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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

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Abstract: Despite the robust literature base that has explored links between household crop diversity and children's dietary diversity, evidence continues to yield mixed results regarding the efficacy of crop diversity in improving childhood dietary outcomes. Given the variance in the association between agrobiodiversity and dietary diversity, we identified wealth and distance to markets as potential factors that may impact these relationships. Through a series of Ordinary Least Square (OLS) regressions, this study examines the associations between crop diversity and dietary diversity among households at different levels of wealth in 10 sub-Saharan African countries. Drawing on the Integrated Public Use Microdata Series and Demographic and Health Surveys system, we find that the significance and direction of the association between crop diversity (as proxied using the Simpsons Diversity Index) and children's dietary diversity (as measured using the Household Dietary Diversity Score) vary by wealth quintile across countries and households: in richer households, crop diversity has a negative effect on dietary diversity, and in poorer households, there is no significant effect. This study indicates the need to understand contextual factors that impact the relationship between agricultural diversity and dietary diversity to inform development policies.

Keywords: food security; crop diversity; dietary diversity; wealth; market access

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1. Introduction

Food insecurity affects over 30% of the world's population and has been on the rise since 2014 [1]. 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 [2]. 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 [2,3]. 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 [4]. 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 [4,5]. 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 [6].

With an increase in the number of food insecure people globally, compounded by the growing threat of climate change [7], 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 [8,9]. For example, Grace et al. [10] 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 backup food sources during unpredictable weather patterns [11,12]. Growing diverse crops can buffer against the negative impacts that weather and climate variation have on agricultural productivity and caloric intake [12,13]. Furthermore, crop diversity has also been shown to lessen the effects of market disruptions on yield stability [14]. 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 [13,14]. Indeed, greater crop diversity is often associated with improved dietary quality [15,16].

Although research linking crop diversity with food security has found a positive association at the household level [16], the strength of these relationships is often marginal, and sometimes the direction is even negative [17]. For example, although Jones [16] 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 [16]. 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 and Grace [18] 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 [16] reviews, dietary diversity is the most common outcome variable, for it is considered a useful proxy for food access, dietary quality, and nutritional adequacy [14–16]. Further, Arimond and Ruel [19] found that dietary diversity and HAZ are significantly associated, suggesting that children's dietary diversity proxies their nutritional status [20]. 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 [21,22]. 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 [16].

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 [9,21,22]. Sibhatu and Qaim [17] 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 [16].

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 [17,23,24]. Tobin et al. [24] found a positive relationship between village-level Simpson's Diversity Index (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 at the household level, initial evidence at the village level provides mixed results and varies significantly among countries in sub-Saharan Africa [25]. According to Isbell et al. [25], 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 relationship (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 the dietary diversity of the individuals who comprise that village.

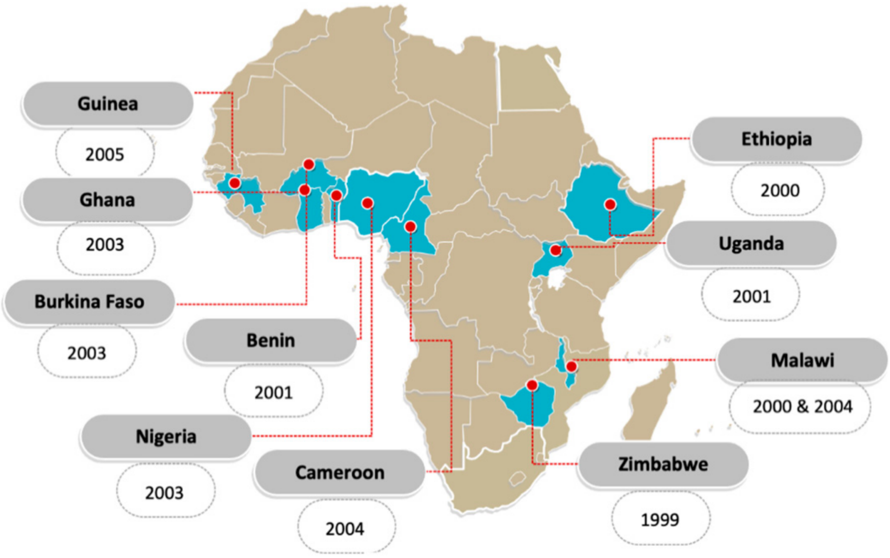

Figure 1. Data on countries and years were extracted.

Socioeconomic as well as geographic indicators are likely candidates to mediate the effects of crop diversity on dietary diversity. Frongillo et al. [26] found that the variability for both stunting and wasting can be explained by geographic region, implying that there are various causes of 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 [16,27]. In Malawi, Koppmair et al. [27] 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 [27]. In urban and more commercialized areas, increasing on-farm crop diversity may decrease revenue due to a loss in specialization [21,27]. 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 the 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 a child's nutritional status and that improved socioeconomic status can reduce the occurrence of childhood stunting. For example, Pongou et al. [28] 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 [28]. This trend is similarly noted in the findings of Sahn and Alderman [29], 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 the household [28,29]. In lower-income countries, poorer households experience certain living conditions, like poor sanitation, that can cause childhood stunting [30,31]. 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 [14,31,32]. 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 well-being as opposed to that of a wealthier household [21,22]. 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:
    1. In poorer households, crop diversity has a positive association with dietary diversity.
    2. 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:
    1. In households with low market engagement, crop diversity has a positive association with dietary diversity.
    2. In households with high market engagement, crop diversity has a negative association with dietary diversity.

2. Materials and Methods

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 [33] and geospatial data on agricultural production at a 10 km surrounding area (derived from Monfreda et al. [34]. 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 geospatial coordinates to allow for DHS survey responses to be integrated with geospatial data [25,35]. We conducted 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.

This study is based on the assumption relating health sciences to crop diversity: a diverse diet is associated with adequate micronutrient and macronutrient intake and better overall human health [16]. Dietary diversity takes the nutritional adequacy of various foods and food groups into consideration and is generally regarded as an acceptable indicator of nutritional status and food security [16,18,21]. Dietary diversity data drawn directly from the DHS include consumption of up to seven different food groups (starches and tubers, legumes, dairy, animal protein, vitamin A-rich vegetables and fruits, other fruits and vegetables, and fats and oils) over a 24 h recall period for young children in the household. In our analysis, we drop observations where key variables of HDDS are missing, resulting in a 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.

Several methods have been used to measure on-farm agrobiodiversity, such as a simple count of crop species grown in the past year [16]. 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, the human health contributions of agrobiodiversity [16,36]. To capture crop diversity, we use Simpson's Diversity Index (SDI), which measures relative abundance as reflected by the number of crops produced and the 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 [37]. Its value increases as the number of crops increases and when the quantity of each crop is more even, with 0 being a monoculture and 1 being a perfectly even distribution of all crops present [36].

Crop area planted data are derived from Monfreda et al. [34] and include harvest area and yield of 175 crops based on a combination of remote sensing and administrative data, available at 10 km × 10 km resolution globally circa-2000. For each DHS survey household, data on local crop cover were extracted from Monfreda et al. [34] at 10 km resolution (Figure 1), as per Tobin et al. [24]. 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 10 km around village points from DHS-IPUMS using the entropyetc package [38] in Stata 17.0 (Statacorp, 2016, College Station, TX, USA). Buffer zones are used to explore the importance of crop diversity at scales beyond the household so as to account for contextual determinants of child health.

We use the following formula to calculate Simpson's Diversity Index (SDI) [39]:

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

where D is SDI, n is the number of individuals of each species, and P_i is the proportion of species i relative to the total number of species.

Many approaches have been used to measure household socioeconomic status. Pongou et al. [28] consider the relationship between food insecurity, dietary diversity, and stunting. They assess specific assets as indicators of economic status: radio, electricity, television, and cars. On the other hand, Sahn and Alderman [29] 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.

To assess the impact that wealth has on the relationship between crop diversity and dietary diversity, we utilize the Integrated Public Use Microdata Series (IPUMS) DHS variable Wealth Quintile (WEALTHQHH). 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. The principal components analysis places households on a continuous scale of relative wealth. This variable separates DHS households within each survey wave (country–year) into wealth quintiles, with 1 coded as the poorest 20% and 5 as 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[1]; hence, WEALTHQHH is not a measure of absolute wealth but rather a measure of relative wealth within a given country at a given time.

The markets are highly varied across the 10 sub-Saharan African countries included in this study. Generally, most smallholder farmers are not integrated into commercial markets due to a lack of information, high transportation costs, and limited assets [40]. 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 [17,40]. Furthermore, markets may allow households to specialize in profitable crops, and therefore, these farmers can earn more to purchase more diverse and sufficient diets [16,17,23,27].

Analysis

The associations between crop diversity and dietary diversity in the study countries (but lacking a wealth variable) are reported in Isbell et al. [25]. 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 following form [41]:

$$Y_{ihjt} = B_0 + B_1 D_{hjt} + B_2 W_{hjt} + e_{ihjt}$$

where Y_{ihjt} is the HDDS (on a scale of 1–7) of a country i at time t, D_{hj} is the crop diversity of a household h as proxied via SDI, W_{hj} is the wealth quintile, j is a vector of household characteristics, and e_{ihjt} is a residual error term.

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.

3. Results

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 1 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 ($p < 0.05$) negative association between SDI at 10 km and HDDS, and further that the richest wealth group has the greatest negative association. Furthermore, we find that after accounting for income, there are different patterns regarding the association between SDI and HDDS across the poorest, poorer, and middle-wealth groups. We also find that the education of the mother is consistently a significant predictor of the dietary diversity of a household across wealth groups.

Building off the OLS regression, as seen in Figure 1, we graph the association coefficients. As seen in Figure 2, we find that there is not a significant association between 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 varies 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.

Table 1. OLS regression of HDDS_7 and Simpson's Diversity Index at different wealth quintiles, including all 10 countries of study.

Variable	(1) Poorest HDDS	(2) Poorer HDDS	(3) Middle HDDS	(4) Richer HDDS	(5) Richest HDDS
Simpson's Diversity	0.078	0.248	−0.156	−0.414	−1.093 ***
	(0.231)	(0.231)	(0.219)	(0.260)	(0.288)
Sex of child = female	0.051	0.040	−0.118 ***	0.072	0.071
	(0.033)	(0.032)	(0.032)	(0.039)	(0.047)
Female head of household	−0.065	−0.208 ***	−0.020	−0.200 ***	−0.092
	(0.047)	(0.050)	(0.043)	(0.050)	(0.059)
Age of child	0.007 ***	0.014 ***	0.004 *	0.005 **	0.012 ***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Education of mother	0.325 ***	0.376 ***	0.352 ***	0.341 ***	0.491 ***
Remoteness (ref = Q1)	(0.047)	(0.045)	(0.046)	(0.057)	(0.058)
Q2	0.105	−0.383 ***	0.066	−0.042	−0.027
	(0.107)	(0.085)	(0.073)	(0.068)	(0.069)
Q3	0.051	−0.170 *	0.116	0.024	−0.410 ***
	(0.109)	(0.084)	(0.074)	(0.075)	(0.084)
Q4	0.153	−0.216 *	−0.114	0.089	−0.266 **
	(0.109)	(0.087)	(0.076)	(0.075)	(0.084)
Q5	0.067	−0.393 ***	−0.118	0.017	−0.444 ***
	(0.111)	(0.090)	(0.081)	(0.083)	(0.092)
Cropland, 10 km radius	−0.081	−0.216	−0.277 *	0.006	−0.109
	(0.155)	(0.147)	(0.141)	(0.173)	(0.232)
Pastureland, 10 km radius	−0.284 *	−0.250 *	−0.318 *	−0.144	0.591 *
	(0.117)	(0.125)	(0.136)	(0.152)	(0.237)
Annual Precipitation Δ	0.016 ***	0.007 ***	0.001	0.009 ***	0.004
	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Constant	1.515 ***	2.679 ***	4.596 ***	3.218 ***	4.642 ***
	(0.373)	(0.348)	(0.241)	(0.384)	(0.393)
Observations	7208	7283	7751	6504	5866
R-squared	0.244	0.266	0.298	0.245	0.196

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$; and Q1–Q5 indicate the remoteness of a household.

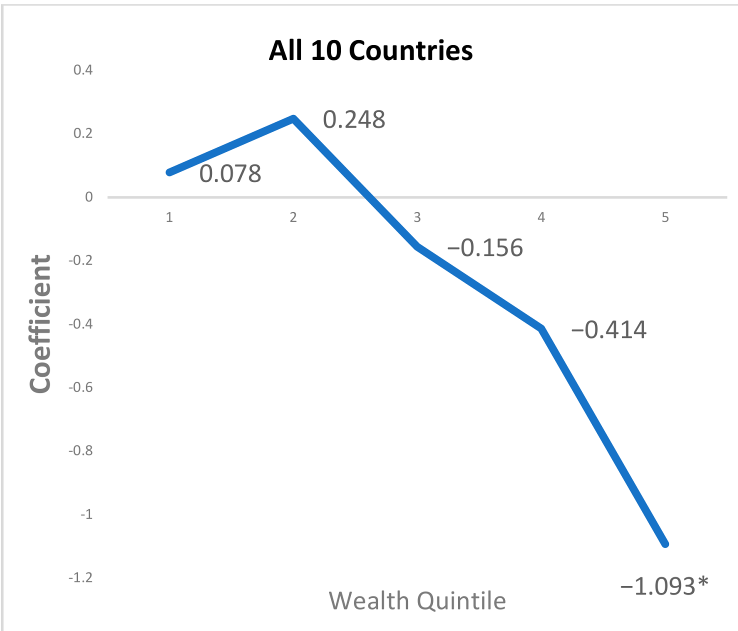

Figure 2. OLS regression coefficients of HDDS_7 and SDI at different wealth quintiles, including all 10 countries of study. * $p < 0.01$.

Next, we conduct OLS regressions in each country separately to understand the relationship between crop diversity and dietary diversity across wealth quintiles. The regressions seen in Figure 3 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 vary across wealth quintiles within all countries. While patterns vary across countries, we find the association to be significant and negative ($p < 0.05$) 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.

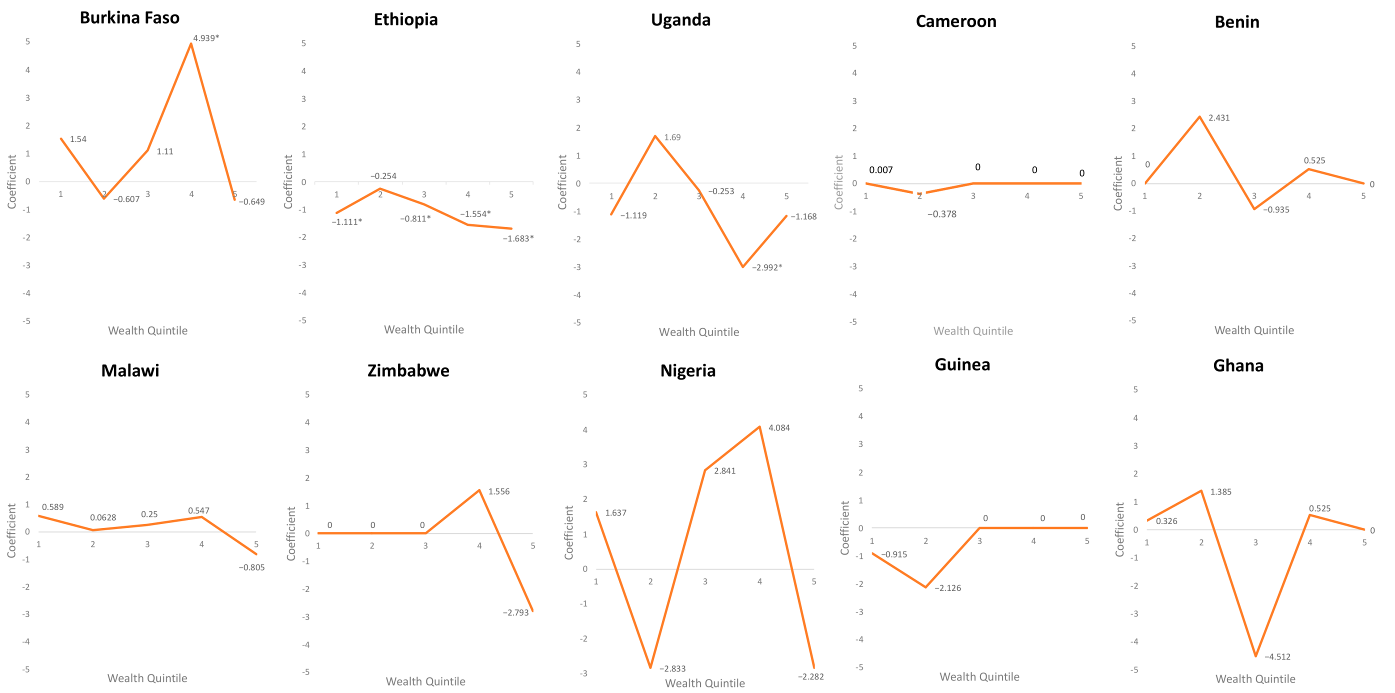

Figure 3. OLS regression of HDDS_7 and Simpson's Diversity Index at different wealth quintiles in each country. * $p < 0.10$.

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 households that 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 that are higher-income monoculture farmers, as well as potentially households that 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.

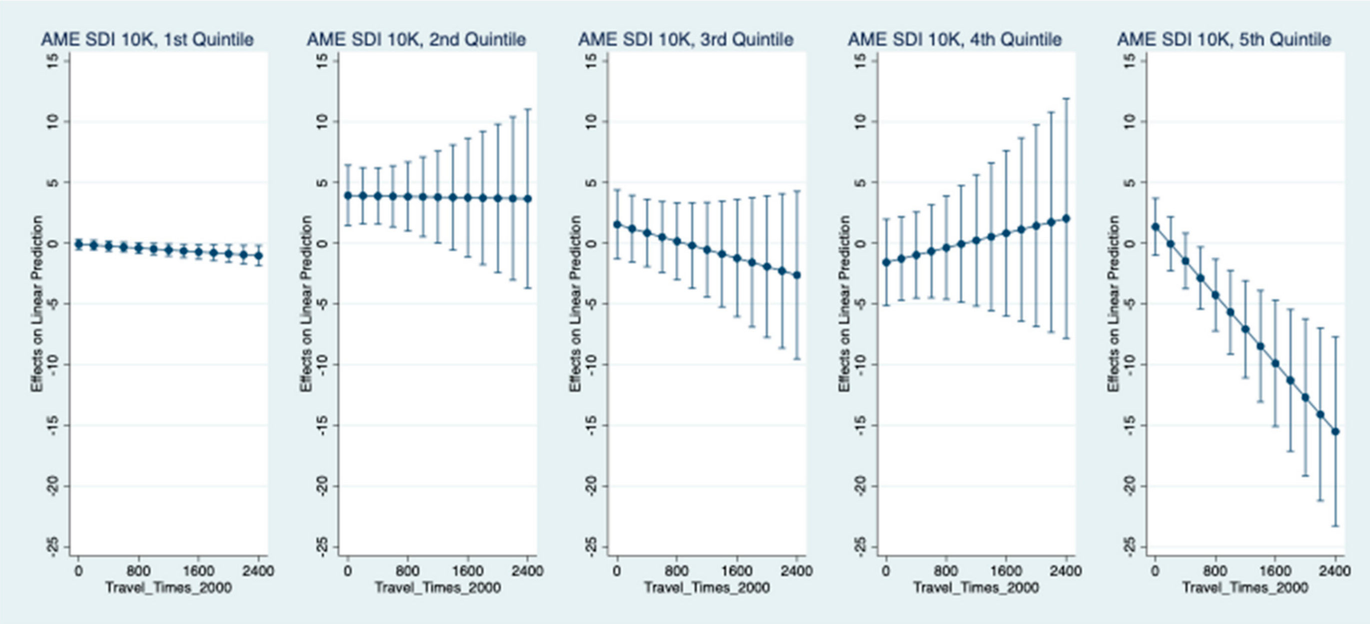

Figure 4. Marginal effect of SDI on HDDS at 10 km based on wealth quintile and distance to market.

4. 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 the previous literature [16,17,23–25], 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 [17]. Based on the literature, we hypothesized that household wealth would influence the significance that crop diversity has on dietary diversity [16,21,27]. 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 with 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 [24,42], which 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. Indeed, our findings are also consistent with those of Isbell et al. [25], 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 [27]. In the poorest wealth group, families are thought to be entirely reliant on their production and face barriers to accessing markets and diverse seeds, which may explain why there is a stronger relationship between SDI and HDDS in poorer households [23]. 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 [17].

Although these results contrast with the findings of Tobin et al. [24], who found that crop diversity has a more positive relationship with the dietary diversity of people in more rural areas, Jones [16] finds that distance to markets does not impact this relationship. Our findings are consistent with those of Bellon et al. [23], 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 [21–23,25].

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 were collected from 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 the 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 the mother is included in 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, a drawback of this study is the fact that we cannot control factors such as political events, war conflicts, or the economic climate. Future research may consider intra-country analyses of these data with these factors included. We acknowledge that while this research focuses on smallholders in sub-Saharan Africa, these issues also pertain to smallholders in Asia and South America. We recommend that future studies consider the relationships between agrobiodiversity and food security in other parts of the world.

We also acknowledge the possible biases within demographic and health surveys that may be present within the DHS program implemented by USAID. For example, Weber et al. [43] 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 [43].

In pursuit of the Sustainable Development Goal to eradicate hunger by 2030, encompassing targets 2.1 (access to nutritious foods) and 2.5 (maintain genetic diversity in food production), research must continue to assess the relationships between agrobiodiversity and food security [44]. Our research provides an important basis for future studies and for policy interventions 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.

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References

1. FAO. The State of Food Security and Nutrition in the World 2021: The World Is at a Critical Juncture. 2020. Available online: https://www.fao.org/state-of-food-security-nutrition (accessed on 24 June 2021).
2. FAO. Africa—Regional Overview of Food Security and Nutrition 2021. Statistics and Trends | Policy Support and Governance | Food and Agriculture Organization of the United Nations. 2021. Available online: https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1470145/ (accessed on 13 July 2022).
3. Cherono, J.; Siren, J.J. Analysis of Coping Strategies Adopted by Smallscale Farmers due to Climate Change Hazardsin Baringo County, Kenya. *Res. Biotechnol. Environ. Sci.* **2023**, *2*, 47–54. [CrossRef]
4. FAO; IFAD; UNICEF; WFP; WHO. *The State of Food Security and Nutrition in the World 2019: Safeguarding against Economic Slowdowns and Downturns*; FAO: Rome, Italy, 2019.
5. UNICEF. (n.d.). Reduce Stunting. UNICEF Eastern and Southern Africa. Available online: https://www.unicef.org/esa/reduce-stunting (accessed on 15 July 2022).
6. OECD/FAO. Agriculture in Sub-Saharan Africa: Prospects and challenges for the next decade. In *OECD-FAO Agricultural Outlook*; OECD Publishing: Paris, France, 2016; pp. 2016–2025.
7. Thiede, B.C.; Strube, J. Climate variability and child nutrition: Findings from sub-Saharan Africa. *Glob. Environ. Chang.* **2020**, *65*, 102192. [CrossRef] [PubMed]
8. Lenné, J.M.; Wood, D. *Agrobiodiversity Management for Food Security: A Critical Review*; CABI: Wallingford, UK, 2011.
9. Furman, B.; Noorani, A.; Mba, C. On-Farm Crop Diversity for Advancing Food Security and Nutrition. In *Landraces—Traditional Variety and Natural Breed*; IntechOpen: London, UK, 2021. [CrossRef]
10. Grace, K.; Davenport, F.; Funk, C.; Lerner, A.M. Child malnutrition and climate in Sub-Saharan Africa: An analysis of recent trends in Kenya. *Appl. Geogr.* **2012**, *35*, 405–413. [CrossRef]
11. Brush, S.B. *The Issues of In Situ Conservation of Crop Genetic Resources. Genes in the Field: On-Farm Conservation of Crop Diversity, Natural Resources, 3–26*; International Plant Genetics Resources Institute: Rome, Italy, 2000.
12. Frison, E.A.; Cherfas, J.; Hodgkin, T. Agricultural Biodiversity Is Essential for a Sustainable Improvement in Food and Nutrition Security. *Sustainability* **2011**, *3*, 238–253. [CrossRef]
13. Grace, K.; Brown, M.; McNally, A. Examining the link between food prices and food insecurity: A multi-level analysis of maize price and birthweight in Kenya. *Food Policy* **2014**, *46*, 56–65. [CrossRef]
14. Kahane, R.; Hodgkin, T.; Jaenicke, H.; Hoogendoorn, C.; Hermann, M.; Keatinge, J.D.H.; D'arros Hughes, J.; Padulosi, S.; Looney, N. Agrobiodiversity for food security, health and income. *Agron. Sustain. Dev.* **2013**, *33*, 671–693. [CrossRef]
15. Steyn, N.; Nel, J.; Nantel, G.; Kennedy, G.; Labadarios, D. Food variety and dietary diversity scores in children: Are they good indicators of dietary adequacy? *Public Health Nutr.* **2006**, *9*, 644–650. [CrossRef] [PubMed]
16. Jones, A.D. Critical review of the emerging research evidence on agricultural biodiversity, diet diversity, and nutritional status in low- and middle-income countries. *Nutr. Rev.* **2017**, *75*, 769–782. [CrossRef]
17. Sibhatu, K.T.; Qaim, M. Review: Meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households. *Food Policy* **2018**, *77*, 1–18. [CrossRef]
18. Bakhtsiyarava, M.; Grace, K. Agricultural production diversity and child nutrition in Ethiopia. *Food Secur.* **2021**, *13*, 1407–1422. [CrossRef]
19. Arimond, M.; Ruel, M.T. Dietary Diversity Is Associated with Child Nutritional Status: Evidence from 11 Demographic and Health Surveys. *J. Nutr.* **2004**, *134*, 2579–2585. [CrossRef] [PubMed]
20. Mekonnen, D.A.; Talsma, E.F.; Trijsburg, L.; Linderhof, V.; Achterbosch, T.; Nijhuis, A.; Ruben, R.; Brouwer, I.D. Can household dietary diversity inform about nutrient adequacy? Lessons from a food systems analysis in Ethiopia. *Food Secur.* **2020**, *12*, 1367–1383. [CrossRef]
21. Sibhatu, K.T.; Krishna, V.V.; Qaim, M. Production diversity and dietary diversity in smallholder farm households. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 10657–10662. [CrossRef] [PubMed]
22. Islam, A.H.M.S.; von Braun, J.; Thorne-Lyman, A.L.; Ahmed, A.U. Farm diversification and food and nutrition security in Bangladesh: Empirical evidence from nationally representative household panel data. *Food Secur.* **2018**, *10*, 701–720. [CrossRef]
23. Bellon, M.; Ntandou-Bouzitou, G.; Caracciolo, F. On-Farm Diversity and Market Participation Are Positively Associated with Dietary Diversity of Rural Mothers in Southern Benin, West Africa. *PLoS ONE* **2016**, *11*, e0162535. [CrossRef] [PubMed]
24. Tobin, D.; Jones, K.; Thiede, B.C. Does crop diversity at the village level influence child nutrition security? Evidence from 11 sub-Saharan African countries. *Popul. Environ.* **2019**, *41*, 74–97. [CrossRef]
25. Isbell, C.; Tobin, D.; Thiede, B.C.; Jones, K.; Reynolds, T. Beyond the Household: The Association between Crop Diversification and Children's Dietary Diversity at Village and Regional Levels. *Food Secur.* **2024**. *under review*.
26. Frongillo, E.A.; de Onis, M.; Hanson, K.M. Socioeconomic and Demographic Factors Are Associated with Worldwide Patterns of Stunting and Wasting of Children. *J. Nutr.* **1997**, *127*, 2302–2309. [CrossRef]
27. Koppmair, S.; Kassie, M.; Qaim, M. Farm production, market access and dietary diversity in Malawi. *Public Health Nutr.* **2017**, *20*, 325–335. [CrossRef]
28. Pongou, R.; Ezzati, M.; Salomon, A.J. Household and community socioeconomic and environmental determinants of child nutritional status in Cameroon. *BMC Public Health* **2006**, *6*, 98. [CrossRef]
29. Sahn, D.E.; Alderman, H. *Nutritional Status and Poverty in Sub-Saharan Africa. Africa Region Findings & Good Practice Infobriefs*; No. 108; World Bank: Washington, DC, USA, 1998; Available online: http://hdl.handle.net/10986/9899 (accessed on 1 July 2021).

30. Rah, J.H.; Sukotjo, S.; Badgaiyan, N.; Cronin, A.A.; Torlesse, H. Improved sanitation is associated with reduced child stunting amongst Indonesian children under 3 years of age. *Matern. Child Nutr.* **2020**, *16*, e12741. [CrossRef] [PubMed]
31. Berhane, H.Y.; Jirström, M.; Abdelmenan, S.; Berhane, Y.; Alsanius, B.; Trenholm, J.; Ekström, E.-C. Social Stratification, Diet Diversity and Malnutrition among Preschoolers: A Survey of Addis Ababa, Ethiopia. *Nutrients* **2020**, *12*, 712. [CrossRef] [PubMed]
32. Codjoe, S.N.A.; Okutu, D.; Abu, M. Urban Household Characteristics and Dietary Diversity: An Analysis of Food Security in Accra, Ghana. *Food Nutr. Bull.* **2016**, *37*, 202–218. [CrossRef] [PubMed]
33. Boyle, E.H.; King, M.; Sobek, M. IPUMS-Demographic and Health Surveys: Version 9 [Dataset]. Minnesota Population Center and ICF International. 2022. Available online: https://www.idhsdata.org/idhs/ (accessed on 24 June 2021).
34. Monfreda, C.; Ramankutty, N.; Foley, J.A. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Glob. Biogeochem. Cycles* **2008**, *22*, 12–15. [CrossRef]
35. Boyle, E.H.; King, M.; Sobek, M. IPUMS-Demographic and Health Surveys: Version 7 [Dataset]. Minnesota Population 478. Center and ICF International. 2019. Available online: https://www.ipums.org/projects/ipums-global-health/d080.v7 (accessed on 1 July 2021).
36. Remans, R.; Flynn, D.F.B.; DeClerck, F.; Diru, W.; Fanzo, J.; Gaynor, K.; Lambrecht, I.; Mudiope, J.; Mutuo, P.K.; Nkhoma, P.; et al. Assessing Nutritional Diversity of Cropping Systems in African Villages. *PLoS ONE* **2011**, *6*, e21235. [CrossRef] [PubMed]
37. Muthini, D.; Nzuma, J.; Nyikal, R. Farm production diversity and its association with dietary diversity in Kenya. *Food Secur.* **2020**, *12*, 1107–1120. [CrossRef]
38. Cox, N. ENTROPYETC: Stata module for entropy and related measures for categories. version 11.2. In *Statistical Software Components*; Boston College Department of Economics: Boston, MA, USA, 2021; Available online: https://econpapers.repec.org/software/bocbocode/S458272.htm (accessed on 14 January 2024).
39. Morris, E.K.; Caruso, T.; Buscot, F.; Fischer, M.; Hancock, C.; Maier, T.S.; Meiners, T.; Müller, C.; Obermaier, E.; Prati, D.; et al. Choosing and using diversity indices: Insights for ecological applications from the German Biodiversity Exploratories. *Ecol. Evol.* **2014**, *4*, 3514–3524. [CrossRef]
40. Otekunrin, O.; Momoh, S.; Idris, A. Smallholder Farmers' Market Participation: Concepts and Methodological Approach from Sub-Saharan Africa. *Curr. Agric. Res. J.* **2019**, *7*, 139. Available online: https://www.agriculturejournal.org/volume7number2/smallholder-farmers-market-participation-concepts-and-methodological-approach-from-sub-saharan-africa/ (accessed on 25 August 2019). [CrossRef]
41. Pohlman, J.T.; Leitner, D.W. A Comparison of Ordinary Least Squares and Logistic Regression. *Ohio J. Sci.* **2003**, *103*, 118–125.
42. Ekesa, B.; Walingo, M.; Abukutsa-Onyango, M. Influence of agricultural biodiversity on dietary diversity of preschool children in Matungu division, western Kenya. *Afr. J. Food Agric. Nutr. Dev.* **2008**, *8*, 390–404. [CrossRef]
43. Weber, A.M.; Gupta, R.; Abdalla, S.; Cislaghi, B.; Meausoone, V.; Darmstadt, G.L. Gender-related data missingness, imbalance and bias in global health surveys. *BMJ Glob. Health* **2021**, *6*, e007405. [CrossRef]
44. The United Nations. Goal 2: Zero Hunger. The Global Goals. 2012. Available online: https://www.globalgoals.org/goals/2-zero-hunger/ (accessed on 24 June 2021).