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Household Farm Production Diversity and Micronutrient Intake: Where Are the Linkages? Panel Data Evidence from Uganda

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Abstract: Hunger and malnutrition are key global challenges whose understanding is instrumental to their elimination, thus realization of important sustainable development goals (SDGs). However, understanding linkages between farm production diversity (FPD) and household micronutrient intake is important in mapping micronutrient deficiencies and hidden hunger. Such understanding would inform appropriate interventions against malnutrition. Unfortunately, empirical literature is scarce to sufficiently inform such understanding. Using nationally representative panel survey data covering about 3300 households, we study linkages between FPD and nutrition, and associated impact pathways. We analyze data using panel regression models. Results show that at least half of sample was deficient in daily energy, iron, zinc, and vitamin A intake vis-à-vis FAO recommendations. Deficiencies were most severe (85%) with vitamin A. Positive and significant associations (about 1% for each added crop/livestock species) exist between FPD and daily household energy, iron, zinc, and vitamin A intake. FPD impacts energy and micronutrient intake via two main consumption pathways; markets (about 0.01% for each shilling), and own farm production (about 0.1% for each shilling). Therefore, own farm production yields better outcomes. Gender effects also exist. Male-headed households exhibited better nutrition outcomes (energy—11%, iron—8%, and zinc—12%) mostly via markets. Effects on Vitamin A were also positive although insignificant.

Keywords: farm production diversity; panel data; nutrition; energy; iron; zinc; vitamin A; Uganda

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1. Introduction

The 2030 Sustainable Development Goals (SDGs) agenda of the United Nations (UN) targets to attain a global population that is liberated from hunger, food insecurity, and malnutrition. However, globally—about two billion people still lack access to adequate and quality food [1]. Therefore, households consistently experience food insecurity from moderate to severe magnitudes, hence exposing them to malnutrition and its related health problems [2]. Hunger has ravaged mostly the world's low-developed regions especially Africa. Almost all Africa's sub-regions are experiencing increases in hunger, which implies that affected populations lack access to enough food [1]. Therefore, these populations are undernourished, since they cannot have adequate dietary energy required for a healthy living [1,2]. Moreover, prevalence of undernourishment in some African countries whose populations are dominantly dependent on smallholder farming mostly in Sub Sahara Africa (SSA) does exceed 35%, the highest prevalence globally [1]. Yet, to achieve the 2030 SDGs' agenda of zero hunger, inclusive appropriate effective and pro-poor mechanisms against hunger, food insecurity and malnutrition need to be realized amidst increasing global challenges to sufficient food supplies like; climate change, increasing global population (144 million babies born per year), and conflict [2]. In general, the UN believe that hunger, food insecurity and malnutrition can be resolved through ensuring proper food systems. However, food systems are a complex nexus involving key components, for instance: food crops/livestock identification, food production, food processing and marketing, market access and purchasing power (income), and food consumption and utilization [1,3–6]. Moreover, different factors can be responsible for determining intended outcomes of each component [2]. Therefore, food systems are characteristic of several interlinkages—which if not well understood, designing appropriate, inclusive, effective and pro-poor interventions against hunger may be impossible.

Unfortunately, empirical literature that would facilitate the understanding of these food system linkages is fragmented. Most literature studies individual components of food systems, yet studying the nexus for instance interlinkages between farm production (agriculture) and nutrition would provide a more comprehensive understanding [4,6,7]. Moreover, most empirical literature has only highlighted importance of certain mechanisms through which these interlinkages manifest their impact on food consumption and nutrition, leaving the nexus limitedly understood. For example, some of the key mechanisms or pathways put forward through which smallholder farmers can enhance their nutrition while relying on their farm production diversity is access to markets [8–10]. These authors argue that enabling households to access markets where they can sell their produce competitively, enables households to galvanize incomes, which they in turn use to smooth consumption. Moreover, other evidence has also linked markets to better food security and nutrition outcomes [11,12]. However, other evidence suggests that if households are able to produce various crops or livestock (farm production diversity), households can then directly consume this produce thus resolving hunger, food insecurity and malnutrition problems [2,5,7,13–17]. Therefore, evidence is mixed and it would be an oversight to assume that mechanisms through which farm production diversity interlinks with nutrition outcomes can be universally deployed to produce similar nutrition outcomes. Moreover, country- or region-specific contextual factors could be important in determining what farm production diversity mechanisms would more effectively improve household food security, and nutrition outcomes [6,8–10,13,18,19].

Therefore, we contribute to the gap in knowledge around the nexus of agriculture (farm production diversity) and nutrition, by studying interlinkages between farm production diversity (FPD) and nutrition outcomes. We also study various impact pathways concurrently to give a more comprehensive understanding of the nexus of these interlinkages. Previous literature mostly focused on individual components in the nexus. We use nationally representative panel data on farm production and food consumption from Uganda to answer these questions: (1) Does FPD impact on household daily energy and micronutrient intake? (2) Through what pathways does FPD impact daily energy and micronutrient intake? (3) Does FPD impact differently on daily energy and micronutrient intake, attained via different consumption pathways (own production, and markets)? (4) If yes in 3, which pathway is more effectively?

Moreover, most studies on FPD and nutrition have studied FPD impacts on household nutrition using household dietary diversity scores (HDDS) which is a dietary quality indicator that provides no clear understanding of the magnitudes of dietary components [18,20]. Therefore, as a novelty, to the best of our knowledge, this is the first study exploring empirical associations of farm production diversity with regards to energy and micronutrient intake among smallholder farmers.

Conceptual Framework

We conceptualize that farm production diversity (FPD) impacts daily energy and micronutrients available to households positively, hence those that are subsequently consumed. In our study, we focus on energy and strategic micronutrients that are indispensable for human growth and development (iron, zinc, and vitamin A), yet often deficient across populations especially in developing economies [21].

If assessed via different consumption pathways (own farm production, and markets), there could be differential effects of FPD on food consumption, and subsequently on daily energy and micronutrient intake. We depict these potential differences using different thickness of the arrows between FPD and the two perceived consumption pathways (Figure 1). Nevertheless, we hypothesize that these differential impacts are stronger via their own farm production consumption pathway, since our sample is largely of subsistence smallholder farmers.

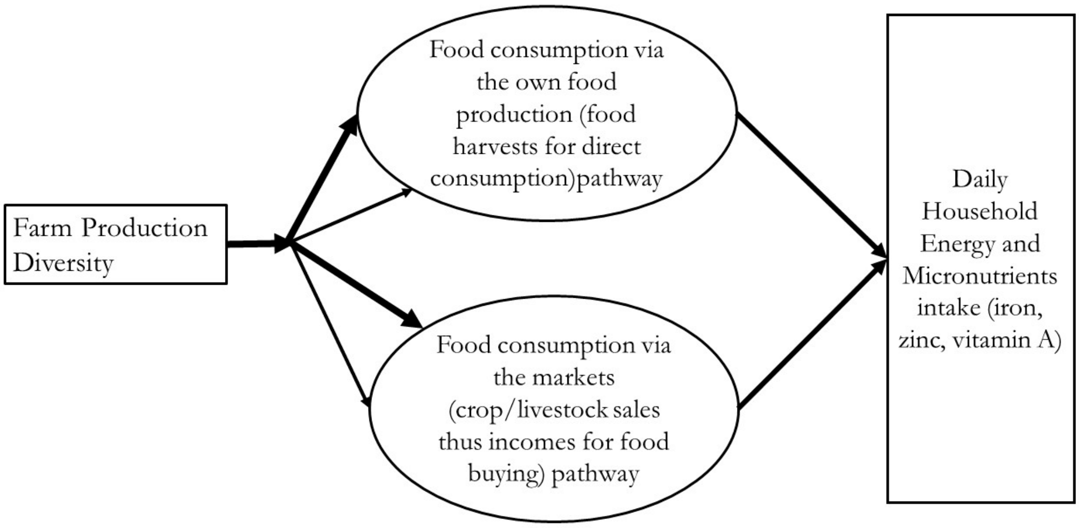

Figure 1. FPD (farm production diversity) impact consumption pathways for energy and micronutrients intake.

Theoretically, when households produce crops and livestock on their farms (farm production diversity), we assume that there are two main pathways through which farm production contributes to household food consumption namely: (1) own farm production, and (2) market's consumption pathways. Under the own farm consumption pathway, we hypothesize that households produce crops and livestock and consume them directly, hence contributing to daily per capita household energy and micronutrient requirements. On the other hand, we hypothesize that households produce crops and livestock, and instead sell them and earn incomes, which are used to purchase food for daily energy and micronutrient requirements. We rely on such conceptualization to answer the research questions above.

2. Materials and Methods

2.1. Data

We used panel survey data from Uganda collected by Uganda Bureau of Statistics (UBOS) that is representative nationally. This data is composed of the Uganda National Panel Survey (UNPS) collected annually with support from the World Banks's Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) segment [22]. We used three (3) panel waves (2009/10, 2010/11, and 2011/12) that uninterruptedly comprised of about 3300 households. The UNPS is a subsection of the 2005/6 Uganda National Household Survey (UNHS) that is nationally representative and comprising of 6775 households. Uganda was selected for this study because LSMS-ISA data waves consecutively existed to comprise a panel. Furthermore, we have used the same data to study farm production diversity and household dietary diversity. In brief, we used the Stata SE 16.0 software and its programming algorithms to identify and select data on crops and livestock species farmed in interviewed households, and other demographic data like age, education, and gender of household heads and other variables. Using these algorithms, we also selected and retained data on household consumption for food types and quantities that we later used to calculate energy and other micronutrients' quantities used in this study. Essentially, all households that reported consumption data (nearly all households) were selected. After identifying and filtering the needed data variables, we used the algorithm to drop all other data variables that were not needed for this study, so that data files could be managed easily.

2.2. Measurement of Farm Production Diversity and Nutrition Variables

We measured farm production diversity (FPD) using the household biodiversity index (HBI) which is a simple count of all crops and livestock species produced on farms. The index has been previously used by Di Falco and Chavas [23], Jones et al. [13], and more recently by Sibhatu et al. [8]. Daily per capita consumption was measured as consumption expenditure in Uganda shilling (UGX), (1 US$ = 3500 UGX). Earlier years' consumption values were deflated using a certified consumer price index (CPI) provided by UBOS [24] to make comparison across years possible. Nutrition has been measured using energy and selected micronutrients including iron, zinc, vitamin A, on a daily intake per adult equivalent (AE) basis, computed by basing on guidelines of Hotz et al. [25] and the United Nations [26]. Studying energy and micronutrients help assess households' nutrition status. Nearly two billion people globally, most of who are in developing countries suffer deficiencies in these micronutrients, yet these are central to mental and physical human development, hence reducing vulnerabilities to diseases and early deaths [21].

2.3. Empirical Strategy

To analyze the descriptive nature of our data, we use descriptive measures, for instance, the mean to report averages of continuous variables, and percentages to report on categorical variables like energy and micronutrient deficiencies.

However, to analyze linkages between farm production diversity (FPD) and daily household energy and micronutrient intake, we employ panel regression models illustrated in Equation (1).

$$EM_{it} = \alpha_0 + \alpha_1 FPD_{it} + \alpha_2 T_t + \alpha_i \boldsymbol{X}_{it} + \varepsilon_{it} \quad (1)$$

where EM_{it} indicates a nutrition outcome (daily energy or micronutrient intake) of household i during year t. α_0 is a constant, and α_1 is the farm production diversity FPD_{it} effect to be determined. α_2 is a parameter for time fixed effects, while α_i is a vector of coefficients to be determined for household and contextual characteristics. T is a year identifier. ε_{it} is normally distributed error term. $\boldsymbol{X}_{it}$ is a vector of observed household (age, education, household size, etc.), and contextual (distance to town centers, locality, etc.) characteristics, that along with FPD affect nutrition outcomes. Due to households self-selected into farming or not farming given species of livestock or crops, this could have bred endogeneity due to observed and unobserved heterogeneity thus biases. Henceforth, instead of using a fixed effects (FE) estimator, we instead used the random effects (RE) estimator. However, because the RE estimator strongly assumes that FPD is uncorrelated with unobserved factors (that may affect nutrition outcomes), the assumption may be violated due to self-selection thus yielding biased estimates. We control for this potential violation of the RE estimator assumption by estimating the Mundlak (MK) estimator, which is a pseudo fixed-effects model [27]. The MK estimator controls for mean values of independent variables alongside other covariates, thus limiting potential biases stemming from time-invariant unobserved heterogeneity [28], as would have been achieved with a normal fixed-effects (FE) estimator [29]. Hence, we interpret our results following MK estimators. However, we present both RE and MK models for comparison.

To analyze impact pathways, we estimated Equation (2), which is a modification of Equation (1), but controlling for potential impact consumption pathways including: (1) own farm production, and (2) market purchases, for nutrition outcomes. Since we only interpreted MK estimator results after Equation (1), we only estimated Equation (2) using an MK estimator.

$$EM_{it} = \delta_0 + \delta_1 OwnFarm_{it} + \delta_2 Markets_{it} + \delta_3 FPD_{it} + \delta_4 T_t + \delta_i \boldsymbol{X}_{it} + \varepsilon_{it} \tag{2}$$

where $OwnFarm_{it}$ is daily household food consumption from own farm production, and δ_1 is the effect of such consumption on nutrition outcomes. $Markets_{it}$ is daily household food consumption from markets, and δ_2 is its effect. Non-defined variables under Equation (2), are the same as those defined under Equation (1), and their respective parameters to be estimated; to minimize space, we do not redefine them.

To analyze potential differential effects of FPD on nutrition outcomes sourced via different consumption pathways, we estimated Equation (3), a modification of Equation (1), only that nutrition outcomes are disaggregated by source consumption pathway.

$$EM\_OwnFarm \ or \ EM\_Markets_{it} = \vartheta_0 + \vartheta_1 FPD_{it} + \vartheta_2 T_t + \vartheta_i \boldsymbol{X}_{it} + \varepsilon_{it} \tag{3}$$

where $EM\_OwnFarm \ orEM\_Markets_{it}$ is daily household energy or micronutrients intake generated from either own farm production consumption pathway or markets respectively. ϑ_1 is the effect of FPD on respective nutrition outcomes. Non-defined variables under Equation (3), are the same as those defined under Equation (1), and their respective parameters to be estimated, but to minimize space, we do not redefine them. We only present and discuss MK estimator results. To further ascertain robustness of our results, we estimated a three-stage least squares regression (see Appendix D for the detailed analytical methodology), and present results after discussions.

3. Results

3.1. Descriptive Results

We present descriptive statistics in Table 1 for variables used in regressions. On average, household consumption expenditure was higher on market-sourced foods (1820 UGX) compared to that from own farms (888 UGX). Households were mostly rural (77%), and located about 30 km from the nearest main markets. Furthermore, sample households were mostly male-headed (70%), with an average size of 7 persons who generally never completed primary school (7 years).

Table 1. Descriptive statistics for variables of the pooled sample (N = 8617).

Variables	Mean	Std. Dev.
Daily per capita consumption via markets (UGX)	1819.62	2204.26
Daily per capita consumption from own production (UGX)	888.24	841.14
Distance to nearest major market (kilometers)	29.543	20.016
Annual precipitation (millimeters)	1237.61	182.572
Elevation (meters)	1228.23	231.368
Urban households (percentage)	22.995	42.082
Male-headed households (percentage)	70.286	45.703
Household size (persons)	6.956	3.639
Household size (adult equivalents)	4.241	2.285
Education (years)	5.335	3.996
Household heads using mobile phones (percentage)	55.971	49.645
Productive assets (millions UGX)	19.700	93.900
Experienced shocks (percentage)	46.854	49.904
Land size (acres by GPS)	3.282	20.217
Free/lease land holders (percentage)	33.678	47.264
Accessed extension services (percentage)	18.255	38.632

Source: Authors' calculations. UGX is Uganda shilling (1 US$ = 3500 UGX); GPS is Global Positioning System.

About 56% of household heads owned and used mobile phones, however, only 18% accessed extension services. Households had a productive assets' value of nearly 20 million UGX, and a land size of 3 acres, with about 34% of households possessing free or lease hold land titles. Nearly half of the sample (47%) experienced shocks to household well-being including death of the head, severe illnesses, floods, famine or drought.

In Table 2, we present mean values of nutrition outcome variables. We disaggregate these variables by respective consumption pathways (markets versus own farm sources). Generally, the sample average for daily energy and iron intake was slightly above FAO recommended thresholds, while that for zinc and vitamin A was clearly below FAO thresholds. About 50% of the sample was deficient in energy and zinc, while a whopping 67% and 85% were deficient in iron and vitamin A respectively.

Table 2. Descriptive statistics for nutrition outcome variables.

Daily Household Energy and Micronutrients Intake per AE	Mean	Std. Dev.
Total from all sources (N = 8574)		
Energy (Kilocalories)	2636	1567
Iron (milligrams)	19.70	11.02
Zinc (milligrams)	13.36	8.156
Vitamin A (RAE—micrograms)	331.9	329.7
Markets sourced (N = 8311)		
Energy (Kilocalories)	1726	1481
Iron (milligrams)	11.74	10.66
Zinc (milligrams)	9.270	8.302
Vitamin A (RAE—micrograms)	145.7	205.9
Own farm sourced (N = 6374)		
Energy (Kilocalories)	1227	1133
Iron (milligrams)	11.26	9.403
Zinc (milligrams)	5.914	5.490
Vitamin A (RAE—micrograms)	249.0	314.1
Consumption Deficiency, 0–1 scale (N = 8574)		
Energy	0.502	0.500
Iron	0.504	0.500
Zinc	0.655	0.476
Vitamin A	0.849	0.358
FAO recommended minimum thresholds per AE		
Energy (Kilocalories)	2400	
Iron (milligrams)	18.27	
Zinc (milligrams)	15.00	
Vitamin A (RAE—micrograms)	625.0	

Source: Authors' calculations. RAE is retinal activity equivalents. AE is adult equivalent. N is number of observations.

From Table 2, energy, iron, and zinc were mainly sourced from markets unlike vitamin A, and we use this data to make graphical illustrations of energy and micronutrient sources in Figure 2.

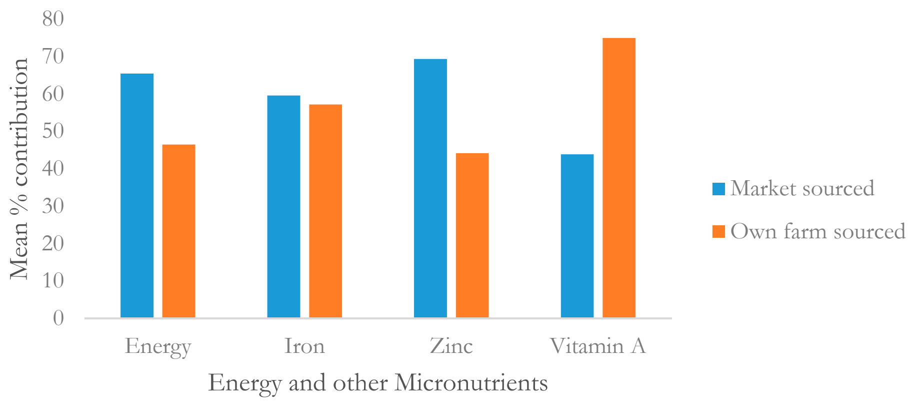

Figure 2. Source (markets or own farm) mean percentage contribution to total daily energy and micronutrient intake per AE.

3.2. Empirical Results

In Table 3, we present results after estimating Equation (1). As had been hypothesized, columns 2, 4, 6, and 8 showed that FPD was positively and significantly associated with household daily energy, iron, zinc, and vitamin A intake. Specifically, a one species increase in the number of crops and livestock produced on farm was associated with increments in daily intake of 6.5 kilocalories, 0.1 milligrams, 0.06 milligrams, and 4.7 RAE—micrograms of energy, iron, zinc, and vitamin A respectively. These incremental associations imply a 0.3, 0.5, 0.4, and 1.4 percentage point increases in daily household energy, iron, zinc, and vitamin A intake, respectively.

Table 3. Regression results for the impact of FPD on daily household energy and micronutrient intake.

Variables	Energy (Kilocalories)		Iron (Milligrams)		Zinc (Milligrams)		Vitamin A (Rae−Mc)	
	RE (1)	MK (2)	RE (3)	MK (4)	RE (5)	MK (6)	RE (7)	MK (8)
FPD (biodiversity index)	7.711 **	6.535 *	0.114 ***	0.102 ***	0.066 ***	0.058 **	5.004 ***	4.704 ***
	(3.868)	(3.906)	(0.030)	(0.031)	(0.022)	(0.023)	(0.873)	(0.900)
Distance nearest main	−1.493 *	2.275	0.005	−0.006	−0.003	−0.0001	0.963 ***	−1.408
market (km)	(0.897)	(3.918)	(0.007)	(0.032)	(0.005)	(0.021)	(0.182)	(1.087)
Head uses mobile phone	217.8 ***	−23.11	0.627 **	−0.557	1.442 ***	−0.007	−27.05 ***	−7.935
(dummy)	(35.10)	(50.66)	(0.276)	(0.420)	(0.203)	(0.292)	(7.991)	(13.51)
Household size (adult	−126.9 ***	−194.5 ***	−0.877 ***	−1.382 ***	−0.691 ***	−0.994 ***	−9.353 ***	−15.16 ***
equivalent)	(7.907)	(18.45)	(0.061)	(0.145)	(0.045)	(0.100)	(1.696)	(4.266)
Male head (dummy)	23.79	279.9 **	−0.046	1.642 **	0.352	1.574 **	−6.288	0.855
	(39.41)	(110.5)	(0.302)	(0.783)	(0.224)	(0.627)	(8.148)	(31.37)
Age of head (years)	1.905	15.58 **	0.0325	0.129 **	0.001	0.084 **	−0.919	2.078
	(4.593)	(7.575)	(0.034)	(0.065)	(0.026)	(0.041)	(1.025)	(2.282)
Age squared of head	−0.028	−0.214 **	−0.0004	−0.001	−0.0001	−0.001 **	0.015	−0.025
(years)	(0.047)	(0.097)	(0.0004)	(0.001)	(0.0003)	(0.001)	(0.010)	(0.031)
Education of head (years)	−16.53	−36.64 **	0.004	−0.274 **	−0.097	−0.300 ***	2.884	0.999
	(11.45)	(17.24)	(0.089)	(0.137)	(0.066)	(0.099)	(2.587)	(4.353)
Educ. squared of head	2.625 ***	3.696 **	0.007	0.027 **	0.016 ***	0.024 ***	−0.155	0.100
(years)	(0.893)	(1.441)	(0.007)	(0.011)	(0.005)	(0.008)	(0.200)	(0.344)
Shock experience	−69.56 **	−45.74	0.007	−0.107	−0.219	−0.197	−5.570	−16.05
(dummy)	(30.80)	(37.53)	(0.245)	(0.308)	(0.180)	(0.226)	(7.406)	(10.23)
Land size (acres by GPS)	1.188	−0.926	0.026	−0.002	0.027 *	−0.001	0.650	−0.195
	(2.449)	(2.930)	(0.019)	(0.026)	(0.014)	(0.017)	(0.572)	(0.791)
Land size squared (acres	−0.004	−0.002	-5×10^{-5} *	-2×10^{-5}	-5×10^{-5} **	-1×10^{-5}	−0.001	−0.0001
by GPS)	(0.004)	(0.004)	(3×10^{-5})	(4×10^{-5})	(2×10^{-5})	(3×10^{-5})	(0.001)	(0.001)
Year 2010	34.99	57.38 *	0.264	0.295	−0.018	0.049	−18.11 **	−21.14 **
	(33.28)	(33.87)	(0.271)	(0.271)	(0.197)	(0.197)	(8.868)	(9.143)
Year 2011	9.166	49.32	0.227	0.301	−0.146	−0.006	−16.91 *	−21.48 **
	(33.37)	(34.52)	(0.271)	(0.277)	(0.197)	(0.203)	(8.818)	(9.088)
Mean values		Yes		Yes		Yes		Yes
Constant	4757 ***	4795 ***	20.53 ***	21.33 ***	14.76 ***	14.74 ***	322.5 ***	337.8 ***
	(115.1)	(145.8)	(0.892)	(1.196)	(0.657)	(0.900)	(25.50)	(31.11)
Observations	8574	8574	8574	8574	8574	8574	8574	8574
No. of households	3258	3258	3258	3258	3258	3258	3258	3258
Wald Chi2 value	358.80 ***	368.45 ***	229.67 ***	262.13 ***	344.79 ***	409.63 ***	138.00 ***	158.75 ***

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; FPD is farm production diversity; GPS is Global Positioning System; rae-mcg is Retinal Activity Equivalents—micrograms; KM is kilometer; MK is Mundlak estimation; RE is random effects estimation. See Appendix A for details.

Table 3 results also unearthed other factors that were important determinants of nutrition outcomes. For instance, increments in normal age of household heads, as well as higher education (squared normal education years) were positively and significantly associated with increases in daily energy and micronutrient intake. An increasing household size was also negatively and significantly associated with all nutrition outcomes. Surprisingly, gender effects were also explicit, whereby male-headed households were associated with significantly better nutrition outcomes. For instance, male-headed households had an associated increase in their daily energy, iron, and zinc intake of 11% (279.9 kilocalories), 8% (1.642 milligrams) and 12% (1.574 milligrams) respectively. Associated increments for vitamin A were also positive even though they were not significant.

In Table 4, we present results after estimating Equation (2). However, now, for each added livestock or crop species, daily intake reduced from 6.5 to 1.8 kilocalories, 0.1 to 0.05 milligrams, 0.06 to 0.05 milligrams, and 4.7 to 1.9 RAE—micrograms for energy, iron, zinc, and vitamin A respectively. Therefore, food consumption via markets and own farm impact pathways helped households attain about 72%, 50%, 17%, and 60% of their daily intake for energy, iron, zinc, and vitamin A respectively based on averages in Table 2. Essentially, with each Uganda shilling (UGX) spent via markets, consumption was associated with increments of 0.007% (0.181 kilocalories), 0.005% (0.001 milligrams), 0.007% (0.001 milligrams), and 0.001% (0.004 rae-mcg) in daily energy, iron, zinc, and vitamin A respectively. However, a similar size of expenditure via own-farm production consumption was associated with increments of 0.055% (1.441 kilocalories), 0.061% (0.012 milligrams), 0.059% (0.008 milligrams), and 0.089% (0.0297 rae-mcg) in daily energy, iron, zinc, and vitamin A respectively.

Table 4. Regression results for impact pathways of FPD on daily energy and micronutrient intake.

Variables	Energy (Kilocalories)	Iron (Milligrams)	Zinc (Milligrams)	Vitamin A (Rae−Mcg)
	MK (1)	MK (2)	MK (3)	MK (4)
Farm Production Diversity (biodiversity index)	1.758 (3.788)	0.050 (0.031)	0.047 ** (0.022)	1.962 ** (0.920)
Daily per AE consumption via markets (Uganda shilling)	0.181 *** (0.011)	0.001 *** (8×10^{-5})	0.001 *** (6×10^{-5})	0.004 * (0.002)
Daily per AE consumption from home production (Uganda shilling)	1.441 *** (0.122)	0.012 *** (0.001)	0.008 *** (0.001)	0.297 *** (0.024)
Distance nearest main market (kilometers)	−5.469 (4.576)	−0.064 * (0.034)	−0.051 ** (0.025)	−2.286 ** (1.114)
Head uses mobile phone (dummy)	−58.08 (51.44)	−0.806 * (0.427)	−0.265 (0.304)	−9.416 (13.50)
Household size (adult equivalent)	−112.8 *** (18.82)	−0.802 *** (0.146)	−0.403 *** (0.103)	−10.38 ** (4.244)
Male head (dummy)	309.7 *** (111.4)	1.857 ** (0.800)	1.804 *** (0.660)	2.094 (31.19)
Age of head (years)	−1.416 (8.259)	0.005 (0.069)	−0.034 (0.046)	0.608 (2.287)
Age squared of head (years)	−0.053 (0.105)	3×10^{-5} (0.001)	7×10^{-5} (0.001)	−0.009 (0.031)
Education of head (years)	−51.98 *** (17.98)	−0.381 *** (0.142)	−0.412 *** (0.104)	0.340 (4.392)
Educ. squared of head (years)	4.650 *** (1.511)	0.033 *** (0.012)	0.031 *** (0.009)	0.158 (0.347)
Shock experience (dummy)	−79.47 ** (38.32)	−0.348 (0.312)	−0.420 * (0.232)	−19.31 * (10.29)
Land size (acres by GPS)	−0.738 (3.100)	-4×10^{-5} (0.028)	0.001 (0.019)	−0.182 (0.765)
Land size squared (acres by GPS)	−0.002 (0.005)	-2×10^{-5} (4×10^{-5})	-2×10^{-5} (3×10^{-5})	−0.0002 (0.001)
Year 2010	14.86 (34.57)	−0.006 (0.276)	−0.254 (0.202)	−24.18 *** (9.125)
Year 2011	−86.24 ** (35.73)	−0.670 ** (0.286)	−0.951 *** (0.212)	−32.36 *** (9.157)
Mean values	Yes	Yes	Yes	Yes
Constant	3921 *** (148.0)	15.36 *** (1.178)	7.858 *** (0.844)	327.3 *** (33.22)
Observations	8574	8574	8574	8574
No. of households	3258	3258	3258	3258
Wald Chi2 value	694.19 ***	579.94 ***	947.38 ***	325.80 ***

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; AE is adult equivalent; GPS is Global Positioning System; rae-mcg is Retinal Activity Equivalents—micrograms; MK is Mundlak estimation. See Appendix B for details.

In Table 5, we present results after estimating Equation (3). FPD is negatively and significantly associated with daily energy and micronutrient intake sourced via the markets consumption pathway, whereas such impact is positive and significant for these nutrition outcomes sourced via the own farm consumption pathway.

There were also differential impacts of gender towards nutrition outcomes vis-à-vis consumption pathways. Gender (household male headship) effects with regards to energy, iron, and zinc intake were more pronounced via the market consumption pathway.

Table 5. Differential FPD impacts on daily energy, iron, zinc, and vitamin A intake given consumption pathways.

Variables	Energy (Kilocalories)		Iron (Milligrams)		Zinc (Milligrams)		Vitamin A (Rae-Mcg)	
	Markets	Own Farm	Markets	Own Farm	Markets	Own Farm	Markets	Own Farm
	MK (1)	MK (2)	MK (3)	MK (4)	MK (5)	MK (6)	MK (7)	MK (8)
FPD (biodiversity index)	−74.58 ***	20.75 ***	−0.208 ***	0.179 ***	−0.099 ***	0.098 ***	−2.535 ***	4.057 ***
	(10.94)	(2.423)	(0.029)	(0.023)	(0.020)	(0.012)	(0.507)	(0.927)
Distance to nearest market (kilometers)	−8.043	4.222 *	−0.017	0.014	−0.015	0.014	0.291	−2.215
	(10.43)	(2.450)	(0.028)	(0.026)	(0.019)	(0.013)	(0.995)	(1.636)
Head uses mobile phone (dummy)	104.7	−34.70	0.224	−0.391	0.272	−0.158	4.798	−10.80
	(142.4)	(33.79)	(0.378)	(0.303)	(0.256)	(0.161)	(7.200)	(14.71)
Household size (Adult equivalents)	−358.7 ***	−98.36 ***	−0.519 ***	−0.932 ***	−0.434 ***	−0.493 ***	−13.84 ***	−7.768
	(45.89)	(10.69)	(0.114)	(0.099)	(0.077)	(0.053)	(2.444)	(4.779)
Male heads (dummy)	444.7	111.8	1.232 *	0.652	0.825 *	0.529	1.182	11.39
	(280.4)	(76.69)	(0.740)	(0.690)	(0.495)	(0.374)	(14.91)	(36.30)
Age of head (years)	15.90	1.514	0.005	0.059	0.008	0.021	0.824	0.368
	(21.55)	(4.757)	(0.058)	(0.047)	(0.039)	(0.024)	(1.499)	(2.331)
Age squared of head (years)	−0.215	−0.002	-9×10^{-5}	−0.0003	-8×10^{-5}	−0.0002	−0.016	0.008
	(0.263)	(0.060)	(0.001)	(0.001)	(0.001)	(0.0003)	(0.022)	(0.027)
Education of head (years)	−33.75	−8.453	−0.090	−0.115	−0.123	−0.049	−2.612	3.381
	(47.40)	(11.47)	(0.124)	(0.106)	(0.084)	(0.056)	(2.686)	(4.895)
Education squared of head (years)	6.028	0.535	0.012	0.007	0.012 *	0.003	0.467 **	−0.357
	(3.925)	(1.002)	(0.010)	(0.009)	(0.007)	(0.005)	(0.226)	(0.397)
Shock experience (dummy)	5.254	−54.36 **	−0.009	−0.389 *	−0.009	−0.227 *	−5.863	−9.351
	(103.6)	(24.82)	(0.273)	(0.228)	(0.189)	(0.119)	(6.238)	(10.59)
Land size (acres by GPS)	5.714	−2.876	0.024	−0.027 *	0.017	−0.015 **	0.216	−1.185 *
	(6.710)	(1.777)	(0.020)	(0.015)	(0.013)	(0.007)	(0.779)	(0.660)
Land size squared (acres by GPS)	−0.015	0.004	-5×10^{-5}	4×10^{-5} *	-4×10^{-5} *	2×10^{-5} **	-5×10^{-5}	0.001
	(0.009)	(0.003)	(3×10^{-5})	(2×10^{-5})	(2×10^{-5})	(1×10^{-5})	(0.001)	(0.001)
Year 2010	−25.37	61.01 ***	−0.232	0.363 *	−0.219	0.304 ***	−11.41 **	−17.34 *
	(92.81)	(23.16)	(0.248)	(0.210)	(0.169)	(0.111)	(5.689)	(10.08)
Year 2011	184.9 *	−18.24	0.371	−0.220	0.173	−0.078	−9.840 *	−19.02 *
	(95.15)	(23.09)	(0.252)	(0.211)	(0.171)	(0.110)	(5.869)	(9.923)
Mean values	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	13,104 ***	1632 ***	18.97 ***	9.411 ***	11.15 ***	3.092 ***	250.4 ***	270.6 ***
	(437.1)	(103.4)	(1.183)	(0.927)	(0.829)	(0.499)	(19.40)	(37.68)
Observations	8310	6373	8310	6373	8310	6373	8310	6373
No. of households	3207	2633	3207	2633	3207	2633	3207	2633
Wald Chi2 value	929.55 ***	278.44 ***	542.38 ***	275.79 ***	623.55 ***	275.61 ***	347.1 ***	337.03 ***

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; FPD is farm production diversity; GPS is Global Positioning System; MK is Mundlak estimation; rae-mcg is Retinal Activity Equivalents—micrograms. See Appendix C for details.

4. Discussion

4.1. Descriptive Results Discussions

High consumption expenditure on market-sourced foods does not necessarily mean that food volumes from respective sources followed a similar trend but may only reflect prices; moreover, market prices are usually higher than farm gate prices. However, by the fact that most household heads had not studied beyond the primary level of education could point to high sample illiteracy levels, which is typical of subsistence farmers. On the other hand, the high micronutrient deficiency levels depicted a serious hidden hunger problem. Moreover, this has been persistent, for instance, the Uganda demographic household survey (UDHS) of 2006 in a supplementary study revealed that 88% of women were iron deficient [7]. The disparity in dominance of sources (markets or own farm production) of micronutrients may be explained by samples' cultural and social behavior, concurring with evidence which points to home production of fruits and vegetables (dominant sources of vitamin A) being associated with more diversity in dietary intakes [14,15]. Foods like vegetables and fruits are also not usually bought by most consumers in Uganda [7]. Furthermore, consumption of such foods is usually seen as a reflection of poverty, while other households would mostly grow them for selling [14]. However, we may not conclude that markets are the more reliable consumption pathway for nutrition outcomes. Moreover, as a novelty, to the best of our knowledge, this is the first study exploring disaggregation of daily household energy and micronutrient intake by source. Such disaggregation is instrumental in establishing appropriate sustainable interventions.

4.2. Empirical Results Discussions

4.2.1. The Impact of FPD on Daily Household Energy and Micronutrient Intake

Although the associated FPD impact on nutrition outcomes was positive and significant, it was less pronounced on daily household energy, iron, zinc, and vitamin A intake, respectively. The trend may not be surprising since, generally, the most consumed foods were the energy dense ones (staple foods), hence the unit incremental effects are smallest for energy, and largest for micronutrients because micronutrient rich foods are less consumed, most notably vitamin A. Our findings are in agreement with McKinney [30] who found that Ugandan households dominantly consume staples (cereals, roots and tubers or banana) on a daily basis, but micronutrient dense foods like milk, eggs, meat, vegetables, and fruit were consumed infrequently. FANTA-2 [7] also found that meals were inadequately varied in Uganda especially for children, and fruits and vegetables were rarely fed to children. The positive effects of age and education of the household heads on nutrition outcomes could be achieved through the income pathway for education, and the knowledge pathway for old age. With better education, households can access better paying jobs and earn better incomes to smooth consumption, while with old age, household heads garner experience on nutrition concepts which may inform proper allocation of resources to optimize nutritional benefits. However, with more persons, available food per capita decreases, hence reductions in nutrition outcomes. Positive male gender effects on nutrition outcomes could be related to increasingly available nutrition information. Besides, households with males usually have better incomes since both man and woman contribute, unlike female-headed households where males have either died or divorced.

4.2.2. Impact Pathways of FPD on Daily Energy and Micronutrient Intake

When we control for consumption pathways, the effect of FPD on daily household energy and micronutrient intake ceases to be significant (energy and iron), and/or reduces in magnitude and significance level (zinc and vitamin A). This confirms that indeed markets or own farm impact pathways are FPD impact pathways for household nutrition outcomes. Moreover, daily consumption from either source exhibited a strong significant and positive association with nutrition outcomes. However, by the fact that FPD remained positive and, in some instances, significant after controlling for studied consumption pathways, it implies that there are other pathways through which FPD impacts nutrition outcomes, for instance, nutrition information and knowledge pathways.

4.2.3. Differential FPD Impacts on Daily Energy, Iron, Zinc, and Vitamin A Intake Given Consumption Pathways

The fact that FPD effects on nutrition outcomes via the market consumption pathway were negative but positive via their own farm production pathway is not surprising. Our sample was predominantly made of subsistence smallholder farmers, who do not sell produce to markets for income towards food consumption. Instead, when such produce was sold, as Kabunga et al. [14] established, incomes were mostly diverted to other non-food consumption needs like: school fees, housing, healthcare, etc. On the other hand, because subsistence farmers mostly consumed what they produced, the strong positive associations with nutrition outcomes via their own farm production pathway were logical. Essentially, FPD reduced household market reliance for both daily energy and micronutrient intake, while FPD enhanced daily intake of energy and micronutrients via own farm produce consumption pathway. Therefore, indeed, differential FPD impacts on daily energy and micronutrient intake vis-à-vis the consumption pathway do exist, and are more pronounced via their own farm production consumption pathway. This is in agreement with studies in [3,6] who established that most households in Uganda, especially rural ones, did mostly consume from their own production sources. To the best of our knowledge, this is the first study exploring differential effects of FPD vis-à-vis consumption pathways for energy and micronutrient intake, more so while using panel data. Related efforts have been done by Islam et al. [16] but they only explored FPD associations with household dietary diversity scores (HDDS). However, our results should not be generalized since Sibhatu et al. [8] found markets to contribute more than own farm reliance to nutrition outcomes. Therefore, country-specific conditions, for instance, urbanization, dominance of the sample (rural vs. urban) etc., could be important in determining the nature of FPD impacts via these consumption pathways on nutrition outcomes. Nevertheless, for the case of Uganda, FPD is more important in contributing to nutrition outcomes via their own farm production consumption pathway.

On the other hand, the male gender's differential impacts that are also more pronounced via the market consumption pathway is an interesting finding and aligns with literature that men's household dominance is more pronounced when farm or off-farm activities are commercialized [31–33]. The comparative advantage from frequenting towns may favor males to access farm products' markets with competitive prices, thus earning better incomes that are used to smooth food consumption and hence nutrition.

4.2.4. Robustness Checks and Limitations of the Study

We check the robustness of our results on importance of consumption pathways by using a different analytical methodology, a three-stage least squares (3SLS) technique elaborated in Appendix D. We present detailed results in Appendix E, Appendix F, Appendix G, Appendix H, but briefly discuss them here. Both FPD impact consumption pathways were strongly associated with a positive and significant impact on daily household energy intake. The own farm production pathway produced the heavier impact, with increments of 5.1 (0.4 percentage points) as opposed to 0.8 kilocalories per AE (0.1 percentage points) added for each shilling spent via markets, see Appendix E. With regards to iron intake, again, both FPD impact consumption pathways were associated with significant increases in daily iron intake, and still, the own farm production pathway showed a stronger impact, with 0.05 milligrams of iron (0.4 percentage points) added for each shilling spent via own farm production consumption, as opposed to 0.01 milligrams (0.1 percentage points) added from an equal expenditure via markets, see Appendix F. With regards to zinc, still both FPD impact consumption pathways were associated with a positive and significant impact on daily intake, and still, the impact was stronger via the own farm production pathway, to tunes of 0.02 milligrams of zinc (0.3 percentage points) added for each shilling spent via own farm production consumption. This is opposed to only 0.004 milligrams (0.04 percentage points) added for each shilling spent via markets, see Appendix G. The pattern depicted by energy, iron, and zinc vis-à-vis FPD impact consumption pathways, is similar to that found by Islam et al. [16] who studied FPD and household dietary diversity scores. Moreover, coefficients interpreted in our main results are more conservative than these from robustness checks.

However, with regards to vitamin A, there was a slight diversion in the trend. The two FPD consumption pathways impacted daily vitamin A intake differently. Whereas, each shilling spent via the own farm consumption pathway was associated with a positive and significant impact (0.97 rae-mcg, implying a 0.4 percentage point increment) on daily vitamin A intake, equal increments via market consumption expenditure bore an associated negative impact (0.10 rae-mcg, implying a 0.1 percentage point decrease). This may be due to the fact that vitamin A dense foods were mostly produced on farm yet buying this for consumption was largely luxurious [7,14,15]. See Appendix G.

As a limitation to the study, generation of nutrition outcomes required a lot of heavy computations, hence could not consider other important macro and micronutrients. Repetitive computations that also required strict consistence could be liable to mistakes. However, using the coding programs of Stata SE 16.0 enabled us to simplify the computation load that would be frequently easily verified to limit mistakes.

5. Conclusions

The study used panel data to study the nexus of farm production diversity (FPD) and nutrition (energy, iron, zinc, and vitamin A intake). At least 50% of sample households were deficient in energy, iron, zinc, or vitamin A vis-à-vis FAO recommended thresholds. Deficiencies were more pronounced for zinc (66%) and vitamin A (85%). FPD was positively associated with daily energy, iron, zinc, and vitamin A intake. Markets and own farm production were important impact pathways through which FPD influenced nutrition outcomes. However, relatively larger increments were attained via the own farm production consumption pathway. Therefore, for Uganda, investments focusing on improving household nutrition outcomes via own farm production could yield better nutrition outcomes than those focused on markets. Remoteness and relatively poor market infrastructure renders own farm reliance more beneficial. Strong gender effects with regards to nutrition outcomes do also exist. Male-headed households were associated with better nutrition outcomes, which were mostly realized via the market consumption pathway. However, our results may not be generalized since some evidence from other countries has pointed to markets being more important towards gains in nutrition outcomes. We also explored the data with a limited number of macro and micronutrients; therefore, extending the scope to other nutrition outcomes would enable a better understanding of the linkages between FPD and household nutrition more comprehensively. Nevertheless, with the rigor exhibited in analyzing this panel data, we are optimistic that our conclusions are binding, especially for Uganda and countries of similar contextual characteristics.

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Institutional Review Board Statement: We used secondary data and we were never in touch with either humans or animals.

Data Availability Statement: Data used in this study was accessed from the World Bank's Central Data Catalog for Living Standards Measurement Study—Integrated Survey on Agriculture (LMSA—ISA) for Uganda, and is available online from https://microdata.worldbank.org/index.php/catalog#_r=1568635091798&collection=&country=&dtype=&from=1890&page=1&ps=&sid=&sk=LSMS%20Uganda&sort_by=rank&sort_order=desc&to=2019&topic=&view=s&vk (accessed on 20 December 2020).

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The impact of FPD on household daily energy and micronutrient intake.

	Energy (Kilocalories)		Iron (Milligrams)		Zinc (Milligrams)		Vitamin A (Rae−Mcg)	
	RE (1)	**MK (2)**	**RE (3)**	**MK (4)**	**RE (5)**	**MK (6)**	**RE (7)**	**MK (8)**
FPD (biodiversity index)	7.711 **	6.535 *	0.114 ***	0.102 ***	0.066 ***	0.058 **	5.004 ***	4.704 ***
	(3.868)	(3.906)	(0.030)	(0.031)	(0.022)	(0.023)	(0.873)	(0.900)
Distance to nearest market (kilometers)	−1.493 *	2.275	0.005	−0.006	−0.003	−0.0001	0.963 ***	−1.408
	(0.897)	(3.918)	(0.007)	(0.032)	(0.005)	(0.021)	(0.182)	(1.087)
Head uses mobile phone (dummy)	217.8 ***	−23.11	0.627 **	−0.557	1.442 ***	−0.007	−27.05 ***	−7.935
	(35.10)	(50.66)	(0.276)	(0.420)	(0.203)	(0.292)	(7.991)	(13.51)
Household size (Adult equivalents)	−126.9 ***	−194.5 ***	−0.877 ***	−1.382 ***	−0.691 ***	−0.994 ***	−9.353 ***	−15.16 ***
	(7.907)	(18.45)	(0.061)	(0.145)	(0.045)	(0.100)	(1.696)	(4.266)
Male heads (dummy)	23.79	279.9 **	−0.046	1.642 **	0.352	1.574 **	−6.288	0.855
	(39.41)	(110.5)	(0.302)	(0.783)	(0.224)	(0.627)	(8.148)	(31.37)
Age of head (years)	1.905	15.58 **	0.0325	0.129 **	0.001	0.084 **	−0.919	2.078
	(4.593)	(7.575)	(0.034)	(0.065)	(0.026)	(0.041)	(1.025)	(2.282)
Age squared of head (years)	−0.028	−0.214 **	−0.0004	−0.001	−0.0001	−0.001 **	0.015	−0.025
	(0.047)	(0.097)	(0.0004)	(0.001)	(0.0003)	(0.001)	(0.010)	(0.031)
Education of head (years)	−16.53	−36.64 **	0.004	−0.274 **	−0.097	−0.300 ***	2.884	0.999
	(11.45)	(17.24)	(0.089)	(0.137)	(0.066)	(0.099)	(2.587)	(4.353)
Education squared of head (years)	2.625 ***	3.696 **	0.007	0.027 **	0.016 ***	0.024 ***	−0.155	0.100
	(0.893)	(1.441)	(0.007)	(0.011)	(0.005)	(0.008)	(0.200)	(0.344)
Shock experience (dummy)	−69.56 **	−45.74	0.007	−0.107	−0.219	−0.197	−5.570	−16.05
	(30.80)	(37.53)	(0.245)	(0.308)	(0.180)	(0.226)	(7.406)	(10.23)
Land size (acres by GPS)	1.188	−0.926	0.026	−0.002	0.027 *	−0.001	0.650	−0.195
	(2.449)	(2.930)	(0.019)	(0.026)	(0.014)	(0.017)	(0.572)	(0.791)
Land size squared (acres by GPS)	−0.004	−0.002	-5×10^{-5} *	-2×10^{-5}	-5×10^{-5} **	-1×10^{-5}	−0.001	−0.0001
	(0.004)	(0.004)	(3×10^{-5})	(4×10^{-5})	(2×10^{-5})	(3×10^{-5})	(0.001)	(0.001)
Year 2010	34.99	57.38 *	0.264	0.295	−0.018	0.049	−18.11 **	−21.14 **
	(33.28)	(33.87)	(0.271)	(0.271)	(0.197)	(0.197)	(8.868)	(9.143)
Year 2011	9.166	49.32	0.227	0.301	−0.146	−0.006	−16.91 *	−21.48 **
	(33.37)	(34.52)	(0.271)	(0.277)	(0.197)	(0.203)	(8.818)	(9.088)
Mean values								
Distance to nearest market (kilometers)		−3.289		0.012		-9×10^{-5}		2.344 **
		(4.030)		(0.033)		(0.022)		(1.112)
Head uses mobile phone (dummy)		414.1 ***		1.812 ***		2.307 ***		−26.88
		(70.06)		(0.559)		(0.401)		(16.83)
Household size (Adult equivalents)		83.07 ***		0.630 ***		0.347 ***		7.138
		(20.59)		(0.162)		(0.115)		(4.865)
Male heads (dummy)		−321.8 ***		−2.184 **		−1.623 **		−8.542
		(118.8)		(0.849)		(0.675)		(32.82)
Age of head (years)		−21.40 **		−0.168 **		−0.124 **		−3.682
		(9.323)		(0.081)		(0.054)		(2.571)
Age squared of head (years)		0.266 **		0.001		0.001 **		0.046
		(0.111)		(0.001)		(0.001)		(0.034)
Education of head (years)		28.52		0.442 **		0.335 **		3.065
		(23.36)		(0.181)		(0.132)		(5.239)
Education squared of head (years)		−2.068		−0.032 **		−0.016		−0.341
		(1.859)		(0.015)		(0.011)		(0.405)
Shock experience (dummy)		−62.43		0.355		0.072		20.04
		(64.66)		(0.507)		(0.372)		(15.06)
Land size (acres by GPS)		4.323		0.052		0.057 *		1.322
		(5.002)		(0.038)		(0.029)		(1.004)
Land size squared (acres by GPS)		−0.004		-5.8×10^{-5}		-6.9×10^{-5}		−0.001
		(0.008)		(6.4×10^{-5})		(4.8×10^{-5})		(0.001)
Constant	4757 ***	4795 ***	20.53 ***	21.33 ***	14.76 ***	14.74 ***	322.5 ***	337.8 ***
	(115.1)	(145.8)	(0.892)	(1.196)	(0.657)	(0.900)	(25.50)	(31.11)
Observations	8574	8574	8574	8574	8574	8574	8574	8574
No. of households	3258	3258	3258	3258	3258	3258	3258	3258
Wald Chi2 value	358.80 ***	368.45 ***	229.67 ***	262.13 ***	344.79 ***	409.63 ***	138.00 ***	158.75 ***

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; rae-mcg is Retinal Activity Equivalents—micrograms; FPD is farm production diversity; GPS is Global Positioning System; MK is Mundlak estimation; RE is random effects estimation.

Appendix B

Table A2. Impact pathways of FPD on household daily energy and micronutrient intake.

	Energy (Kilocalories)	Iron (Milligrams)	Zinc (Milligrams)	Vitamin A (Rae−Mcg)
	MK (1)	MK (2)	MK (3)	MK (4)
Farm production diversity (biodiversity index)	1.758	0.050	0.047 **	1.962 **
	(3.788)	(0.031)	(0.022)	(0.920)
Daily per adult equivalent consumption via markets (Uganda shilling)	0.181 ***	0.001 ***	0.001 ***	0.004 *
	(0.011)	(8×10^{-5})	(6×10^{-5})	(0.002)
Daily per adult equivalent consumption from home production (Uganda shilling)	1.441 ***	0.012 ***	0.008 ***	0.297 ***
	(0.122)	(0.001)	(0.001)	(0.024)
Distance nearest market (kilometers)	−5.469	−0.064 *	−0.051 **	−2.286 **
	(4.576)	(0.034)	(0.025)	(1.114)
Head uses mobile phone (dummy)	−58.08	−0.806 *	−0.265	−9.416
	(51.44)	(0.427)	(0.304)	(13.50)
Household size (adult equivalent)	−112.8 ***	−0.802 ***	−0.403 ***	−10.38 **
	(18.82)	(0.146)	(0.103)	(4.244)
Male heads (dummy)	309.7 ***	1.857 **	1.804 ***	2.094
	(111.4)	(0.800)	(0.660)	(31.19)
Age of head (years)	−1.416	0.005	−0.034	0.608
	(8.259)	(0.069)	(0.046)	(2.287)
Age squared of head (years)	−0.053	3×10^{-5}	7×10^{-5}	−0.009
	(0.105)	(0.001)	(0.001)	(0.031)
Education of head (years)	−51.98 ***	−0.381 ***	−0.412 ***	0.340
	(17.98)	(0.142)	(0.104)	(4.392)
Educ. squared of head (years)	4.650 ***	0.033 ***	0.031 ***	0.158
	(1.511)	(0.012)	(0.009)	(0.347)
Shock experience (dummy)	−79.47 **	−0.348	−0.420 *	−19.31 *
	(38.32)	(0.312)	(0.232)	(10.29)
Land size (acres by GPS)	−0.738	-4×10^{-5}	0.001	−0.182
	(3.100)	(0.028)	(0.019)	(0.765)
Land size squared (acres by GPS)	−0.002	-2×10^{-5}	-2×10^{-5}	−0.0002
	(0.005)	(4×10^{-5})	(3×10^{-5})	(0.001)
Year 2010	14.86	−0.006	−0.254	−24.18 ***
	(34.57)	(0.276)	(0.202)	(9.125)
Year 2011	−86.24 **	−0.670 **	−0.951 ***	−32.36 ***
	(35.73)	(0.286)	(0.212)	(9.157)
Mean values				
Distance nearest market (kilometers)	3.501	0.061 *	0.048 *	2.864 **
	(4.647)	(0.034)	(0.025)	(1.136)
Head uses mobile phone (dummy)	315.4 ***	1.210 **	1.406 ***	−18.56
	(67.68)	(0.549)	(0.388)	(16.74)
Household size (adult equivalent)	33.76 *	0.264 *	0.019	2.247
	(20.41)	(0.159)	(0.113)	(4.808)
Male heads (dummy)	−369.5 ***	−2.534 ***	−1.959 ***	−12.27
	(118.2)	(0.857)	(0.695)	(32.58)
Age of head (years)	−9.029	−0.078	−0.037	−2.614
	(9.408)	(0.081)	(0.054)	(2.542)
Age squared of head (years)	0.151	0.001	0.001	0.032
	(0.114)	(0.001)	(0.001)	(0.033)
Education of head (years)	36.06	0.462 **	0.421 ***	0.013
	(22.98)	(0.180)	(0.130)	(5.222)
Educ. squared of head (years)	−3.404 *	−0.039 ***	−0.029 ***	−0.071
	(1.848)	(0.015)	(0.011)	(0.403)
Shock experience (dummy)	−70.67	0.268	0.115	13.27
	(61.18)	(0.486)	(0.346)	(14.86)
Land size (acres by GPS)	1.005	0.024	0.041	0.492
	(4.885)	(0.038)	(0.028)	(0.914)
Land size squared (acres by GPS)	0.001	-2×10^{-5}	-5×10^{-5}	5×10^{-5}
	(0.007)	(7×10^{-5})	(5×10^{-5})	(0.001)
Constant	3921 ***	15.36 ***	7.858 ***	327.3 ***
	(148.0)	(1.178)	(0.844)	(33.22)
Observations	8574	8574	8574	8574
No. of households	3258	3258	3258	3258
Wald Chi2 value	694.19 ***	579.94 ***	947.38 ***	325.80 ***

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; rae-mcg is Retinal Activity Equivalents—micrograms; GPS is Global Positioning System; MK is Mundlak estimation.

Appendix C

Table A3. Differential impacts of FPD on energy and micronutrient intake with regards to different consumption sources (markets vs. own production).

Variables	Energy (Kilocalories)		Iron (Milligrams)		Zinc (Milligrams)		Vitamin A (Rae−Mcg)	
	Markets	**Own Farm**	**Markets**	**Own Farm**	**Markets**	**Own Farm**	**Markets**	**Own Farm**
	MK (1)	**MK (2)**	**MK (3)**	**MK (4)**	**MK (5)**	**MK (6)**	**MK (7)**	**MK (8)**
FPD (biodiversity index)	−74.58 ***	20.75 ***	−0.208 ***	0.179 ***	−0.099 ***	0.098 ***	−2.535 ***	4.057 ***
	(10.94)	(2.423)	(0.029)	(0.023)	(0.020)	(0.012)	(0.507)	(0.927)
Distance to nearest market (kilometers)	−8.043	4.222 *	−0.017	0.014	−0.015	0.014	0.291	−2.215
	(10.43)	(2.450)	(0.028)	(0.026)	(0.019)	(0.013)	(0.995)	(1.636)
Head uses mobile phone (dummy)	104.7	−34.70	0.224	−0.391	0.272	−0.158	4.798	−10.80
	(142.4)	(33.79)	(0.378)	(0.303)	(0.256)	(0.161)	(7.200)	(14.71)
Household size (Adult equivalents)	−358.7 ***	−98.36 ***	−0.519 ***	−0.932 ***	−0.434 ***	−0.493 ***	−13.84 ***	−7.768
	(45.89)	(10.69)	(0.114)	(0.099)	(0.077)	(0.053)	(2.444)	(4.779)
Male heads (dummy)	444.7	111.8	1.232 *	0.652	0.825 *	0.529	1.182	11.39
	(280.4)	(76.69)	(0.740)	(0.690)	(0.495)	(0.374)	(14.91)	(36.30)
Age of head (years)	15.90	1.514	0.005	0.059	0.008	0.021	0.824	0.368
	(21.55)	(4.757)	(0.058)	(0.047)	(0.039)	(0.024)	(1.499)	(2.331)
Age squared of head (years)	−0.215	−0.002	-9×10^{-5}	-3×10^{-4}	-8×10^{-5}	−0.0002	−0.016	0.008
	(0.263)	(0.060)	(0.001)	(0.001)	(0.001)	(0.0003)	(0.022)	(0.027)
Education of head (years)	−33.75	−8.453	−0.090	−0.115	−0.123	−0.049	−2.612	3.381
	(47.40)	(11.47)	(0.124)	(0.106)	(0.084)	(0.056)	(2.686)	(4.895)
Education squared of head (years)	6.028	0.535	0.012	0.007	0.012 *	0.003	0.467 **	−0.357
	(3.925)	(1.002)	(0.010)	(0.009)	(0.007)	(0.005)	(0.226)	(0.397)
Shock experience (dummy)	5.254	−54.36 **	−0.009	−0.389 *	−0.009	−0.227 *	−5.863	−9.351
	(103.6)	(24.82)	(0.273)	(0.228)	(0.189)	(0.119)	(6.238)	(10.59)
Land size (acres by GPS)	5.714	−2.876	0.024	−0.027 *	0.017	−0.015 **	0.216	−1.185 *
	(6.710)	(1.777)	(0.020)	(0.015)	(0.013)	(0.007)	(0.779)	(0.660)
Land size squared (acres by GPS)	−0.015	0.004	-5×10^{-5}	4×10^{-5} *	-4×10^{-5} *	2×10^{-5} **	-5×10^{-5}	0.001
	(0.009)	(0.003)	(3×10^{-5})	(2×10^{-5})	(2×10^{-5})	(1×10^{-5})	(0.001)	(0.001)
Year 2010	−25.37	61.01 ***	−0.232	0.363 *	−0.219	0.304 ***	−11.41 **	−17.34 *
	(92.81)	(23.16)	(0.248)	(0.210)	(0.169)	(0.111)	(5.689)	(10.08)
Year 2011	184.9 *	−18.24	0.371	−0.220	0.173	−0.078	−9.840 *	−19.02 *
	(95.15)	(23.09)	(0.252)	(0.211)	(0.171)	(0.110)	(5.869)	(9.923)
Means of variables								
Distance to nearest market (kilometers)	−10.29	−2.665	−0.019	−0.004	−0.004	−0.006	−0.266	2.483
	(10.77)	(2.520)	(0.029)	(0.026)	(0.019)	(0.013)	(1.004)	(1.660)
Head uses mobile phone (dummy)	1624 ***	58.38	2.876 ***	0.434	2.577 ***	0.326	11.95	−12.25
	(198.4)	(46.05)	(0.528)	(0.409)	(0.361)	(0.217)	(9.596)	(18.49)
Household size (Adult Equivalents)	15.05	55.85 ***	−0.099	0.479 ***	−0.033	0.268 ***	−0.190	6.113
	(53.05)	(12.33)	(0.135)	(0.113)	(0.092)	(0.059)	(2.867)	(5.455)
Male heads (dummy)	−888.8 ***	−33.60	−1.989 **	−0.378	−1.015 *	−0.278	−13.15	−20.22
	(308.0)	(81.26)	(0.818)	(0.731)	(0.549)	(0.396)	(16.13)	(38.07)
Age of head (years)	−38.30	−2.190	−0.038	−0.058	−0.042	−0.020	−0.718	−3.337
	(28.30)	(6.153)	(0.076)	(0.059)	(0.053)	(0.031)	(1.720)	(2.623)
Age squared of head (years)	0.331	0.019	0.0002	0.0004	0.0002	0.0002	0.012	0.028
	(0.323)	(0.071)	(0.001)	(0.001)	(0.001)	(0.0004)	(0.024)	(0.029)
Education of head (years)	−133.9 **	30.01 *	−0.234	0.297 **	−0.018	0.131 *	−7.511 **	9.263
	(64.72)	(15.83)	(0.173)	(0.143)	(0.118)	(0.076)	(3.285)	(6.172)
Education squared of head (years)	14.54 ***	−3.371 ***	0.033 **	−0.030 **	0.015 *	−0.014 **	0.641 **	−0.798
	(5.108)	(1.307)	(0.014)	(0.012)	(0.009)	(0.006)	(0.263)	(0.499)
Shock experience (dummy)	−269.9	−15.99	0.323	−0.321	0.042	−0.063	−2.804	2.583
	(183.7)	(42.90)	(0.479)	(0.384)	(0.330)	(0.203)	(9.538)	(16.37)
Land size (acres by GPS)	−39.00 **	11.92 ***	−0.102 **	0.093 ***	−0.052 *	0.058 ***	0.001	1.065
	(16.49)	(2.852)	(0.042)	(0.020)	(0.028)	(0.011)	(1.005)	(1.083)
Land size squared (acres by GPS)	0.066 ***	−0.019 ***	-2×10^{-4} ***	-2×10^{-4} ***	9×10^{-5} **	-9×10^{-5} ***	3×10^{-4}	−0.001
	(0.023)	(0.004)	(6×10^{-5})	(4×10^{-5})	(4×10^{-5})	(2×10^{-5})	(0.001)	(0.002)
Constant	13,104 ***	1632 ***	18.97 ***	9.411 ***	11.15 ***	3.092 ***	250.4 ***	270.6 ***
	(437.1)	(103.4)	(1.183)	(0.927)	(0.829)	(0.499)	(19.40)	(37.68)
Observations	8310	6373	8310	6373	8310	6373	8310	6373
No. of households	3207	2633	3207	2633	3207	2633	3207	2633
Wald Chi2 value	929.55 ***	278.44 ***	542.38 ***	275.79 ***	623.55 ***	275.61 ***	347.1 ***	337.03 ***

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; rae-mcg is Retinal Activity Equivalents—micrograms; GPS is Global Positioning System; MK is Mundlak estimation.

Appendix D

Specification of the Three-Stage Least Squares regressions (3SLS)

We ran robustness checks on our main FPD results for impact pathways on daily energy and micronutrient intake following a 3SLS procedure in Equations (A1) to (A4). Essentially, first, we estimated reduced equations individually, then after, estimated structural Equations (results of (A4) fed into (A2) and (A3)) individually in second stage. Then finally, we used results from the second stage in the core Equation (A1). Note that this system of equations was estimated simultaneously. The procedure is based on explanations of Zellner and Theil (1962). We have also executed tests of identification to establish the viability of variables used as system instruments.

$$EM_{it} = \alpha_0 + \alpha_1 OwnFarm_{it} + \alpha_2 Markets_{it} + \alpha_3 \boldsymbol{X}_{it} + \alpha_4 T_t + \varepsilon_{it2} \quad (A1)$$

$$OwnFarm_{it} = \beta_0 + \beta_1 FPD_{it} + \beta_2 \boldsymbol{Y}_{it} + \beta_3 T_t + \varepsilon_{it3} \quad (A2)$$

$$Markets_{it} = \gamma_0 + \gamma_1 FPD_{it} + \gamma_2 \boldsymbol{Z}_{it} + \gamma_3 T_t + \varepsilon_{it4} \quad (A3)$$

$$FPD_{it} = \delta_0 + \delta_1 \boldsymbol{A}_{it} + \delta_2 T_t + \varepsilon_{it5} \quad (A4)$$

where EM_{it} is daily energy or micronutrient intake (iron, zinc, or vitamin A) of household i in year t, $OwnFarm_{it}$ is the daily own farm generated household per capita food consumption expenditure in UGX. $Markets_{it}$ is the market generated daily household per capita food consumption expenditure from market channels (direct purchases consumed at home, those purchased and consumed away from homes, and consumption from in-kind sources). FPD_{it} is farm production diversity of household i in year t. Parameters to be estimated included α, β, γ, and δ while ε is the random error term. T is the year identifier, $\boldsymbol{X}$, $\boldsymbol{Y}$, $\boldsymbol{Z}$, and $\boldsymbol{A}$ are respectively vectors of household, contextual, and farm characteristics that affect household daily energy and micronutrient intake, own farm production consumption value, market-sourced consumption value, and farm production diversity for instance: age, gender, and education of the head, household size, farm size, accessibility to markets, and agricultural extension access, locality etc.

Theoretically, FPD could positively influence own farm food consumption and the market sourced one, which could both positively influence energy or micronutrient intake. Further, farm or market-sourced food consumption are endogenous because both could theoretically be influenced by FPD. Energy or micronutrient intake are also thus endogenous since both could be directly influenced by own farm consumption or the market-based one. Besides, own farm or market-based consumption could reversely be driven by consumers' energy or micronutrient values. For instance, if a household bears a favorable or non-favorable energy or micronutrient value, this could determine household's food expenditure via either consumption pathway (own farm or markets). The 3SLS technique enables specification of endogenous variables that are instrumented by other covariates, thus controlling endogeneity. Subsequently, the system of equations is estimated simultaneously yielding successively independent error terms that are homoscedastic and with a zero mean [34]. For this estimation, exogenous variables were: size, gender, type of land tenure, distance to nearest market, age, elevation, location dummy, household annual precipitation, year dummy, education of household head, land size, value of productive assets, and if households had access to extension services or experienced consumption shocks. From the available exogenous variables, the system automatically selects instruments to instrument pre-selected endogenous variables.

Appendix E

Table A4. FPD impact pathways for daily household energy intake using simultaneous equations.

Variables	Energy (Kilocalories)	Daily per AE Consumption via Markets (UGX)	Daily per AE Consumption from Home Production (UGX)	Farm Production Diversity (Biodiversity Index)
	(1)	(2)	(3)	(4)
Daily per AE consumption via markets (UGX)	0.842 *** (0.063)			
Daily per AE consumption from home production (UGX)	5.129 *** (0.447)			
Farm production diversity (biodiversity index)		−70.63 *** (21.45)	67.30 *** (1.940)	
Distance to nearest market (kilometers)	−4.965 *** (1.044)	−0.376 (1.130)		
Head uses mobile phone (dummy)	−1122 *** (248.0)	1502 *** (338.3)	−290.0 *** (22.33)	
Household size (Adult equivalents)	78.52 *** (20.59)	−232.4 *** (16.48)	−14.05 *** (1.947)	0.424 *** (0.020)
Male heads (dummy)	−79.48 ** (36.45)	66.80 (42.80)	−17.34 *** (5.614)	0.655 *** (0.099)
Age of head (years)	−6.928 (4.757)	−1.963 (2.083)	−1.746 *** (0.178)	0.017 *** (0.003)
Age squared of head (years)	0.041 (0.046)			
Education of head (years)	−26.36 ** (12.99)	42.32 *** (11.60)	4.855 *** (1.058)	0.027 ** (0.011)
Education squared of head (years)	1.414 * (0.859)			
Shock experience (dummy)	−248.1 *** (36.96)	106.3 *** (38.59)	−14.60 *** (4.894)	0.437 *** (0.092)
Land size (acres by GPS)	−3.814 (2.489)		−0.677 *** (0.137)	0.017 *** (0.003)
Land size squared (acres by GPS)	0.001 (0.004)			
Year 2010	−147.3 *** (40.13)	165.8 *** (54.16)	81.90 *** (5.906)	−0.913 *** (0.108)
Year 2011	−540.7 *** (57.12)	518.7 *** (58.67)	36.78 *** (6.525)	0.607 *** (0.109)
Urban household (dummy)		747.5 *** (100.8)		
Productive assets (UGX)			1×10^{-7} *** (3×10^{-8})	-1×10^{-9} *** (5×10^{-10})
Access to extension services (dummy)				0.779 *** (0.088)
Free/lease hold land tenure (dummy)				1.759 *** (0.079)
Annual precipitation (mm)				0.002 *** (0.0002)
Elevation (meters)				−0.001 *** (0.0001)
Constant	518.2 (324.6)	5184 *** (205.7)	−336.2 *** (24.77)	6.399 *** (0.344)
Observations	8490	8490	8490	8490
Chi2 value	568.58 ***	2795.66 ***	4371.26 ***	1708.34 ***

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; GPS is Global Positioning System; AE is adult equivalent; UGX is Uganda shilling (1 US$ = 3500 UGX).

Appendix F

Table A5. FPD impact pathways on daily household iron intake using simultaneous equations.

Variables	Iron (Milligrams)	Daily per AE Consumption via Markets (UGX)	Daily per AE Consumption from Home Production (UGX)	Farm Production Diversity (Biodiversity Index)
	(1)	(2)	(3)	(4)
Daily per AE consumption via markets (UGX)	0.008 ***			
	(0.001)			
Daily per AE consumption from home production (UGX)	0.047 ***			
	(0.005)			
Farm production diversity (biodiversity index)		−55.01 **	67.39 ***	
		(21.61)	(1.940)	
Distance to nearest market (kilometers)	−0.035 ***	−0.715		
	(0.011)	(1.132)		
Head uses mobile phone (dummy)	−14.44 ***	1399 ***	−289.2 ***	
	(2.701)	(339.4)	(22.34)	
Household size (Adult equivalents)	0.962 ***	−235.7 ***	−14.13 ***	0.423 ***
	(0.225)	(16.49)	(1.947)	(0.020)
Male heads (dummy)	−0.707 *	62.52	−17.42 ***	0.655 ***
	(0.394)	(42.80)	(5.614)	(0.099)
Age of head (years)	−0.052	−2.742	−1.745 ***	0.017 ***
	(0.052)	(2.091)	(0.178)	(0.003)
Age squared of head (years)	0.0001			
	(0.001)			
Education of head (years)	0.026	44.23 ***	4.817 ***	0.027 **
	(0.142)	(11.62)	(1.059)	(0.011)
Education squared of head (years)	−0.002			
	(0.009)			
Shock experience (dummy)	−1.604 ***	100.0 ***	−14.58 ***	0.435 ***
	(0.400)	(38.61)	(4.894)	(0.092)
Land size (acres by GPS)	−0.020		−0.682 ***	0.017 ***
	(0.027)		(0.137)	(0.003)
Land size squared (acres by GPS)	-7×10^{-6}			
	(4×10^{-5})			
Year 2010	−1.179 ***	188.9 ***	81.96 ***	−0.913 ***
	(0.434)	(54.33)	(5.906)	(0.108)
Year 2011	−4.149 ***	527.0 ***	36.65 ***	0.605 ***
	(0.619)	(58.73)	(6.526)	(0.109)
Urban household (dummy)		805.6 ***		
		(101.5)		
Productive assets (UGX)			1×10^{-7} ***	-1×10^{-9} ***
			(3×10^{-8})	(5×10^{-10})
Access to extension services (dummy)				0.813 ***
				(0.089)
Free/lease hold land tenure (dummy)				1.745 ***
				(0.079)
Annual precipitation (mm)				0.002 ***
				(0.0002)
Elevation (meters)				−0.001 ***
				(0.0001)
Constant	−1.101	5091 ***	−337.2 ***	6.417 ***
	(3.542)	(206.1)	(24.78)	(0.345)
Observations	8490	8490	8490	8490
Chi2 value	291.58 ***	2794.26 ***	4372.02 ***	1706.00 ***

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; GPS is Global Positioning System; AE is adult equivalent; UGX is Uganda shilling (1 US$ = 3500 UGX).

Appendix G

Table A6. FPD impact pathways towards daily household zinc intake using simultaneous equations.

Variables	Zinc (Milligrams)	Daily per AE Consumption via Markets (UGX)	Daily per AE Consumption from Home Production (UGX)	Farm Production Diversity (Biodiversity Index)
	(1)	(2)	(3)	(4)
Daily per AE consumption via markets (UGX)	0.004 *** (0.0003)			
Daily per AE consumption from home production (UGX)	0.019 *** (0.002)			
Farm production diversity (biodiversity index)		−61.46 *** (21.70)	67.35 *** (1.940)	
Distance to nearest market (kilometers)	−0.011 ** (0.005)	−0.547 (1.133)		
Head uses mobile phone (dummy)	−4.276 *** (1.277)	1466 *** (340.0)	−289.8 *** (22.34)	
Household size (Adult equivalents)	0.383 *** (0.107)	−235.3 *** (16.49)	−14.10 *** (1.947)	0.423 *** (0.020)
Male heads (dummy)	−0.079 (0.185)	63.01 (42.80)	−17.38 *** (5.614)	0.655 *** (0.099)
Age of head (years)	−0.025 (0.025)	−2.308 (2.095)	−1.748 *** (0.178)	0.0167 *** (0.003)
Age squared of head (years)	0.0001 (0.0002)			
Education of head (years)	−0.058 (0.067)	42.68 *** (11.63)	4.838 *** (1.059)	0.027 ** (0.011)
Education squared of head (years)	0.003 (0.005)			
Shock experience (dummy)	−0.799 *** (0.189)	103.2 *** (38.62)	−14.59 *** (4.894)	0.435 *** (0.092)
Land size (acres by GPS)	0.002 (0.013)		−0.681 *** (0.137)	0.017 *** (0.003)
Land size squared (acres by GPS)	-1.9×10^{-5} (2.1×10^{-5})			
Year 2010	−0.793 *** (0.204)	178.0 *** (54.43)	81.95 *** (5.906)	−0.913 *** (0.108)
Year 2011	−2.386 *** (0.292)	520.4 *** (58.77)	36.75 *** (6.526)	0.605 *** (0.109)
Urban household (dummy)		774.5 *** (102.0)		
Productive assets (UGX)			1×10^{-7} *** (3×10^{-8})	-1×10^{-9} *** (5×10^{-10})
Access to extension services (dummy)				0.810 *** (0.089)
Free/lease hold land tenure (dummy)				1.746 *** (0.079)
Annual precipitation (mm)				0.002 *** (0.0002)
Elevation (meters)				−0.001 *** (0.0002)
Constant	−2.381 (1.677)	5121 *** (206.4)	−336.5 *** (24.78)	6.427 *** (0.345)
Observations	8490	8490	8490	8490
Chi2 value	432.04 ***	2791.94 ***	4372.63 ***	1706.12 ***

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$; GPS is Global Positioning System; AE is adult equivalent; UGX is Uganda shilling (1 US$ = 3500 UGX).

Appendix H

Table A7. FPD impact pathways towards daily household vitamin A intake using simultaneous equations.

Variables	Vitamin A (RAE—Micrograms)	Daily per AE Consumption via Markets (UGX)	Daily per AE Consumption from Home Production (UGX)	Farm Production Diversity (Biodiversity Index)
	(1)	(2)	(3)	(4)
Daily per AE consumption via markets (UGX)	−0.102 ** (0.044)			
Daily per AE consumption from home production (UGX)	0.972 *** (0.302)			
Farm production diversity (biodiversity index)		−59.20 *** (22.01)	67.38 *** (1.940)	
Distance to nearest market (kilometers)	1.862 *** (0.696)	−0.604 (1.137)		
Head uses mobile phone (dummy)	223.8 (168.2)	1444 *** (342.1)	−289.6 *** (22.35)	
Household size (Adult equivalents)	−63.20 *** (14.11)	−235.5 *** (16.51)	−14.12 *** (1.947)	0.423 *** (0.020)
Male heads (dummy)	−6.315 (24.06)	62.77 (42.81)	−17.40 *** (5.614)	0.655 *** (0.099)
Age of head (years)	0.246 (3.303)	−2.454 (2.109)	−1.747 *** (0.178)	0.017 *** (0.003)
Age squared of head (years)	0.002 (0.032)			
Education of head (years)	−17.96 ** (8.908)	43.19 *** (11.66)	4.829 *** (1.059)	0.027 ** (0.011)
Education squared of head (years)	1.991 *** (0.600)			
Shock experience (dummy)	−24.47 (24.54)	102.1 *** (38.66)	−14.59 *** (4.894)	0.435 *** (0.092)
Land size (acres by GPS)	1.435 (1.715)		−0.682 *** (0.137)	0.017 *** (0.003)
Land size squared (acres by GPS)	−0.003 (0.003)			
Year 2010	−56.89 ** (26.53)	181.7 *** (54.77)	81.97 *** (5.906)	−0.913 *** (0.108)
Year 2011	−57.21 (38.15)	522.6 *** (58.90)	36.71 *** (6.526)	0.605 *** (0.109)
Urban household (dummy)		785.0 *** (103.5)		
Productive assets (UGX)			1×10^{-7} *** (3×10^{-8})	-1×10^{-9} *** (5×10^{-10})
Access to extension services (dummy)				0.814 *** (0.089)
Free/lease hold land tenure (dummy)				1.744 *** (0.079)
Annual precipitation (mm)				0.002 *** (0.0002)
Elevation (meters)				−0.001 *** (0.0002)
Constant	3435 *** (221.6)	5110 *** (207.3)	−336.8 *** (24.78)	6.409 *** (0.346)
Observations	8490	8490	8490	8490
Chi2 value	234.77 ***	2791.83 ***	4373.51 ***	1705.59 ***

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$; rae-mcg is Retinal Activity Equivalents—micrograms; GPS is Global Positioning System; AE is adult equivalent; UGX is Uganda shilling (1 US$ = 3500 UGX).

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