THE INTERPLAY BETWEEN FARM PRODUCTION DIVERSITY AND FOOD MARKET VISITS IN SHAPING SMALLHOLDER HOUSEHOLD DIETS IN ETHIOPIA

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Abstract

Apart from the mixed results on the relative influence of farm production diversity and market access in previous literature, the effort to empirically investigate their joint interplay in shaping household dietary diversity was scant. This research aims to address this gap based on cross-sectional data from 396 smallholder households selected using a stratified sampling technique from rural Tigray in Northern Ethiopia. In the analysis, the graphical interpretation of the relationship between farm production diversity and market access is integrated with the econometrics results of the Poisson estimation models. We introduce a novel measure of market access, households' frequency of food market visits, rigorously tested for its stability, and compared against alternative measures. Our findings reveal that there is a joint positive and significant nonlinear relationship between farm production diversity and households' frequency of food market visits, highlighting an optimal point of combination for a maximum attainable household diet. Moreover, the finding shows that independently, farm production diversity has a positive and significant nonlinear contribution to rural household dietary diversity with three possible stages of returns, positive, diminishing, and negative. Frequency food market visits also has a positive and significant nonlinear influence, with two possible stages of returns, positive and diminishing. The finding also indicates that frequency of food market visits not only complements but also enhances farm production diversity. Farm production diversity is found to be significantly higher in households closer to markets than those in areas which are more remote from markets. Fresh food market visits correlated with household dietary diversity, and the composition of diets on market days is more diverse than on non-market days. Household remoteness exhibits close to a similar negative influence on farm production diversity, households' frequency of food market visits, and rural household dietary diversity.

Contents

1. INTRODUCTION

This research is prompted by the alarming global issue of hunger, with reports in 2021 revealing that approximately 702 to 828 million people worldwide were affected by this crisis (FAO, IFAD, UNICEF, WFP, and WHO 2022). Despite the persistence of global undernourishment, particularly in African subregions, there is a lack of detailed information regarding Ethiopia. Nevertheless, recent data by Bezu (2018) highlighted that 33 million people in Ethiopia were already grappling with undernourishment. The prevailing conditions in Sub-Saharan Africa, particularly in Ethiopian rural smallholder households, contribute to low daily energy consumption, poor nutritional quality, and monotonous diets (Dorosh and Minten 2020).

Many studies have explored strategies to understand and address challenges related to smallholder household diets. Agriculture and market channels are recognized as pivotal entry points for comprehending these challenges (Sibhatu and Qaim 2018). The relative impacts of farm production and market access on dietary diversity have been explored in existing research, yielding conflicting results (Nandi and Ravula 2021). While some studies found greater influence on farm production diversity (Jones 2017; Kumar et al. 2015; Muthini et al. 2020; Romeo et al. 2016; Tesfaye and Tirivayi 2020), others indicated that market access has greater influence on dietary diversity (Bellon et al. 2020; Bonuedi et al. 2022; Kihiu and Amuakwa-Mensah 2021; Koppmair et al. 2017; Sibhatu and Qaim 2017); Usman and Haile 2022). However, empirical studies on the joint interplay between farm production diversity and market access in shaping household dietary diversity are scant. This paper, therefore, addresses the gap in the literature by examining the joint interplay between farm production diversity and market access in shaping household dietary diversity. Notably, only Zanello et al. (2019) in Afghanistan and Morrissey et al. (2023) in Uganda examined the interplay between farm production diversity and market access on smallholders' dietary diversity using panel data.

In addressing the identified gap, this study aims to capture the discrete impacts and joint interplay between farm production diversity and market access in defining rural smallholder household diets.

An innovative contribution of this study is the introduction of a novel metric for measuring market access. Traditional measures, such as distance to markets, cost of transportation, and so on have been criticized for their limitations in capturing farmers' access to market (Chamberlin and Jayne 2013) and the quality of markets and their impact on nutrition (Headey et al. 2019). The newly introduced metric aims to integrate both endogenous and exogenous factors influencing households' decisions to participate in markets, offering a more comprehensive understanding of smallholders' access to the market.

The research is conducted in Tigray, Ethiopia, focusing on smallholder households engaged in staple crops, livestock, and vegetable/fruit production. The alternative metric of market access, namely households' frequency of food market visits, is introduced and compared with traditional measures. The study hypothesizes a significant positive contribution of both farm production diversity and frequency of food market visits to household dietary diversity.

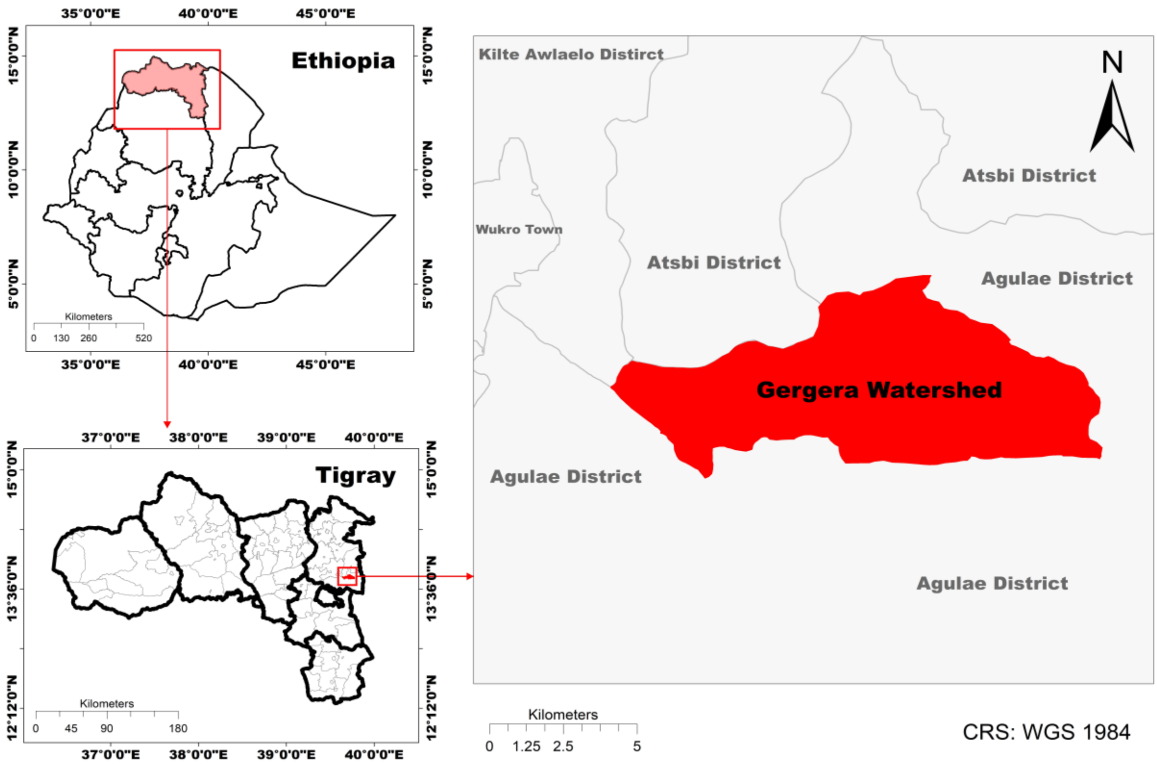
The subsequent sections contain the materials and methods, presenting the study area, data collection techniques, and analysis methods. Descriptive statistics and econometric findings will follow, leading to conclusions.

2. MATERIALS AND METHODS

The study was conducted in the Geregera watershed, located in the rural administrative area of Hayelom, Tigray, northern Ethiopia. The watershed encompasses 2,302 hectares and resides in a semi-arid climate with an annual rainfall regime of 450mm to 600mm. Positioned at an altitude of 2,066 to 2,505 meters above sea level, the area is classified as both highlands (dega) and midland (woyna dega). The terrain is characterized by undulating topography with predominantly silt-loam and loam soils (Woldewahid et al. 2012).

The farming practices in the Gergera watershed involve mixed crop and livestock cultivation, featuring cereals like barley, wheat, teff, maize, and sorghum, as well as pulses such as beans, peas, and lentils (Deribe 2008). Additionally, irrigation activities are observed in lower valley areas, cultivating vegetables and fruits (Woldewahid et al. 2011). Livestock production includes cattle, sheep, goats, donkeys, horses, and chickens, with designated areas for fodder grass collection and beekeeping (Gessesse 2016).

Figure 1: Map of the study area



Data for the study were collected through a cross-sectional survey of 396 rural smallholder households across four sub-districts in the Gergera watershed. Using stratified random sampling and systematic techniques, households were selected in proportion to population size. The survey questionnaire covered demographic and socioeconomic characteristics, household food consumption, farm production diversity, and market interaction. The data collection period spanned September to October 2020, capturing detailed information on crop and livestock production from September 2019 to August 2020. The study aims to provide insights into the interplay between farm production diversity and market access in shaping the dietary diversity of rural smallholder households in this specific geographic context.

Measurement of Key Variables

Measuring Household Dietary Diversity

The paper employed the Household Dietary Diversity Score (HDDS) as a metric to assess the diversity of access to household food. Following guidelines from (Swindale and Bilinsky 2006; FAO 2011) this study is based on household consumption data of a 24-hour recall period. The food items consumed by the household were categorized into 12 groups based on their nutritional contribution (Sibhatu and Qaim 2018; Admasu et al. 2011). These groups encompassed cereals, white tubers and roots, vegetables, fruits, meat, eggs, fish and other seafood, legumes, nuts, and seeds, milk and milk products, oils and fats, sweets and honey, and spices, condiments, and beverages.

Households were approached to identify the food items they consumed from the 12 food groups within the past 24 hours. The value ‘1’ is recorded for each consumed item and '0' otherwise. The sum of these values yielded the total HDDS for a household, ranging from zero (if no food was consumed) to twelve (if items were consumed from all 12 groups). The HDDS methodology considered repeated consumption of a specific food item within 24 hours as a single point, irrespective of quantity, frequency, or the number of consumers. Notably, food consumed outside the home was excluded from the HDDS calculation, ensuring a focus on household dietary patterns. The computation of HDDS involves a straightforward tallying process, reflecting the diversity of food groups consumed within the specified timeframe.

$$HDDS_i = \sum_1^{12} FG\ consumed\ by\ the\ HH_i\ in\ 24\ hrs \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Measuring Production Diversity (PDS)

Smallholder households’ farm production diversity in this study was measured using the Production Diversity Score (PDS). The calculation of the production diversity score (PDS) is based on the classification of the crops and livestock produced during the agricultural year (from September 2019 to August 2020) by the household into the 12 food groups. The classification of the PDS into the 12 food groups is consistent with that of the HDDS (Chegere and Stage 2020; Koppmair et al. 2017; Sibhatu and Qaim 2018).

However, the PDS has limitations, particularly regarding the potential multiple counting of certain food groups, mainly related to animal products. For instance, a household keeping chickens might record a PDS value of two, accounting for both meat and eggs. Similarly, a cow could contribute to three food groups: meat, milk, and butter/oil. While acknowledging the possible overestimation due to such multiple counting, the paper prefers to align with the established methodology.

Measuring Households' Access* to *Market

Previous literature has employed proxy measures, such as distance to the market, distance to roads or other public infrastructures, cost of transportation to the market, and so on, to assess market access (Hoddinott et al. 2015; Jones et al. 2014; Sibhatu et al. 2015; Koppmair et al. 2017; Muthini et al. 2020; Zanello et al. 2020). However, those proxy measures of market access have been criticized for their weakness in explaining the influence of markets in shaping diets and nutrition (Bonuedi et al. 2022; Chamberlin and Jayne 2013; Headey et al. 2019; Matita et al. 2021; Nandi and Ravula 2021). These proxy measures of market access are mostly exogenous (Usman and Haile, 2022), neglecting the households' social, economic, cultural, and other factors that can influence a decision to engage in market transactions. Heady et al. (2019) for instance has criticized those measures and employed a combination of the market diversity, the numbers of traders selling foods, and other variables instead of the traditional market access measures. Those measures have, however, focused on the quality of the market and gives little attention to the household ability to take advantage of the existing market. This paper, therefore, introduces a novel metric of market access which is based on household decisions that implicitly integrates the internal and external factors influencing their market engagement.

The new measure of market access is, therefore, *the households' frequency of food market visits in 30 days with the aim to purchase food items or* in short, the Frequency of food Market Visits (FMV). The frequency of food market visits (FMV) is a comprehensive measure of smallholder farmers' access to the market, reflecting not only the physical proximity to the market but also nuanced dimensions of households' preferences, willingness, and ability to participate in market transactions. As a continuation of this new measure, we also use the length of days households abstain from food markets since their last visit, as a second alternative measure of market access. Examination of the length of absence from the food markets facilitates the evaluation of how households' level of dietary diversity is impacted if they refrain from purchasing foods for an extended period. Our new measure of market access is preferred to the previous approaches because (i) it considers market access as an outcome of households' decision to transact in a market, (ii) the decision made is related to food purchases which has a direct influence on the households' dietary diversity, (iii) it is flexible in response to various factors (including seasonal, social, economic, cultural, and political factors) affecting households decision to engage in market transactions in a specific period.

We collected data on households' frequency of food market visits in 30 days, a period that can be well remembered by the household. This period is not typical of the year. We have selected 30 days to give space for a range of variations among household market engagements. To compare the results and check the robustness of the frequency of food market visits (FMV), we included two alternative metrics of market access in this paper. The first is, the households' proximity to the food markets (PM), measured in walking minutes, an established metric of market access (Koppmair et al. 2017). We also add a second approach, the length of absence from food markets (AM) which refers to the number of days elapsed since the household's last food market visit which, to our knowledge has not been in the literature before.

Econometric Analysis

Poisson Regression Equation

The Poisson regression equation is based on the count outcomes of the number of food groups consumed by households at a fixed interval of time, such as in 24 hours. The count outcomes of food group consumption by households are assumed to have the characteristics of a Poisson probability distribution function. This distribution function is revealed by the occurrence of non-negative discrete outcomes at a fixed interval of time, where each event is independent of one another. The Poisson regression equation is used to model the probability that a household consumes a fixed number of food groups in 24 hours, given their household and socioeconomic characteristics. Mathematically, the Poisson regression equation takes the form:

$$HDDS_i = \beta_0 + \beta_1 PDS_i + \beta_2 FMV_i + \beta_2 AM_i + \beta_4 PM_i + \beta_5 SE_i + \varepsilon_i \quad \text{.................} (2)$$

In the regression models, the dependent variable $HDDS_i$ represents the household i's extent of dietary diversity in the 24 hours. The key explanatory variables are the farm production diversity score PDS_i and market access. Market access is alternatively explained by the household i's frequency of food market visits, FMV_i. Length of absence from the market (length of days since last food market visit) AM_i and household i's Proximity to the market centre PM_i. We hypothesise that both PDS_i and FMV_i have a positive association with HDDS, while AM_i and PM_i have negative correlations with $HDDS_{i.}$

SE_i- represents the vector of the socioeconomic characteristics of the household which includes age of the head, sex of the head, family size, level of education, and marital status of the head, owned rainfed farmland holding size, irrigated land holding size, and household residential sub-district/ kushet/.

3. RESULTS AND DISCUSSIONS

Descriptive Statistics

This study aims to assess the interplay between farm production diversity and market access on household dietary diversity. The report is based on the primary data collected using a cross-sectional household survey in the Gergera watershed in eastern Tigray, northern Ethiopia. Stratified sampling was used to select participating households proportionate to sub-district populations that comprise 120 households from Damaino, 116 from Geter Haiki Mesihal, 84 from Degaabur, and 76 from Gergera. Male-headed households constitute 290, while female-headed households are 106, with a mean head age of 54 years old and an average family size of 5.11 members. The average household dietary diversity score (HDDS) in the study area was 5.86 food groups per day per household (Table 1). Male-headed households show slightly higher HDDS, 5.99 food groups, than female-headed households, 5.53 food groups, per week. The mean farm production diversity in the study area was 3.48 food groups production per annum.

Table 1: Summary statistics for selected socioeconomic characteristics

	HDDS	PDS	Freq. Market visits *(no. visits in 30 days)*	days of length of absence from market	Proximity to market *(In walking minutes)*	Age	Family size	Education	Rainfed Land size *(In Tsimad)*	Irrigated land size *(In Tsimad)*
GENDER										
Female: N	106	106	106	106	106	106	106	106	106	106
Mean	5.53	2.90	2.75	7.20	75.75	51.58	3.42	0.37	0.77	0.22
Male: N	290	290	290	290	290	290	290	290	290	290
Mean	5.99	3.70	3.13	6.26	71.8	54.96	5.73	1.54	1.33	0.32
MARITAL STATUS										
Divorced: N	46	46	46	46	46	46	46	46	46	46
Mean	5.50	2.96	2.98	7.02	62.93	50.07	2.87	0.37	0.74	0.2
Married: N	287	287	287	287	287	287	287	287	287	287
Mean	6.00	3.71	3.15	6.12	72.46	54.3	5.81	1.6	1.32	0.33
Single: N	2	2	2	2	2	2	2	2	2	2
Mean	6.50	2	1.50	9.00	120	25	3	0	0.5	0.12
Widowed: N	61	61	61	61	61	61	61	61	61	61
Mean	5.48	2.87	2.59	7.89	80.66	56.85	3.57	0.16	0.86	0.23
SUB-DISTRICTS										
Geter Haki Mesihal: N	116	116	116	116	116	116	116	116	116	116
Mean	6.06	3.69	3.63	4.77	27.17	56.49	5.26	1.66	1.23	0.3
Damaino N:	120	120	120	120	120	120	120	120	120	120
Mean	5.82	3.42	2.84	7.76	82.42	49.76	5.08	1.11	1.26	0.46
Gergera N:	76	76	76	76	76	76	76	76	76	76
Mean	6.03	3.82	3.84	3.77	42.37	57.92	5.24	1.49	1.03	0.35
Degaabur N	84	84	84	84	84	84	84	84	84	84
Mean	5.51	3	2.13	5.11	149.88	53.32	4.82	0.56	1.11	0.00
TOTAL: N	***396***	***396***	***396***	***396***	***396***	***396***	***396***	***396***	***396***	***396***
Mean	***5.86***	***3.48***	***3.03***	***6.49***	***72.86***	***54.05***	***5.11***	***1.23***	***1.18***	***0.3***

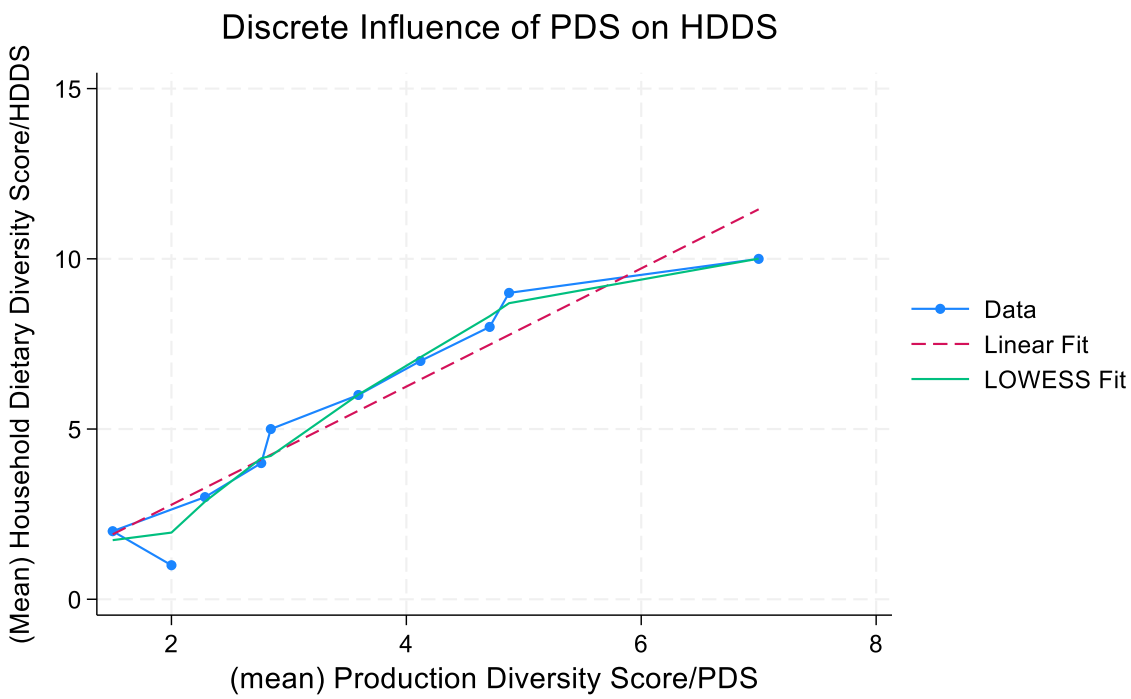
Source: *authors' own computation from survey data collected in Sep. – Oct. 2020.*

The statistics appear with notable gender-wise variation in farm production diversity, with male-headed households exhibiting a higher mean annual production diversity score (PDS) of 3.70 compared to 2.90 for female-headed households. The mean frequency of food market visits was 3.03 times per month and varies across genders with male-headed households made 3,13 times while their female-headed counterparts made 2.75 visits per month. The frequency of food market visits and households' absence from the market display inconsistent associations with households' proximity to the market. Damaino residents experience the longest days of absence from the market (7.77 days) despite their 3rd closest position to the market. Female-headed households generally exhibit longer days of absence (7.20 days) than male-headed households (6.26 days). Gender-wise comparisons indicate that male-headed households have higher averages in age, family size, education level, and rainfed and irrigated land-holding sizes.

Independent Relationship between Farm Production Diversity and Household Dietary Diversity

Figure 2 illustrates the relationship between mean Production Diversity Score (PDS) and household dietary diversity score (HDDS). The figure reveals three distinct stages of returns, a positive return in the early stages of farm diversification, followed by diminishing returns in the intermediate stages, and a potential for negative returns in later stages of farm diversification.

Figure 2: **Relationship between Farm Production Diversity and Household Dietary Diversity**



Source: *authors' own computation from survey data collected in Sep. – Oct. 2020.*

The linear and LOWESS fit confirm this pattern, showing an initial substantial increase in HDDS with additional food group production. However, beyond a certain point (approximately 5 PDS levels and beyond), the rate of increase in HDDS diminishes, indicating a nonlinear relationship. The figure also suggests an optimal point of HDDS from which further farm production diversification may result in diminishing marginal contributions, potentially leading to negative outcomes for HDDS.

Independent Relationship between Market Access and Household Dietary Diversity

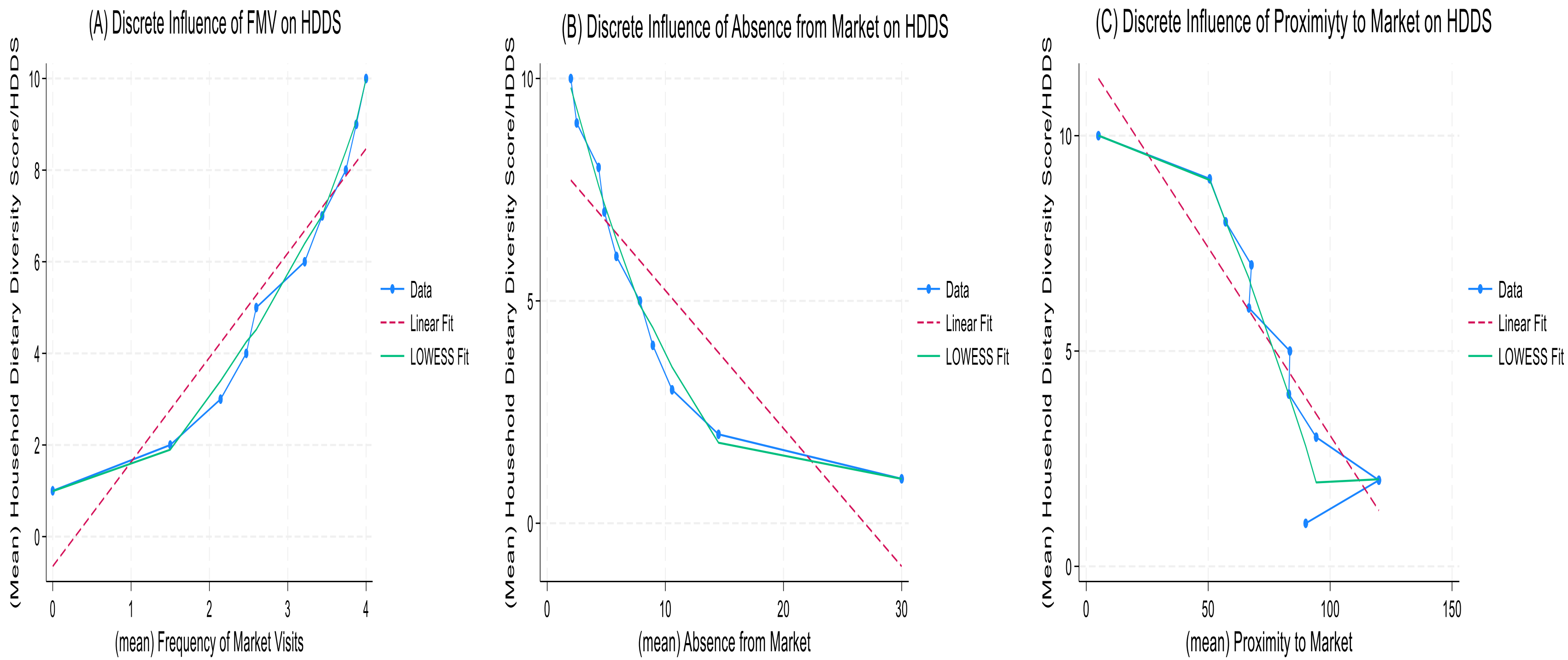
Figure 3 (A-C) presents three graphs exploring the independent influence of the three distinct market access measures on household dietary diversity. In Figure 3A, the relationship between the frequency of food market visits (FMV) and household dietary diversity score (HDDS) is depicted. The graph suggests a positive contribution of additional food market visits to household diet, with an initial slower rate of increase in HDDS that accelerates with more visits. This relationship is nonlinear, indicating an optimal point beyond which marginal food market visits offer minimal contributions to HDDS, yet unlike the PDS, do not result in negative returns.

Figure 3B presents the influence of households' absence from food markets on their dietary diversity. The graph reveals that longer days of absence leads to a lower level of dietary diversity. In other words, fresh market visits contribute to diverse diets, and households experience higher dietary diversity on market days compared to subsequent days. The graph suggests that longer days of absence from markets may not lead to zero or negative HDDS due to the possible existence of other food sources that fill the gap. Overall, the graph illustrates the importance of regular market attendance for maintaining higher HDDS in smallholder households.

Figure 3C depicts the impact of the proximity to the market (measured in walking minutes) on HDDS. This graph indicates that longer walking minutes deteriorate HDDS implying an inverse relationship. The graph shows that households in closer proximity, up to a certain distance, to the market enjoy higher dietary diversity, while the negative influence also diminishes beyond a certain distance.

Overall, the results from Figures 2 and 3(A-C) highlight that the market plays a crucial role in providing diverse foods for achieving maximum dietary diversity. While farm production diversity has a direct impact on dietary diversity up to a certain extent, market access contributes significantly, offering the potential for households to attain the highest achievable level of dietary diversity. The finding is in line with Sibhatu and Qaim (2018) suggesting that an excessive increasing on-farm production diversification may limit improvement in dietary diversity.

Graph 3: Discrete Relationship between Market Access and Household Dietary Diversity



Source: *authors' own computation from survey data collected in Sep. – Oct. 2020.*

Joint Interplay between Market Access and Farm Production Diversity

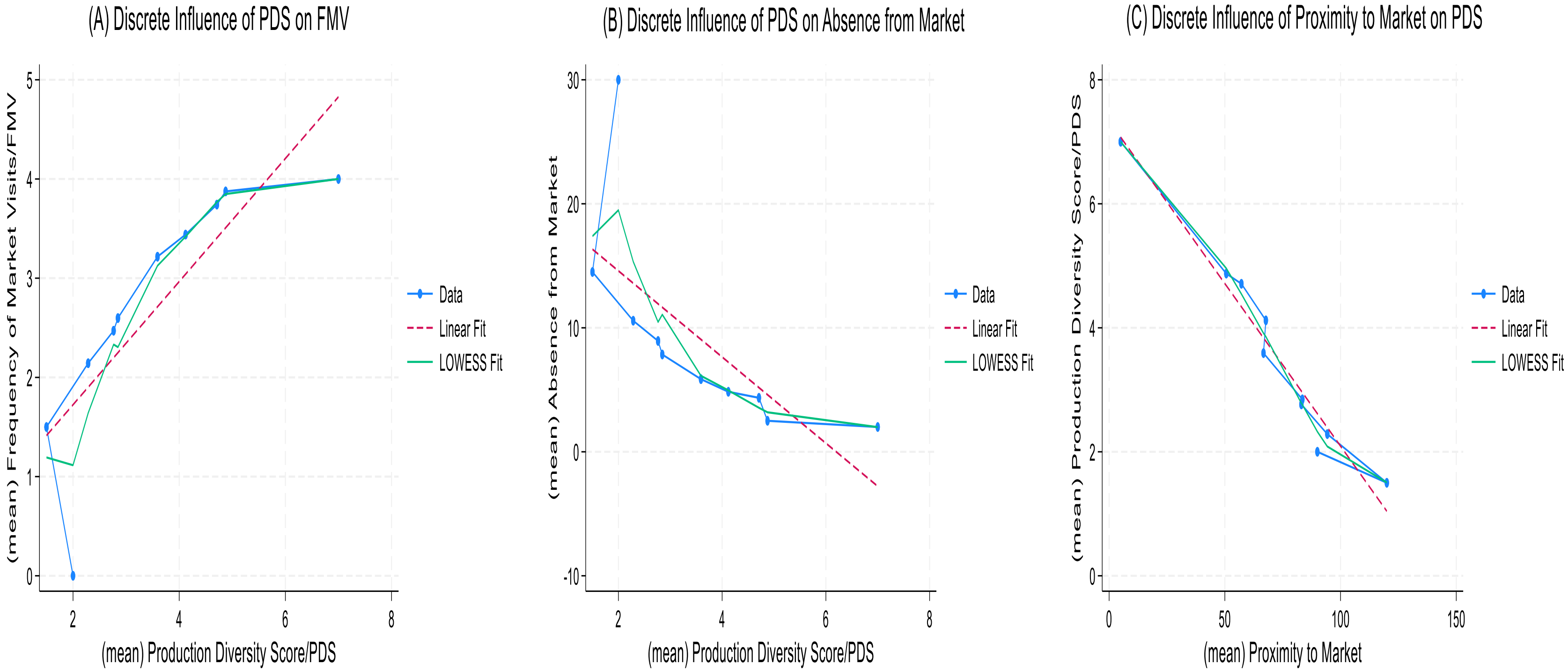
In Figure 4A-C, the joint interplay between farm production diversity (PDS) and market access measures is examined. Figure 4A illustrates that increased farm diversity encourages more food market visits, exhibiting a sharp initial increase followed by diminishing returns. Beyond an optimal PDS level, additional farm diversity contributes minimally to market visits, echoing the temporal aspect observed in the previous relationship between market visits and PDS.

Figure 4B presents an inverse relationship, indicating that longer days of absence from the market is associated with lower farm diversity. Households with better market attendance demonstrate greater farm production diversity. There exists an optimal PDS level, beyond which further diversity yields zero additional market attendance.

In Figure 4C, the association between households' proximity to markets and farm production diversity is revealed. Proximity to markets positively influences farm production diversity, with households closer to markets exhibiting higher diversity. This result is noteworthy, suggesting that market access not only complements but also encourages farm production diversification. Surprisingly, households in remote areas do not significantly compensate for limited market access by diversifying production for subsistence.

The overall findings emphasize the strong positive influence of market access on farm production diversity. Contrary to expectations, remote households do not compensate for poor market access by intensifying on-farm diversification. The joint relationship indicates that market access not only complements but also stimulates farm production diversification. Conversely, poor market access discourages both farm diversification and frequent food market visits or purchases. The results emphasize the intricate dynamics between market access, farm diversity, and dietary diversity, highlighting the pivotal role of markets in shaping food production and consumption patterns in rural smallholder households.

Graph 4: Relationship between Farm Production Diversity and Market Access



Source: *authors' own computation from survey data collected in Sep. – Oct. 2020.*

Econometrics Results

The study utilizes Poisson regression to assess the discrete and joint influence of farm production diversity and market access on smallholder household dietary diversity. Two sets of models are employed in Table 2; the first set of the models (Columns 1 to 4) evaluates the discrete influence of farm production diversity and the three market access measures on household dietary diversity. The second set of the models in Table 2 (Columns 5 to 10) estimates the joint influence of farm production diversity and the three market access measures on household dietary diversity. In Table 2 household dietary diversity score (HDDS) is explained independently and jointly by production diversity score (PDS) and the three market access measures (frequency of food market visits/FMV, Length of absence from market/AM, Proximity to market/PM). In Table 3, HDDS is explained as the mix of the PDS, the three market access measures, and the socioeconomic/SE factors. The results in Table 2 and Table 3 are presented in marginal effects of the coefficients at the mean, using Poisson regressions. The different regression models aim to understand how these variables, individually and jointly, influence HDDS.

Discrete influence

Farm Production Diversity**:** The findings reveal the positive influence of farm production diversity on household dietary diversity. This finding is supported by previous studies such as Kumar et al. (2015), Jones et al. (2014), and Tesfaye and Tirivayi (2020), highlighting the consistent positive effect of farm diversity on dietary quality. The discrete influence of PDS on HDDS is significantly positive (0.285), affirming that an additional farm production diversity by a food group increases dietary diversity by an average of 0.285 food groups.

Market Access Measures**:** Market access measures – frequency of food market visits/FMV, absence from food markets/AM, and proximity to market/PM indicate significant relationships. FMV exhibits a highly significant positive association (0.452) with HDDS, indicating that each additional food market visit increases dietary diversity by an average of 0.452 food groups. Conversely, both AM (-0.011) and PM (-0.004) show negative influences, suggesting that longer days of absence from food markets and longer walking distances to the market lead to lower dietary diversity.

Table 2: Poisson Regression

Household Dietary Diversity Score/ HDDS	Column (1)	Column (2)	Column (3)	Column (4)	Column (5)	Column (6)	Column (7)	Column (8)	Column (9)	Column (10)
Production Diversity Score/PDS	0.285***				0.205***	0.223***	0.271***			
	(0.037)				(0.038)	(0.038)	(0.037)			
Frequency of Market Visits		0.452***			0.338***					
		(0.058)			(0.059)					
Length of absence from market			-0.011**			-0.088***				
(In number of days)			(0.004)			(0.015)				
Proximity to Market				-0.004***			-0.003***			
(Walking minutes)				(0.001)			(0.001)			
Frequency of visits X PDS								0.070***		
(Interaction)								(0.007)		
Length of absence X PDS									-0.012**	
(Interaction)									(0.004)	
Proximity X PDS										0.000
(Interaction)										(0.000)
Observations	**396**	**396**	**396**	**396**	**396**	**396**	**396**	**396**	**396**	**396**

Table 2 presents the marginal effects after Poisson estimation. The dependent variable is the household dietary diversity score, based on the 12 food groups. The models were estimated using Poisson model. The coefficient estimates are shown in column (1) to (4), robust standard errors in brackets. ** p<0.05, ** p<0.01, *** p<0.001.*
Source: *authors' own computation from survey data collected in Sep. – Oct. 2020.*

Joint Influence: The joint interplay between farm production diversity and market access yields interesting insights. The combined effect of PDS (0.205) and FMV (0.333) is positive, emphasizing that frequent food market visits in farm-diversifying households enhance dietary diversity. Conversely, compared to the discrete influence, the joint interplay of PDS and AM exhibits a positive but lower magnitude of PDS (0.223) and a higher negative influence of longer absence from food markets (-0.088) on HDDS. This signifies that reduced market attendance not only diminishes food purchases but also discourages farm production diversity. Conversely, the joint interplay between PDS (0.271) and PM (-0.003) shows a downgrade in HDDS, reflecting the negative effect of households' remoteness from the market on farm production diversity and dietary diversity.

Interaction Effects: Further analysis on the joint interplay between PDS and market access involves evaluation of their interaction effects. The coordination between PDS and FMV reveals a positive influence (0.070), indicating that frequent food market visits in farm-diversifying households increases household dietary diversity. The interaction between PDS and AM is negative (-0.012), highlighting that low level of market attendance negatively affect rural household dietary diversity. The interaction between PDS and PM is insignificant, may be suggesting weaker predictive capability of proximity to the market.

Table 3: ***Marginal effects after Poisson estimation:***

The influence of farm production diversity, market access and other socioeconomic variables on household dietary diversity.

Household dietary diversity score (HDDS)	**-1-**	**-2-**	**-3-**	**-4-**	**-5-**	**-6-**
	HDDS	**HDDS**	**HDDS**	**HDDS**	**HDDS**	**HDDS**
Production diversity Score/PDS	0.208***	0.198***	0.255***			
	(0.037)	(0.037)	(0.038)			
Frequency of market visits	0.332***					
	(0.068)					
Length of absence from market		-0.095***				
(In number of days)		(-0.017)				
Proximity to market			-0.003			
(Walking minutes)			(0.002)			
Frequency X PDS				0.066***		
(interaction)				(0.008)		
Length of absence X PDS					-0.010***	
(Interaction)					(0.005)	
Proximity X PDS						0.001***
(interaction)						(0.000)
Marital Status						
Divorced	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)

Married	0.184	-0.003	0.238	0.245	0.264	0.162
	(0.49)	(0.377)	(0.468)	(0.469)	(0.437)	(0.463)
Single	1.387***	1.367***	1.485***	1.434***	1.765***	1.211**
	(0.386)	(0.324)	(0.428)	(0.384)	(0.373)	(0.523)
Widowed	-0.013	0.036	0.102	0.032	0.12	-0.057
	(0.27)	(0.263)	(0.265)	(0.263)	(0.265)	(0.271)
Sub-district						
Geter Haiki Mesihal	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)
Damaino	-0.621***	-0.001	-0.036	-0.083	0.031	-0.246
	(0.183)	(0.142)	(0.15)	(0.196)	(0.156)	(0.16)
Gergera	-0.128	-0.114	0.018	-0.015	0.013	-0.041
	(0.198)	(0.173)	(0.18)	(0.184)	(0.179)	(0.189)
Degaabur	-0.819***	0.164	0.038	0.167	0.189	-0.217
	(0.223)	(0.173)	(10.175)	(0.299)	(0.185)	(0.187)
Gender						
Female	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)
Male	0.018	0.109	-0.018	-0.066	-0.048	0.007
	(0.416)	(0.300)	(0.398)	(0.396)	(0.369)	(0.387)
Education level	0.044*	0.031	0.040*	0.042*	0.038*	0.041
	(0.024)	(0.022)	(0.023)	(0.023)	(0.022)	(0.025)
Age	-0.004	-0.003	-0.003	-0.005	-0.003	-0.001
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Family size	0.033	0.024	0.021	0.021	0.011	0.060*
	(0.033)	(0.032)	(0.033)	(0.033)	(0.033)	(0.033)
Rainfed farmland holding size	0.047	-0.003	-0.056	-0.016	-0.064	0.108
(In tsimad= 1/4 hectare)	(0.062)	(0.057)	(0.060)	(0.061)	(0.060)	(0.063)
Irrigated landholding size	0.595***	0.495***	0.320**	0.446***	0.275*	0.568*
(In tsimad= 1/4 hectare)	(0.150)	(0.136)	(0.137)	(0.138)	(0.140)	(0.151)
Observations	**396**	**396**	**396**	**396**	**396**	**396**

Table 3 presents the marginal effects after Poisson estimation. The dependent variable is the household dietary diversity score, based on the 12 food groups. The models were estimated using Poisson model. The coefficient estimates are shown in column (1) to (4), robust standard errors in brackets. ** p<0.05, ** p<0.01, *** p<0.001.*
Source: *authors' own computation from survey data collected in Sep. – Oct. 2020.*

In Table 3, we have examined the influence of the key variables of interest when estimated alongside the households' socioeconomic variables on household dietary diversity. Accordingly, we found a few socioeconomic variables that can influence household dietary diversity. The first variable which is consistent and significant influencer of the HDDS is marital status, being a single household head. However, caution should be taken in handling the results because the number of single household heads in our survey is too small (only 2) to be generalized (See Table 1). The other influencing factor that we find is the geographic locations of the households, the sub-districts. It was found significant only when estimated along with PDS and the frequency of food market visits. Households in sub-district Damaino, on average consume 0.621 lower food groups, significant at 1%, than those in Geter Haiki-Mesihal, the reference category. Similarly, residents of Degaabur face 0.819 food groups lower dietary diversity than Geter Haiki-Mesihals', significant at 1%. Household heads' education level has also been found to create a positive effect on household dietary diversity, at 5%. The other significant influencer of HDDS in our study areas is the size of households' irrigated farmland. An additional one Tsimad (a quarter of a hectare) irrigated land ownership leads to an average increase in HDDS by 0.320 – 0.595 food groups, significant at 1% -5% levels.

Robustness of Results: The robustness of the paper's objectives, focusing on the discrete and joint interplay of farm production diversity and market access on household dietary diversity, is assessed through rigorous multiple estimations. This involves Poisson regression and Ordinary Least Squares (OLS) estimation. The results consistently align across different models, providing a robust foundation. The inclusion of various socioeconomic variables ensures a comprehensive analysis, minimizing potential bias.

Robustness Check for the Frequency of Food Market Visits (FMV): A critical aspect is introducing an alternative measure of market access – households' frequency of food market visits in 30 days. This measure aims to capture the complexity of households' decisions to engage in food markets, considering factors beyond mere geographic distance. The robustness check involves comparing this new measure with the previously tested measure, proximity to the market, and households' length of absence from the market. The frequency of food market visits (FMV) consistently exhibits a high level of significance across various models, establishing its validity. The empirical testing of the theoretical argument supporting the FMV as a comprehensive measure of market access involves multiple estimations using different models. The results demonstrate the stability and consistency of the FMV's coefficient, indicating its reliability. Further validation through OLS estimation yields similar outcomes, reinforcing the credibility of the FMV as a robust alternative measure of market access.

4. CONCLUSION

This research aims to explore the joint interplay between farm production diversity and market access to household dietary diversity in rural Tigray, Ethiopia. Primary data was collected from a cross-sectional household survey involving 396 smallholders. The analysis of the results is based on the smooth integration of the graphical presentations and Poisson estimation methods. A novel measure of market access, households' frequency of food market visits in 30 days, is introduced, validated for its robustness.

Independently, farm production diversity exhibits a positive and significant nonlinear impact on rural household dietary diversity, presenting possible three stages of returns. Positive, diminishing, and negative returns. Similarly, the frequency of food market visits exerts a positive and significant nonlinear influence on household dietary diversity, with two stages of returns – positive and diminishing returns.

In a joint analysis, farm production diversity and household frequency of food market visits reveal a positive and significant nonlinear relationship, indicating the existence of a possible optimal point for maximum attainable dietary diversity. The frequency of food market visits seems to not only complement but also enhance farm production diversity. Contrary to expectations, households in remote areas do not compensate for limited market access by increasing farm production diversity. Instead, remoteness from markets discourages further farm production diversity, contributing a two-fold negative impact on household dietary diversity. Better market attendance is linked with greater farm production diversity and higher household dietary diversity. Fresh food market visits are correlated with diverse diets, and market day diets are more diverse than non-market days. Overall, remoteness exhibits significant negative influence on farm production diversity, households' frequency of food market visits, and rural household dietary diversity.

Future research with the application of the frequency of food market visits to assess farmers' access to market using national and cross-national data could provide valuable insights in explaining the role of markets on dietary diversity.

Policy Implication: Our finding indicates that the right combination of farm production diversity and frequency of food market visits helps to enhance rural smallholders' dietary diversity. In terms of policy, the implication is that farm production diversity that simultaneously target market sales and own consumption would enhance household dietary diversity more than a single focus on one or the other. Governments and development agencies should, therefore, look for initiatives that focus on greater production of nutritious foods that can lead to both market sales and enhanced household consumption. Farm production of crop and livestock varieties with relatively higher market demand not only has the potential to increase income (and thus the consumption of purchased foods) but also promote frequent market visits. Such products in our study includes vegetables, like tomatoes, kale, spinach, lettuce and green chillies, and small livestock such as chickens, sheep, and goats. These products have relatively short production cycles, high nutrition and are affordable by smallholders compared to other farm products. The production of those diverse foods therefore increases the opportunity for self-consumption and income generation from the sale of the excess produce. Ultimately, this approach is a promising entry point for policy makers and farm households themselves to address the challenges of micronutrient under-nutrition and the resulting short-term diseases and long-term cognitive problems persisting in poor households in Ethiopia and elsewhere in similar settings in Sub-Saharan Africa.

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6. APPENDIX

Appendix A: Ordinary Least Squares (OLS) Regression of Key variables

Household Dietary Diversity Score/ HDDS	**Column (1)**	**Column (2)**	**Column (3)**	**Column (4)**	**Column (5)**	**Column (6)**	**Column (7)**	**Column (8)**	**Column (9)**	**Column (10)**
Production Diversity Score/PDS	0.211***	0.223***	0.279***	0.292***						
	(0.039)	(0.038)	(0.039)	(0.039)						
Frequency of Market Visits	0.333***				0.449***					
	(0.058)				(0.057)					
Length of absence from market		-0.088***				-0.112***				
(In number of days)		(0.015)				(0.014)				
Proximity to Market			-0.003**				-0.004***			
(Walking minutes)			(0.001)				(0.001)			
Frequency of visits X PDS								0.073***		
(Interaction)								(0.008)		
Length of absence X PDS									-0.011*	
(Interaction)									(0.004)	
Proximity X PDS										0.000
(Interaction)										(0.000)
Observations	**396**	**396**	**396**	**396**	**396**	**396**	**396**	**396**	**396**	**396**

Appendix A presents the marginal effects after Poisson estimation. The dependent variable is the household dietary diversity score, based on the 12 food groups. The models were estimated using Poisson model. The coefficient estimates are shown in column (1) to (4), robust standard errors in brackets. ** p<0.05, ** p<0.01, *** p<0.001.*

***Source:** authors' own computation from survey data collected in Sep. – Oct. 2020.*

Appendix B: Ordinary Least Squares (OLS) regression of the key variables along with other socioeconomic variables

	(1)	(2)	(3)	(4)	(5)	(6)
Household Dietary Diversity Score/HDDS	**HDDS**	**HDDS**	**HDDS**	**HDDS**	**HDDS**	**HDDS**
Marital status						
Divorced	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)
Married	0.244	-0.031	0.241	0.231	0.155	0.188
	(0.421)	(0.348)	(0.467)	(0.458)	(0.463)	(0.490)
Single	1.587***	1.217***	1.336***	1.386***	1.140*	1.290***
	(0.354)	(0.301)	(0.382)	(0.416)	(0.508)	(0.386)
Widowed	0.106	0.022	0.023	0.095	-0.058	-0.013
	(0.261)	(0.249)	(0.260)	(0.260)	(0.265)	(0.266)
Sub-districts						
Geter Haki Mesihal	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)
Damaino	0.021	-0.005	-0.096	-0.036	-0.244	-0.609***
	(0.161)	(0.147)	(0.198)	(0.153)	(0.165)	(0.182)
Gergera	0.001	-0.109	-0.023	0.007	0.038	-0.120
	(0.188)	(0.183)	(0.192)	(0.187)	(0.195)	(0.197)
Degaabur	0.191	0.168	0.166	0.054	-0.201	-0.800***
	(0.182)	(0.170)	(0.291)	(0.172)	(0.187)	(0.225)
Gender						
Female	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)
Male	-0.044	0.121	-0.076	-0.026	-0.000	0.005
	(0.349)	(0.281)	(0.389)	(0.386)	(0.389)	(0.417)
Education level	0.041	0.035	0.041	0.043	0.045	0.047
	(0.024)	(0.024)	(0.025)	(0.025)	(0.027)	(0.026)
Age	-0.003	-0.002	-0.004	-0.003	-0.001	-0.004
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Family size	0.008	0.021	0.018	0.018	0.059	0.031
	(0.033)	(0.033)	(0.034)	(0.033)	(0.034)	(0.033)
Rainfed landholding size	-0.061	0.000	-0.013	-0.056	0.111	0.051
(In tsimad= 1/4 hectare)	(0.062)	(0.060)	(0.063)	(0.062)	(0.066)	(0.065)
Irrigated landholding size	0.300	0.518***	0.471**	0.336*	0.594***	0.619***

(In tsimad= 1/4 hectare)	(0.153)	(0.149)	(0.151)	(0.149)	(0.164)	(0.163)
Production Diversity Score/PDS	0.214***	0.206***	0.261***			
	(0.040)	(0.040)	(0.040)			
Frequency of market visits	0.324***					
	(0.067)					
Length of absence from market		-0.089***				
(In number of days)		(0.015)				
Proximity to market			-0.003			
(Walking minutes)			(0.002)			
Frequency X PDS				0.069***		
(Interaction)				(0.009)		
Length of absence from market					-0.010*	
(In number of days)					(0.005)	
Proximity X PDS						0.001***
(Interaction)						(0.000)
	3.947***	5.458***	4.999***	3.872***	5.461***	5.517***
	(0.414)	(0.361)	(0.355)	(0.345)	(0.352)	(0.350)
Observations	**396**	**396**	**396**	**396**	**396**	**396**

Appendix B presents the marginal effects after Poisson estimation. The dependent variable is the household dietary diversity score, based on the 12 food groups. The models were estimated using Poisson model. The coefficient estimates are shown in column (1) to (4), robust standard errors in brackets. ** p<0.05, ** p<0.01, *** p<0.001.*
***Source:** authors' own computation from survey data collected in Sep. – Oct. 2020.*

Appendix C: OLS regression results on the relationship between PDS and Market Access

Production Diversity Score (PDS)	**(1) PDS**	**(2) PDS**	**(3) PDS**	**(4) HDDS**	**(5) FMV**
Frequency of Market Visits/FMV	0.551***				
(Number of market visits in 30 days)	(0.069)				
Length of absence from market		-0.106***			
(Length of days since last market visit)		(0.015)			
Proximity to market			-0.004**		
(In walking minutes)			(0.002)		
Proximity to market				-0.004***	-0.010***
(In walking minutes)				(0.001)	(0.001)
Constant	1.815***	4.178***	3.202***	6.931***	3.758***
	(0.208)	(0.142)	(0.151)	(0.108)	(0.088)
Observations	**396**	**396**	**396**	**396**	**396**

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Source: *authors' own computation from survey data collected in Sep. – Oct. 2020.*

Appendix D: Proximity to market on frequency of market visits