatu et al. 2015). This study is based upon the assumption relating health sciences to crop diversity: a diverse diet is associated with adequate micronutrient and macronutrient intake and better overall human health (Jones, 2017). To measure dietary diversity, respondents are asked to identify food groups that have been consumed over a recall period such as 24 h, 1 week, or 1 month (Jones 2017; Sibhatu et al. 2015).

This study utilizes data from the Demographic and Health Surveys (DHS) Program implemented by the United States Agency for International Development (USAID). Household Dietary Diversity Scores (HDDS) is measured by the DHS as the consumption of seven food groups (starches and tubers, legumes, dairy, animal protein, vitamin A-rich vegetables and fruits, other vegetables and fruits, and fats and oils) over a 24hr recall period for the young children in a household. Dietary diversity takes the nutritional adequacy of various foods and food groups into consideration as opposed to a simple count of food groups. Dietary diversity is generally regarded as an acceptable indicator of nutritional status and food security (Sibhatu et al., 2015; Jones, 2017; Bakhtsiyarava & Grace, 2021). In our analysis, we drop observations where key variables of HDDS are missing, resulting in the sample size of 34,612 children aged between 24-59 months. Due to the role that breastfeeding plays in the diets of young children, we do not include children aged 0-24 months.

Measuring Crop Diversity

Diversifying crops is thought to improve nutritional outcomes by providing a more balanced diet and more possibility to access nutritious foods through the cash generated from crop sales (Chinnadurai et al. 2016; Ekesa et al. 2008; Kahane et al. 2013). Additionally, crop diversity is thought to buffer against global market instability (Kahane et al., 2013; Koppmair et al., 2017). Several methods have been used to measure on-farm agrobiodiversity such as a simple count of crop species grown in the past year (Jones, 2017). Other studies utilize functional diversity which accounts for both species diversity and nutritional
diversity. This measure categorizes crops based on their nutritional content and therefore, to the human health contributions of agrobiodiversity (Jones, 2017; Remans, 2011).

To capture crop diversity, we use another common indicator, the Simpsons Diversity Index (SDI), which measures relative abundance reflected by the number of crops produced and evenness of the quantities of each crop. SDI is the probability that two randomly selected quantities of crops produced are the same type of crop (Muthini et al., 2020). Its value increases as the number of crops increases and when the quantity of each crop is more even: 0 being a monoculture and 1 being perfectly even distribution of all crops present (Muthini et al., 2020).

**Measuring Socioeconomic Status**

Many approaches have been used to measure household socioeconomic status. Pongou et al. (2006) consider the relationship between food insecurity, dietary diversity, and stunting. They assess specific assets as indicators of economic status: radio, electricity, television, and cars. Similarly, in their study assessing socioeconomic status and nutritional status. Hatloy et al. (2000) consider 14 different possessions to calculate a socioeconomic score. On the other hand, Sahn & Alderman (1998) study nutritional status and poverty by comparing poor and non-poor children, where poor children are defined as children whose households’ income per capita is below two-thirds of the mean national income per capita. Codjoe et al. (2016) use household wealth quintile to assess household characteristics and dietary diversity, which is the approach we utilize in our analyses.

To assess the impact that wealth has on the relationship between crop diversity and dietary diversity, we utilize the IPUMS DHS variable WEALTHQ. This variable provides the relative wealth of a household, divided into quintiles from the poorest (1) to the richest (5). The wealth index is a composite measure of the standard of living of a household. This is calculated by assessing a household’s ownership of certain assets such as televisions, housing construction materials, water access and sanitation facilities. Principal components analysis places households on a continuous scale of relative wealth. Households are separated into five quintiles of wealth based on information obtained from the interview.

**Market Access**

Markets are highly varied across the 10 sub-Saharan African countries included within this study. Generally, most smallholder farmers are not integrated into commercial markets due to a lack of information, high transportation costs, and limited assets (Otekunrin et al., 2019). However, many households participate in local or regional farmers markets; these markets vary greatly within and across countries in terms of formality, size, frequency, season, and types of foods sold. In more urban spaces, farmers markets may be more formal, larger, and contain a greater variety of crops sold while more rural markets may be informal, smaller, and less diverse.

These markets are important for some rural subsistence-based households and contribute to the cash earnings of households (Sibhatu and Qaim, 2018; Otekunrin et al., 2019). Furthermore, markets may allow households to specialize in profitable crops, and therefore, these farmers can earn more to
purchase more diverse and sufficient diets (Koppmair et al., 2017; Bellon et al., 2016; Jones et al., 2014; Sibhatu and Qaim, 2018).

**Data and analysis**

To examine the association between crop diversity and dietary diversity and the possible mediating role of wealth, we use household data from the USAID Demographic and Health Surveys (DHS) Program and geospatial data on agricultural production at a 10km surrounding area (derived from Monfreda et al. 2008). The DHS are large-scale household-level surveys in low- and middle-income countries designed to be representative at the national and regional levels. The questions asked are standardized across countries and over time, allowing for both cross-sectional and time-series analyses, and furthermore, include geo-spatial coordinates to allow for DHS survey responses to be integrated with geospatial data (Boyle et al., 2019; Isbell et al., 2022). We conduct analyses in these 10 countries because the IPUMS-DHS collected comparable data for our key measures of interest within a +/- 5-year window (1995-2005). We assume that agricultural production does not significantly shift during this time period. Across the available data, 11 samples from 10 countries meet these criteria. Despite the potential for trends to have evolved since this time period, this paper presents a new approach to understanding the impacts of crop diversification and socioeconomic status across landscapes.

*Figure 1: Countries and years data was extracted from*

Dietary diversity data drawn directly from the DHS include consumption of up to seven different food groups (starches & tubers, legumes, dairy, animal protein, vitamin A rich vegetables and fruits, other fruits and vegetables, and fats & oils) over a 24-hour recall period for young children in the household. In the final sample for analyses, the observations with missing key variables were dropped, resulting in a sample size of 34,612 children aged 24-59 months.

Crop area planted data are derived from Monfreda et al. (2008) and include harvest area and yield of 175 crops based on a combination of remote sensing and administrative data, available at 10km x 10km
resolution globally circa-2000. For each DHS survey household, data on local crop cover were extracted from the Monfreda et al. (2008) at 10km resolution (Figure 1), as per Tobin et al. (2019). This allowed for the computation of crop diversity indices at a spatial scale of 10-km.

We calculate Simpson’s diversity for a buffer of 10km around village points from DHS-IPUMS using the entropyetc package (Cox, 2016). Buffer zones are used to explore the importance of crop diversity at scales beyond the household as to account for contextual determinant of child health.

We use the following formula to calculate Simpson’s Diversity Index

\[ 1 - D = 1 - \sum_{i=0}^{n} P_i^2 \]

The possible mediating role of wealth in the relationship between crop diversity and dietary diversity is examined through the DHS variable WEALTHQHH (HV270). This variable separates DHS households within each survey wave (country-year) into wealth quintiles, with 1 coded as the poorest 20% and 5 the richest 20% of survey respondents within that sample. Wealth is measured using an asset score, whose contents vary across countries and across survey waves; hence WEALTHQHH is not a measure of absolute wealth, but rather a measure of relative wealth within a given country at a given time.

**Analysis**

The associations between crop diversity and dietary diversity in the study countries (but lacking a wealth variable are reported in Isbell et al. (under review). This paper focuses on the potential explanatory power of wealth quintiles across countries and within individual countries, asking if wealth mediates the relationship between crop diversity and dietary diversity.

The core Ordinary Least Squares (OLS) regression model takes the form:

\[ Y_{ihjt} = B_0 + B_1D_{ihjt} + B_2W_{ihjt} + e_{ihjt} \]

where \( Y_{ihjt} \) is HDDS (on scale of 1-7) of individual \( i \) in household \( h \) in country \( j \) at time \( t \), \( D_{ihjt} \) is crop diversity within a 10-kilometer buffer as proxied by SDI, and \( W_{ihjt} \) is the wealth quintile of the household; \( e_{ij} \) is a residual error term.

We further test the robustness of findings by including of a set of individual-level control variables \( X_{ihjt} \) including child sex and age, maternal educational attainment and age, and sex of household head; and a set of household-level control variables, \( H_{ihjt} \), including rural/urban status of the household, travel time to the nearest city of 50,000 or more population, and the shares of land within a 10-km radius used for cropland and for pastureland (measured circa 2000).

\[ Y_{ihjt} = B_0 + B_1D_{ihjt} + B_2W_{ihjt} + B_3X_{ihjt} + B_4H_{ihjt} + e_{ihjt} \]
Results are visualized in the form of marginal effects of crop diversity on dietary diversity at each income quintile within each country, after accounting for other control variables.

Findings

First, we conducted an OLS regression including all 10 countries to understand the relationship between crop diversity and dietary diversity across the wealth quintiles. Table 2 displays the results of these regressions controlling for sociodemographic, geographic, and climate variables. We find that in the richest wealth group, there is a statistically significant (p < .05) negative association between SDI at 10km and HDDS, and further that the richest wealth group has the greatest negative association. Contrary to the findings of Tobin et al. (2019) who found an overall positive association between SDI at 10km and dietary diversity, we find that after accounting for income there are different patterns across the poorest, poorer, and middle wealth groups. We also find that education of mother is consistently a significant predictor of the dietary diversity of a household across wealth groups.

Table 2: OLS regression of HDDS_7 and Simpson’s Diversity Index at different wealth quintiles

<table>
<thead>
<tr>
<th>Variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>Poorest</td>
<td>Poorer</td>
<td>Middle</td>
<td>Richer</td>
<td>Richest</td>
</tr>
<tr>
<td>Simpson’s Diversity</td>
<td>0.078</td>
<td>0.248</td>
<td>-0.156</td>
<td>-0.414</td>
<td>-1.093***</td>
</tr>
<tr>
<td></td>
<td>(0.231)</td>
<td>(0.231)</td>
<td>(0.219)</td>
<td>(0.260)</td>
<td>(0.288)</td>
</tr>
<tr>
<td>Sex of child = female</td>
<td>0.051</td>
<td>0.040</td>
<td>-0.118***</td>
<td>0.072</td>
<td>0.071</td>
</tr>
<tr>
<td></td>
<td>(0.033)</td>
<td>(0.032)</td>
<td>(0.032)</td>
<td>(0.039)</td>
<td>(0.047)</td>
</tr>
<tr>
<td>Female head of household</td>
<td>-0.065</td>
<td>-0.208***</td>
<td>-0.020</td>
<td>-0.200***</td>
<td>-0.092</td>
</tr>
<tr>
<td></td>
<td>(0.047)</td>
<td>(0.050)</td>
<td>(0.043)</td>
<td>(0.050)</td>
<td>(0.059)</td>
</tr>
<tr>
<td>Age of child</td>
<td>0.007***</td>
<td>0.014***</td>
<td>0.004*</td>
<td>0.005**</td>
<td>0.017***</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>Education of mother</td>
<td>0.325***</td>
<td>0.376***</td>
<td>0.352***</td>
<td>0.341***</td>
<td>0.491***</td>
</tr>
<tr>
<td></td>
<td>(0.047)</td>
<td>(0.045)</td>
<td>(0.046)</td>
<td>(0.057)</td>
<td>(0.058)</td>
</tr>
<tr>
<td>Remoteness (ref = Q1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2</td>
<td>0.105</td>
<td>-0.383***</td>
<td>0.066</td>
<td>-0.042</td>
<td>-0.027</td>
</tr>
<tr>
<td></td>
<td>(0.107)</td>
<td>(0.085)</td>
<td>(0.073)</td>
<td>(0.068)</td>
<td>(0.069)</td>
</tr>
<tr>
<td>Q3</td>
<td>0.051</td>
<td>-0.170*</td>
<td>0.116</td>
<td>0.024</td>
<td>-0.410***</td>
</tr>
<tr>
<td>---------</td>
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<tr>
<td></td>
<td>(0.109)</td>
<td>(0.084)</td>
<td>(0.074)</td>
<td>(0.075)</td>
<td>(0.084)</td>
</tr>
<tr>
<td>Q4</td>
<td>0.153</td>
<td>-0.216*</td>
<td>-0.114</td>
<td>0.089</td>
<td>-0.266**</td>
</tr>
<tr>
<td></td>
<td>(0.109)</td>
<td>(0.087)</td>
<td>(0.076)</td>
<td>(0.075)</td>
<td>(0.084)</td>
</tr>
<tr>
<td>Q5</td>
<td>0.067</td>
<td>-0.393***</td>
<td>-0.118</td>
<td>0.017</td>
<td>-0.444***</td>
</tr>
<tr>
<td></td>
<td>(0.111)</td>
<td>(0.090)</td>
<td>(0.081)</td>
<td>(0.083)</td>
<td>(0.092)</td>
</tr>
<tr>
<td>Cropland, 10km radius</td>
<td>-0.081</td>
<td>-0.216</td>
<td>-0.277*</td>
<td>0.006</td>
<td>-0.109</td>
</tr>
<tr>
<td></td>
<td>(0.155)</td>
<td>(0.147)</td>
<td>(0.141)</td>
<td>(0.173)</td>
<td>(0.232)</td>
</tr>
<tr>
<td>Pastureland, 10km radius</td>
<td>-0.284*</td>
<td>-0.250*</td>
<td>-0.318*</td>
<td>-0.144</td>
<td>0.591*</td>
</tr>
<tr>
<td></td>
<td>(0.117)</td>
<td>(0.125)</td>
<td>(0.136)</td>
<td>(0.152)</td>
<td>(0.237)</td>
</tr>
<tr>
<td>Annual Precipitation Δ</td>
<td>0.016***</td>
<td>0.007***</td>
<td>0.001</td>
<td>0.009***</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>Constant</td>
<td>1.515***</td>
<td>2.679***</td>
<td>4.596***</td>
<td>3.218***</td>
<td>4.642***</td>
</tr>
<tr>
<td></td>
<td>(0.373)</td>
<td>(0.348)</td>
<td>(0.241)</td>
<td>(0.384)</td>
<td>(0.393)</td>
</tr>
<tr>
<td>Observations</td>
<td>7,208</td>
<td>7,283</td>
<td>7,751</td>
<td>6,504</td>
<td>5,866</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.244</td>
<td>0.266</td>
<td>0.298</td>
<td>0.245</td>
<td>0.196</td>
</tr>
</tbody>
</table>

Building off the OLS Regression as seen in Table 3, we graph the association coefficients. We find that there is not a significant association in the poorest, poorer, middle, and richer wealth groups. Recognizing the nuances in context between wealth groups, we find that the variance in association takes the form of an inverse u-shape, illustrating that the association between crop diversity and dietary diversity vary across wealth quintiles. While overall (including households from all socioeconomic backgrounds), there is a negative association, this trend does not characterize all household wealth quintiles, emphasizing the importance of considering household characteristics.

*Figure 2: OLS Regression coefficients of HDDS_7 and SDI at different wealth quintiles*
Next, we conduct OLS regressions in each country separately to understand the relationship between crop diversity and dietary diversity across wealth quintiles. These regressions also control for sociodemographic, geographic, and climate variables and reveal a similar pattern: the significance and direction of the association between crop diversity and dietary diversity varies across wealth quintiles within all countries. While patterns vary across countries, we find the association to be significant and negative ($p < .05$) only among the two highest income quintiles. In lower income quintiles we see no association in most countries. For example, in both Ethiopia and Uganda there is a significant negative association in the richer wealth groups, yet the associations in the three lowest wealth groups are insignificant.

Figure 3: OLS Regression of HDDS_7 and Simpson’s Diversity Index at different wealth quintiles in each country
Figure 4 shows the estimated marginal effect of SDI on HDDS based on households’ distance to markets. We include all 10 countries and consider the marginal effects in each wealth quintile. Travel time is measured in minutes and is used as an indicator of market access. We find two main patterns within these analyses. First, we find that SDI has a positive impact on HDDS among poorer households (Quintile 2) but only for the households who are relatively closer to markets. The impact of SDI on HDDS is more ambiguous in lower-income households further from markets. Next, we again see that the only negative association between SDI and HDDS is among the richest households. Further, we note that the marginal effect of SDI on HDDS in Quintile 5 is the most negative in households that are furthest from markets. However, these findings may reflect a small sample size, as there are few households with high socioeconomic standing that are far from markets. Quintile 5 may also contain many households who are higher-income monoculture farmers, as well as potentially households who do not expect farming to be their primary source of income or food (investors or hobby farmers). We note that travel time does not appear to explain the discrepancies in the association between SDI and HDDS across wealth quintiles – rather, the findings in Figure 4 again suggest that other variables not yet accounted for in our models may be shaping the association between crop diversity and dietary diversity.

Figure 4: Marginal effect of SDI on HDDS at 10km based in wealth quintile and distance to market
Discussion:

This study draws on IPUMS-DHS data and geospatial covariates to explore the variance across contexts regarding the relationship between agrobiodiversity and dietary diversity. Building on previous literature (Tobin et al., 2019; Isbell et al., under review; Jones, 2017; Sibbhatu & Qaim, 2018; Bellon, 2016), we address the need to consider contextual variables such as wealth and distance to markets to determine the effectiveness of crop diversity as a means of promoting food security. Socioeconomic context appears to influence the relationship between crop diversity and dietary diversity including a household’s reliance on subsistence production and access to markets (Sibbhatu & Qaim, 2018). Based on the literature, we hypothesized that household wealth would influence the significance that crop diversity has on dietary diversity (Koppmair et al., 2017; Sibbhatu et al, 2015; Jones, 2017). More specifically, we expected that in lower-income households, crop diversity would have a positive effect on dietary diversity, while in higher-income households, crop diversity would have a negative effect on dietary diversity. The results of this analysis provide partial support for our hypotheses: we find that the relationship between crop diversity and dietary diversity in households of lower socioeconomic status is not significant but among households of higher socioeconomic status, there is a statistically significant negative relationship. These findings indicate that in higher income and market-oriented households, crop diversity may decrease profit, and therefore, the ability to purchase more diverse foods. Our analysis thus provides two key findings: crop diversity and dietary diversity are negatively associated within the richer and richest wealth groups.

Results from the analysis of the association between crop diversity and dietary diversity suggest that overall, SDI is negatively associated with dietary diversity. These findings contrast with previous research (Tobin et al., 2019; Ekesa et al., 2008), who found a consistent positive relationship between village-level SDI and dietary diversity. Our findings also suggest that the effect of crop diversity on dietary diversity is marginal. Similarly, Sibbhatu et al. (2015) and Furman et al. (2021) suspect that other factors such as market access and commercialization have a significant effect on this relationship and that the direction and strength of the association varies situationally. Indeed, our findings are also consistent with
those of Isbell et al. (under review), finding that the significance and direction of the association between SDI and dietary diversity differ based on country, indicating the need to study other contextual variables that influence this relationship. Our results confirm the importance of country-level studies and further emphasize the importance of considering household wealth in these analyses.

Our analysis becomes further nuanced in that our findings provide evidence that wealth moderates the relationship between crop diversity and dietary diversity. OLS regression results suggest that in the richest households, there is a strong negative association between crop diversity and dietary diversity. These findings provide support for our hypothesis that in richer and richest households, diversification is negatively associated with dietary diversity. However, in the poorest, poorer, and middle wealth groups, there is not a significant association. The poorer wealth group appears to have the most positive relationship between crop diversity and dietary diversity (though the effect is not statistically significant), possibly because they do not have the means to engage in cash cropping and they still predominately rely on their own production for food (Koppmair et al., 2017). In the poorest wealth group, families are thought to be entirely reliant on their production and face barriers to access markets and diverse seeds, which may explain why there is a stronger relationship between SDI and HDDS in poorer households (Bellon et al., 2016). It is possible that the richer and richest households have greater market access and that the cash generated through sales has a greater impact on dietary diversity (Sibhatu & Qaim, 2018).

Although these results contrast with the findings of Tobin et al. (2019) who found that crop diversity has a more positive relationship with the dietary diversity of people in more rural areas, Jones (2017) finds that distance to markets does not impact this relationship. Our findings are consistent with those of Bellon et al. (2016), suggesting that production for household consumption and purchasing foods are complementary in their contribution to dietary diversity. Further, these findings provide support for our hypothesis that the association between crop diversity and dietary diversity varies according to household wealth. While our results do not allow us to assume that diversification generally improves dietary diversity, we also cannot assume that crop diversity is associated with lower dietary diversity among all households as the association is impacted by other factors (Bellon et al., 2016; Islam et al., 2018; Sibhatu et al., 2015; Isbell et al., forthcoming).

As future studies continue to examine factors influencing the relationship between crop diversity and dietary diversity, they should take note of several recommendations we offer based on the limitations of this study. Our analyses within country-specific contexts demonstrate the impact of wealth, yet the household wealth quintile variable in the DHS data is relative within a given country. Therefore, in poorer countries, the poorest quintile may experience different socioeconomic conditions compared to those of the poorest quintile in richer countries. Further, the data used in this study are collected in the years 1995 to 2005 due to the need for comparable data. Therefore, this study assumes that conditions impacting these relationships have not drastically changed. Newly emerging datasets such as the World Bank’s Living Standards Measurement Study (LSMS) can provide updated and alternate measures of socioeconomic status as well as food security. Dietary diversity is utilized within this study as an indicator of nutritional status; however, other measures of nutritional adequacy may provide additional insight. Lastly, we recommend that future studies utilize primary data collection to account for the characteristics of wealth
such as the possibility of richer households as hobby farmers or monoculture farmers. These factors may inform a household’s decisions and land management practices.

Future research should continue to explore the impact that wealth has on the efficacy of crop diversity as a means of improving dietary diversity and therefore, nutritional outcomes. This research affirms the narrative that diversification can contribute to health outcomes in certain contexts by increasing dietary diversity and that contextual variables are important to consider. The impact that wealth quintile has on the association between crop diversity and dietary diversity varies based on country which signifies that local context impacts this relationship. Our findings also demonstrate the need for studies to consider household wealth in order to understand the effect that crop diversity has on dietary diversity. Finally, the educational status of the mother is significant among the associations between SDI and HDDS across all wealth quintiles. One possible explanation is that educated women of all socioeconomic backgrounds who live in agrobiodiverse areas are more familiar with nutritional guidelines and therefore, can make decisions in their household that better contribute to dietary diversity. Further research should investigate how the education of mothers moderates the relationship between crop diversity and dietary diversity.

Additional variables may be useful to include in future research that may contribute to findings regarding the relationships between crop diversity and dietary diversity. While the education of mother is included within this research and found to be statistically significant across all wealth groups, paternal education may provide important insights as we observe the impact that education can have on providing adequate diets for children within a household. Other variables to consider that may be valuable in future studies include race, ethnicity, soil quality, and conflict. Furthermore, we acknowledge the possible biases within demographic and health surveys that may be present within the DHS program implemented by the USAID. For example, Weber et al. (2021) find that gender-related biases have been built into global surveys due to missing data across gender dimensions leading to imbalanced representations of populations and biased gender-related information (Weber et al., 2021).

Our research provides an important basis for future studies and for policy intervention targeted at improving the livelihoods and health outcomes of smallholders, as this study demonstrates the fact that increasing agricultural diversity is not a universally applicable tool for improving dietary diversity and therefore, nutritional outcomes. Further analysis is needed to understand the characteristics of socioeconomic status such as educational attainment, market access, seed access, and households’ status as urban or rural; all of which may impact the effect of crop diversity on dietary diversity.
References


