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 3,300 households, we study linkages between FPD and nutrition, and associated impact pathways. We analyze the data using panel regression models. Results show that at least half of sample was deficient in daily energy, iron, zinc, and vitamin A intake, given FAO recommended thresholds. Deficiencies were most severe (85%) with vitamin A. However, positive and significant associations between FPD and daily household energy, iron, zinc, and vitamin A intake exist. FPD impacts energy and micronutrient intake via two main consumption pathways; markets, and own farm production. The own farm production pathway yields better outcomes. Gender effects also exist, as male-headed households exhibited better nutrition outcomes especially via the markets consumption pathway.

Key words: farm production diversity, panel data, nutrition, energy, iron, zinc, vitamin A, Uganda

JEL codes: C33, C55, D02, Q12, Q18

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, 4, 5, 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 systems 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, 9, 10]. These authors argue that enabling households to access markets where they can sell their produce competitively, enables households 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, 14, 15, 16, 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, 9, 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.

1.1. 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].

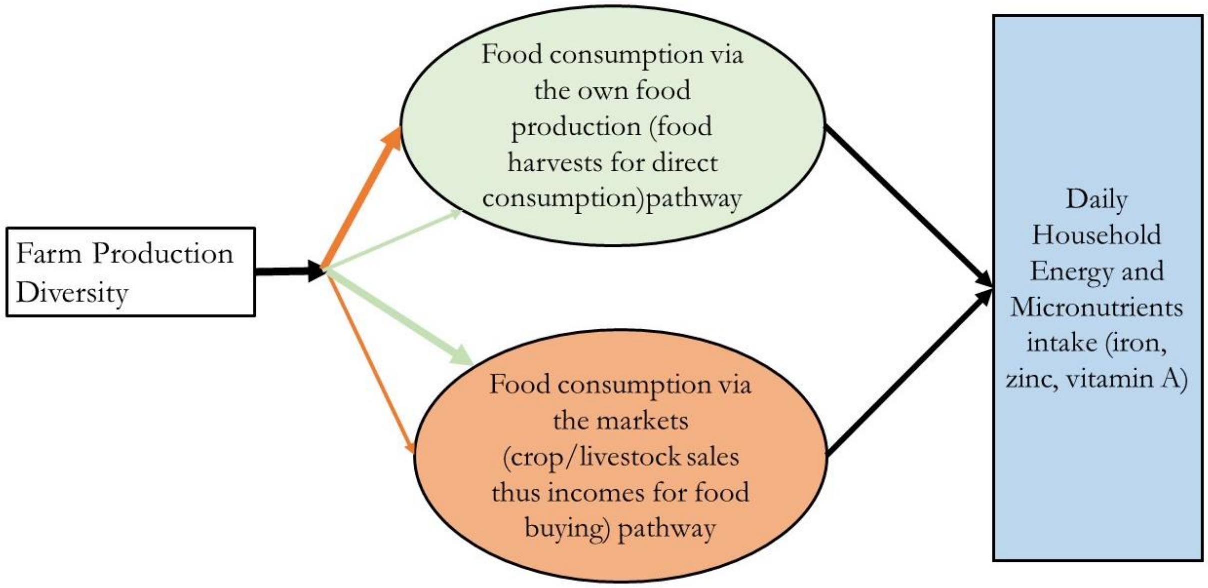

Figure 1: FPD impact consumption pathways for energy and micronutrients intake

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 two same color arrows via the two perceived consumption pathways. Nevertheless, we hypothesize that these differential impacts are stronger via the own farm production consumption pathway, since our sample is largely of subsistence smallholder farmers.

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) markets 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, that are used to purchase food for daily energy and micronutrient requirements. We rely on such conceptualization to answer research questions above.

2. Methods and Data

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 3,300 households. The UNPS is a subsection of the 2005/6 Uganda National Household Survey (UNHS) that is nationally representative and comprising of 6,775 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.

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 farm. 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 shillings (UGX), (1 US$ = 3,500 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 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 whom 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 linkages between farm production diversity (FPD) and daily household energy and micronutrient intake, we employ panel regression models illustrated in equation 1.

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

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. Because 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. But, 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.

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

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.

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.

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

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. 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), and present results after discussions.

3. Results and Discussions

3.1. Descriptive Results

We present descriptive statistics in Table 1 for variables used in regressions. On average, household consumption expenditure was higher on markets sourced foods (1,820 UGX) compared to that from own farms (888 UGX). This doesn't 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. Households were mostly rural (77%), and located about 30 kilometers from 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)	1,819.62	2,204.26
Daily per capita consumption from Own production (UGX)	888.24	841.14
Distance to nearest major market (kilometers)	29.543	20.016
Annual Precipitation (mm)	1,237.61	182.572
Elevation (meters)	1,228.23	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 – AE)	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 measured by GPS)	3.282	20.217
Free/lease hold land holders (percentage)	33.678	47.264
Accessed extension services (percentage)	18.255	38.632

Source: Authors Calculations (1 US$ = 3,500 UGX)

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 outcomes 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, depicting 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].

Table **2**: Descriptive statistics for nutrition outcome variables

Daily household energy and micronutrients intake per AE	Mean	Std. dev.
Total from all sources (N=8,574)		
Energy (Kilocalories)	2,636	1,567
Iron (milligrams)	19.70	11.02
Zinc (milligrams)	13.36	8.156
Vitamin A (RAE – micrograms)	331.9	329.7
Markets sourced (N=8,311)		
Energy (Kilocalories)	1,726	1,481
Iron (milligrams)	11.74	10.66
Zinc (milligrams)	9.270	8.302
Vitamin A (RAE – micrograms)	145.7	205.9
Own farm sourced (N=6,374)		
Energy (Kilocalories)	1,227	1,133
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=8,574)		
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)	2,400	
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

From Table 2, energy, iron, and zinc were mainly sourced from markets unlike vitamin A. These findings concur with recent evidence pointing to home production of fruits and vegetables (dominant sources of vitamin A) being associated with more diversity in dietary intakes [14, 15].

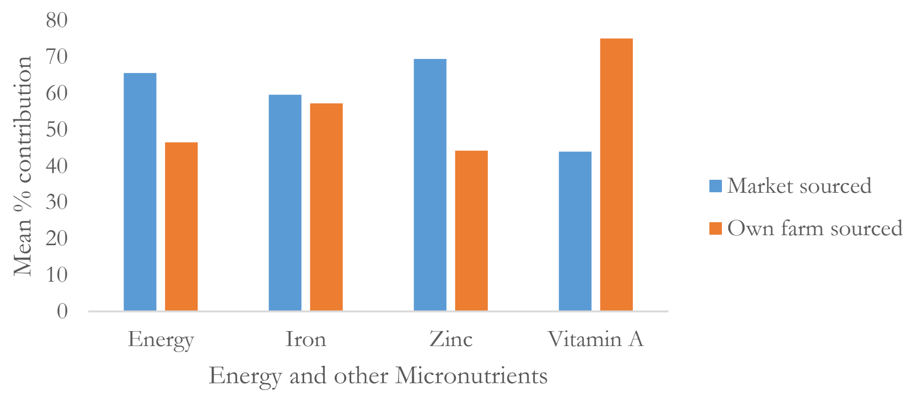

Figure 2. Source (markets or own farm) mean percentage contribution to total daily energy and micronutrient intake per AE

We make graphical illustrations of energy and micronutrient sources in Figure 2. The disparity in dominance of sources may be explained by samples' cultural and social behavior. For instance, foods like vegetables and fruits, are 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 micronutrients intake by source. Such disaggregation is instrumental in establishing appropriate sustainable interventions.

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	7.711**	6.535*	0.114***	0.102***	0.066***	0.058**	5.004***	4.704***
index)	(3.868)	(3.906)	(0.030)	(0.031)	(0.022)	(0.023)	(0.873)	(0.900)
Distance nearest	-1.493*	2.275	0.005	-0.006	-0.003	-0.0001	0.963***	-1.408
main market (km)	(0.897)	(3.918)	(0.007)	(0.032)	(0.005)	(0.021)	(0.182)	(1.087)
Head uses mobile	217.8***	-23.11	0.627**	-0.557	1.442***	-0.007	-27.05***	-7.935
phone (dummy)	(35.10)	(50.66)	(0.276)	(0.420)	(0.203)	(0.292)	(7.991)	(13.51)
Household size	-126.9***	-194.5***	-0.877***	-1.382***	-0.691***	-0.994***	-9.353***	-15.16***
(adult 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	-0.028	-0.214**	-0.0004	-0.001	-0.0001	-0.001**	0.015	-0.025
head (years)	(0.047)	(0.097)	(0.0004)	(0.001)	(0.0003)	(0.001)	(0.010)	(0.031)
Education of head	-16.53	-36.64**	0.004	-0.274**	-0.097	-0.300***	2.884	0.999
(years)	(11.45)	(17.24)	(0.089)	(0.137)	(0.066)	(0.099)	(2.587)	(4.353)
Educ. squared of	2.625***	3.696**	0.007	0.027**	0.016***	0.024***	-0.155	0.100
head (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 (GPS	1.188	-0.926	0.026	-0.002	0.027*	-0.001	0.650	-0.195
meters)	(2.449)	(2.930)	(0.019)	(0.026)	(0.014)	(0.017)	(0.572)	(0.791)
Land size squared	-0.004	-0.002	-5.4e-5*	-1.8e-5	-4.9e-5**	-1.3e-5	-0.001	-0.0001
(GPS meters)	(0.004)	(0.004)	(3.1e-5)	(4.0e-5)	(2.3e-5)	(2.7e-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	4,757***	4,795***	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	8,574	8,574	8,574	8,574	8,574	8,574	8,574	8,574
No. households	3,258	3,258	3,258	3,258	3,258	3,258	3,258	3,258
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; see Appendix A for details.

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.

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. These effects 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, increasing household size was negatively and significantly associated with all nutrition outcomes. With more persons, available food per capita decreases, hence reductions in nutrition outcomes. Surprisingly, gender effects were explicit. Male headed households were associated with significantly better nutrition outcomes. This 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.

In Table 4, we present results after estimating equation 2. However, 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). When we control for consumption pathways, for each added livestock or crop species, daily intake reduces 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. This confirms that indeed food consumption via markets or own farm are FPD impact pathways for households to attain about 72%, 50%, 17%, and 60% of their daily intake for energy, iron, zinc, and vitamin A respectively. Besides, daily consumption from either source exhibits a strong significant and positive association with nutrition outcomes.

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

Variables	**Energy (kilocalories)** MK(1)	**Iron (milligrams)** MK(2)	**Zinc (milligrams)** MK(3)	**Vitamin A (rae-mcg)** MK(4)
FPD (biodiversity index)	1.758	0.050	0.047**	1.962**
	(3.788)	(0.031)	(0.022)	(0.920)
Daily per AE Consumption via	0.181***	0.001***	0.001***	0.004*
Markets (UGX)	(0.011)	(8.1e-5)	(6.3e-5)	(0.002)
Daily per AE Consumption from	1.441***	0.012***	0.008***	0.297***
Home production (UGX)	(0.122)	(0.001)	(0.001)	(0.024)
Distance nearest main market (km)	-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 head (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	2.9e-5	7.3e-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 (GPS meters)	-0.738	-4.4e-5	0.001	-0.182
	(3.100)	(0.028)	(0.019)	(0.765)

Land size squared (GPS meters)	-0.002	-2.4e-5	-1.9e-5	-0.0002
	(0.005)	(4.3e-5)	(2.9e-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	Yes	Yes	Yes	Yes
Constant	3,921***	15.36***	7.858***	327.3***
	(148.0)	(1.178)	(0.844)	(33.22)
Observations	8,574	8,574	8,574	8,574
No. of households	3,258	3,258	3,258	3,258
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; see appendix B for details

However, by the fact that FPD remains 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.

In Table 5, we present results after estimating equation 3. Results reveal that 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. These results were however not surprising. Because our sample was predominantly made of subsistence smallholder farmers, less produce was sold in 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 the 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 the own farm production consumption pathway. This is in agreement with [3, 6] who established that most households in Uganda, especially rural ones did mostly consume from 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 micronutrients 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 contributing to nutrition outcomes via the own farm production 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-mc)	
	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)
Farm production D	-74.58***	20.75***	-0.208***	0.179***	-0.099***	0.098***	-2.535***	4.057***
(biodiversity index)	(10.94)	(2.423)	(0.029)	(0.023)	(0.020)	(0.012)	(0.507)	(0.927)
Distance to nearest	-8.043	4.222*	-0.017	0.014	-0.015	0.014	0.291	-2.215
market (kilometers)	(10.43)	(2.450)	(0.028)	(0.026)	(0.019)	(0.013)	(0.995)	(1.636)
Head uses mobile	104.7	-34.70	0.224	-0.391	0.272	-0.158	4.798	-10.80
phone (dummy)	(142.4)	(33.79)	(0.378)	(0.303)	(0.256)	(0.161)	(7.200)	(14.71)
Household size (Adult	-358.7***	-98.36***	-0.519***	-0.932***	-0.434***	-0.493***	-13.84***	-7.768
Equivalents)	(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	-0.215	-0.002	-8.6e-5	-0.0003	-7.9e-5	-0.0002	-0.016	0.008
(years)	(0.263)	(0.060)	(0.001)	(0.001)	(0.001)	(0.0003)	(0.022)	(0.027)
Education of head	-33.75	-8.453	-0.090	-0.115	-0.123	-0.049	-2.612	3.381
(years)	(47.40)	(11.47)	(0.124)	(0.106)	(0.084)	(0.056)	(2.686)	(4.895)
Education squared of	6.028	0.535	0.012	0.007	0.012*	0.003	0.467**	-0.357
head (years)	(3.925)	(1.002)	(0.010)	(0.009)	(0.007)	(0.005)	(0.226)	(0.397)
Shock experience	5.254	-54.36**	-0.009	-0.389*	-0.009	-0.227*	-5.863	-9.351
(dummy)	(103.6)	(24.82)	(0.273)	(0.228)	(0.189)	(0.119)	(6.238)	(10.59)
Land size (GPS	5.714	-2.876	0.024	-0.027*	0.017	-0.015**	0.216	-1.185*
meters)	(6.710)	(1.777)	(0.020)	(0.015)	(0.013)	(0.007)	(0.779)	(0.660)
Land size squared	-0.015	0.004	-4.9e-5	3.9e-5*	-3.6e-5*	2.3e-5**	-4.8e-5	0.001
(GPS meters)	(0.009)	(0.003)	(3.1e-5)	(2.2e-5)	(2.1e-5)	(1.0e-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***	1,632***	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	8,310	6,373	8,310	6,373	8,310	6,373	8,310	6,373
No. of households	3,207	2,633	3,207	2,633	3,207	2,633	3,207	2,633
Wald Chi2 value	929.55***	278.44***	542.38***	275.79***	623.55***	275.61***	347.1***	337.03***

Robust standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$. See appendix C for details

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. This 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, 32, 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.

3.3. Robustness check

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 appendices E, F, G, and 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.

4. 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 associated positively to daily energy, iron, zinc, or vitamin A intake. Moreover, markets and own farm production were indeed important impact pathways through which FPD influenced nutrition outcomes. However, although households gained positive increments towards daily household energy and micronutrient intake via both consumption pathways, larger increments were attained via the own farm production consumption pathway. Therefore, for the case of Uganda by investments focusing on improving household nutrition outcomes via consumption of own farm produce could yield better nutrition outcomes than a markets focus. Remoteness and relatively poor markets 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, that were mostly realized via the markets consumption pathways.

However, our results may not be generalized since some evidence from other countries has pointed to markets being more important towards nutrition outcomes. We have also explored the data with a limited number of macro and micronutrients, hence extending the scope to other nutrition outcomes would help better understand the linkages between FPD and household nutrition more comprehensively. Nevertheless, with the rigor exhibited in analyzing such a panel data, we are optimistic that our conclusions are binding especially for Uganda and countries of similar contextual characteristics.

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Appendices

Appendix A: 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)
Farm production D	7.711**	6.535*	0.114***	0.102***	0.066***	0.058**	5.004***	4.704***
(biodiversity index)	(3.868)	(3.906)	(0.030)	(0.031)	(0.022)	(0.023)	(0.873)	(0.900)
Distance to nearest	-1.493*	2.275	0.005	-0.006	-0.003	-0.0001	0.963***	-1.408
market (kilometers)	(0.897)	(3.918)	(0.007)	(0.032)	(0.005)	(0.021)	(0.182)	(1.087)
Head uses mobile	217.8***	-23.11	0.627**	-0.557	1.442***	-0.007	-27.05***	-7.935
phone (dummy)	(35.10)	(50.66)	(0.276)	(0.420)	(0.203)	(0.292)	(7.991)	(13.51)
Household size	-126.9***	-194.5***	-0.877***	-1.382***	-0.691***	-0.994***	-9.353***	-15.16***
(Adult Equivalents)	(7.907)	(18.45)	(0.061)	(0.145)	(0.045)	(0.100)	(1.696)	(4.266)
Male heads	23.79	279.9**	-0.046	1.642**	0.352	1.574**	-6.288	0.855
(dummy)	(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	-0.028	-0.214**	-0.0004	-0.001	-0.0001	-0.001**	0.015	-0.025
head (years)	(0.047)	(0.097)	(0.0004)	(0.001)	(0.0003)	(0.001)	(0.010)	(0.031)
Education of head	-16.53	-36.64**	0.004	-0.274**	-0.097	-0.300***	2.884	0.999
(years)	(11.45)	(17.24)	(0.089)	(0.137)	(0.066)	(0.099)	(2.587)	(4.353)
Education squared	2.625***	3.696**	0.007	0.027**	0.016***	0.024***	-0.155	0.100
of head (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 (GPS	1.188	-0.926	0.026	-0.002	0.027*	-0.001	0.650	-0.195
meters)	(2.449)	(2.930)	(0.019)	(0.026)	(0.014)	(0.017)	(0.572)	(0.791)
Land size squared	-0.004	-0.002	-5.4e-5*	-1.8e-5	-4.9e-5**	-1.3e-5	-0.001	-0.0001
(GPS meters)	(0.004)	(0.004)	(3.1e-5)	(4.0e-5)	(2.3e-5)	(2.7e-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		-3.289		0.012		-8.6e-5		2.344**
market (kilometers)		(4.030)		(0.033)		(0.022)		(1.112)
Head uses mobile		414.1***		1.812***		2.307***		-26.88
phone (dummy)		(70.06)		(0.559)		(0.401)		(16.83)
Household size		83.07***		0.630***		0.347***		7.138
(Adult Equivalents)		(20.59)		(0.162)		(0.115)		(4.865)
Male heads		-321.8***		-2.184**		-1.623**		-8.542
(dummy)		(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		0.266**		0.001		0.001**		0.046
head (years)		(0.111)		(0.001)		(0.001)		(0.034)
Education of head		28.52		0.442**		0.335**		3.065
(years)		(23.36)		(0.181)		(0.132)		(5.239)
Education squared		-2.068		-0.032**		-0.016		-0.341
of head (years)		(1.859)		(0.015)		(0.011)		(0.405)
Shock experience		-62.43		0.355		0.072		20.04
(dummy)		(64.66)		(0.507)		(0.372)		(15.06)
Land size (GPS		4.323		0.052		0.057*		1.322
meters)		(5.002)		(0.038)		(0.029)		(1.004)
Land size squared		-0.004		-5.8e-5		-6.9e-5		-0.001
(GPS meters)		(0.008)		(6.4e-5)		(4.8e-5)		(0.001)
Constant	4,757***	4,795***	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	8,574	8,574	8,574	8,574	8,574	8,574	8,574	8,574
No. of households	3,258	3,258	3,258	3,258	3,258	3,258	3,258	3,258
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

Appendix B: 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)
FPD (biodiversity index)	1.758	0.050	0.047**	1.962**
	(3.788)	(0.031)	(0.022)	(0.920)
Daily per AE Consumption via Markets (UGX)	0.181***	0.001***	0.001***	0.004*
	(0.011)	(8.1e-5)	(6.3e-5)	(0.002)
Daily per AE Consumption from Home	1.441***	0.012***	0.008***	0.297***
production (UGX)	(0.122)	(0.001)	(0.001)	(0.024)
Distance nearest market (km)	-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	2.9e-5	7.3e-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 (GPS meters)	-0.738	-4.4e-5	0.001	-0.182
	(3.100)	(0.028)	(0.019)	(0.765)
Land size squared (GPS meters)	-0.002	-2.4e-5	-1.9e-5	-0.0002
	(0.005)	(4.3e-5)	(2.9e-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 (km)	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 (GPS meters)	1.005	0.024	0.041	0.492
	(4.885)	(0.038)	(0.028)	(0.914)
Land size squared (GPS meters)	0.001	-1.5e-5	-4.6e-5	4.8e-5
	(0.007)	(6.5e-5)	(4.7e-5)	(0.001)
Constant	3,921***	15.36***	7.858***	327.3***
	(148.0)	(1.178)	(0.844)	(33.22)
Observations	8,574	8,574	8,574	8,574
No. of households	3,258	3,258	3,258	3,258
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

Appendix C: Differential impacts of FPD on energy and micronutrients 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)
Farm production D	-74.58***	20.75***	-0.208***	0.179***	-0.099***	0.098***	-2.535***	4.057***
(biodiversity index)	(10.94)	(2.423)	(0.029)	(0.023)	(0.020)	(0.012)	(0.507)	(0.927)
Distance to nearest	-8.043	4.222*	-0.017	0.014	-0.015	0.014	0.291	-2.215
market (kilometers)	(10.43)	(2.450)	(0.028)	(0.026)	(0.019)	(0.013)	(0.995)	(1.636)
Head uses mobile	104.7	-34.70	0.224	-0.391	0.272	-0.158	4.798	-10.80
phone (dummy)	(142.4)	(33.79)	(0.378)	(0.303)	(0.256)	(0.161)	(7.200)	(14.71)
Household size (Adult	-358.7***	-98.36***	-0.519***	-0.932***	-0.434***	-0.493***	-13.84***	-7.768
Equivalents)	(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	-0.215	-0.002	-8.6e-5	-0.0003	-7.9e-5	-0.0002	-0.016	0.008
(years)	(0.263)	(0.060)	(0.001)	(0.001)	(0.001)	(0.0003)	(0.022)	(0.027)
Education of head	-33.75	-8.453	-0.090	-0.115	-0.123	-0.049	-2.612	3.381
(years)	(47.40)	(11.47)	(0.124)	(0.106)	(0.084)	(0.056)	(2.686)	(4.895)
Education squared of	6.028	0.535	0.012	0.007	0.012*	0.003	0.467**	-0.357
head (years)	(3.925)	(1.002)	(0.010)	(0.009)	(0.007)	(0.005)	(0.226)	(0.397)
Shock experience	5.254	-54.36**	-0.009	-0.389*	-0.009	-0.227*	-5.863	-9.351
(dummy)	(103.6)	(24.82)	(0.273)	(0.228)	(0.189)	(0.119)	(6.238)	(10.59)
Land size (GPS	5.714	-2.876	0.024	-0.027*	0.017	-0.015**	0.216	-1.185*
meters)	(6.710)	(1.777)	(0.020)	(0.015)	(0.013)	(0.007)	(0.779)	(0.660)
Land size squared	-0.015	0.004	-4.9e-5	3.9e-5*	-3.6e-5*	2.3e-5**	-4.8e-5	0.001
(GPS meters)	(0.009)	(0.003)	(3.1e-5)	(2.2e-5)	(2.1e-5)	(1.0e-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	-10.29	-2.665	-0.019	-0.004	-0.004	-0.006	-0.266	2.483
market (kilometers)	(10.77)	(2.520)	(0.029)	(0.026)	(0.019)	(0.013)	(1.004)	(1.660)
Head uses mobile	1,624***	58.38	2.876***	0.434	2.577***	0.326	11.95	-12.25
phone (dummy)	(198.4)	(46.05)	(0.528)	(0.409)	(0.361)	(0.217)	(9.596)	(18.49)
Household size (Adult	15.05	55.85***	-0.099	0.479***	-0.033	0.268***	-0.190	6.113
Equivalents)	(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	0.331	0.019	0.0002	0.0004	0.0002	0.0002	0.012	0.028
(years)	(0.323)	(0.071)	(0.001)	(0.001)	(0.001)	(0.0004)	(0.024)	(0.029)
Education of head	-133.9**	30.01*	-0.234	0.297**	-0.018	0.131*	-7.511**	9.263
(years)	(64.72)	(15.83)	(0.173)	(0.143)	(0.118)	(0.076)	(3.285)	(6.172)
Education squared of	14.54***	-3.371***	0.033**	-0.030**	0.015*	-0.014**	0.641**	-0.798
head (years)	(5.108)	(1.307)	(0.014)	(0.012)	(0.009)	(0.006)	(0.263)	(0.499)
Shock experience	-269.9	-15.99	0.323	-0.321	0.042	-0.063	-2.804	2.583
(dummy)	(183.7)	(42.90)	(0.479)	(0.384)	(0.330)	(0.203)	(9.538)	(16.37)
Land size (GPS	-39.00**	11.92***	-0.102**	0.093***	-0.052*	0.058***	0.001	1.065
meters)	(16.49)	(2.852)	(0.042)	(0.020)	(0.028)	(0.011)	(1.005)	(1.083)
Land size squared	0.066***	-0.019***	0.0002***	-0.0002***	9.2e-5**	-9.1e-5***	0.0003	-0.001
(GPS meters)	(0.023)	(0.004)	(6.3e-5)	(3.6e-5)	(4.1e-5)	(1.8e-5)	(0.001)	(0.002)
Constant	13,104***	1,632***	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	8,310	6,373	8,310	6,373	8,310	6,373	8,310	6,373
No. of households	3,207	2,633	3,207	2,633	3,207	2,633	3,207	2,633
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

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 (1a) to (4a). Essentially, first we estimated reduced equations individually, then after estimated structural equations (results of (4a) fed into (2a) and (3a)) individually in second stage. Then finally, we used results from the second stage in the core equation, (1a). 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.

$$EM_{it} = \alpha_0 + \alpha_1 OwnFarm_{it} + \alpha_2 Markets_{it} + \alpha_3 \boldsymbol{X}_{it} + \alpha_4 T_t + \varepsilon_{it2} \quad (1a)$$

$$OwnFarm_{it} = \beta_0 + \beta_1 FPD_{it} + \beta_2 \boldsymbol{Y}_{it} + \beta_3 T_t + \varepsilon_{it3} \quad (2a)$$

$$Markets_{it} = \gamma_0 + \gamma_1 FPD_{it} + \gamma_2 \boldsymbol{Z}_{it} + \gamma_3 T_t + \varepsilon_{it4} \quad (3a)$$

$$FPD_{it} = \delta_0 + \delta_1 \boldsymbol{A}_{it} + \delta_2 T_t + \varepsilon_{it5} \quad (4a)$$

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, markets 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 markets 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 (Zellner and Theil, 1962). 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: FPD Impact Pathways for Daily Household Energy Intake Using Simultaneous Equations

Variables	Energy (Kilocalories) (1)	Daily per AE Consumption via Markets (UGX) (2)	Daily per AE Consumption from Home production (UGX) (3)	Farm Production Diversity (biodiversity index) (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***	67.30***	
		(21.45)	(1.940)	
Distance to nearest market (kilometers)	-4.965***	-0.376		
	(1.044)	(1.130)		
Head uses mobile phone (dummy)	-1,122***	1,502***	-290.0***	
	(248.0)	(338.3)	(22.33)	
Household size (Adult Equivalents)	78.52***	-232.4***	-14.05***	0.424***
	(20.59)	(16.48)	(1.947)	(0.020)
Male heads (dummy)	-79.48**	66.80	-17.34***	0.655***
	(36.45)	(42.80)	(5.614)	(0.099)
Age of head (years)	-6.928	-1.963	-1.746***	0.017***
	(4.757)	(2.083)	(0.178)	(0.003)
Age squared of head (years)	0.041			
	(0.046)			
Education of head (years)	-26.36**	42.32***	4.855***	0.027**
	(12.99)	(11.60)	(1.058)	(0.011)
Education squared of head (years)	1.414*			
	(0.859)			
Shock experience (dummy)	-248.1***	106.3***	-14.60***	0.437***
	(36.96)	(38.59)	(4.894)	(0.092)
Land size (GPS meters)	-3.814		-0.677***	0.017***
	(2.489)		(0.137)	(0.003)
Land size squared (GPS meters)	0.001			
	(0.004)			
Year 2010	-147.3***	165.8***	81.90***	-0.913***
	(40.13)	(54.16)	(5.906)	(0.108)
Year 2011	-540.7***	518.7***	36.78***	0.607***
	(57.12)	(58.67)	(6.525)	(0.109)
Urban household (dummy)		747.5***		
		(100.8)		
Productive assets (UGX)			1.3e-7***	-1.4e-9***
			(2.5e-8)	(4.7e-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	5,184***	-336.2***	6.399***
	(324.6)	(205.7)	(24.77)	(0.344)
Observations	8,490	8,490	8,490	8,490
Chi2 value	568.58***	2,795.66***	4,371.26***	1,708.34***

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Appendix F: FPD Impact Pathways on Daily Household Iron Intake Using Simultaneous Equations

Variables	Iron (Milligrams) (1)	Daily per AE Consumption via Markets (UGX) (2)	Daily per AE Consumption from Home production (UGX) (3)	Farm Production Diversity (biodiversity index) (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***	1,399***	-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 (GPS meters)	-0.020		-0.682***	0.017***
	(0.027)		(0.137)	(0.003)
Land size squared (GPS meters)	-6.8e-6			
	(4.4e-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)			1.3e-7***	-1.4e-9***
			(2.6e-8)	(4.7e-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	5,091***	-337.2***	6.417***
	(3.542)	(206.1)	(24.78)	(0.345)
Observations	8,490	8,490	8,490	8,490
Chi2 value	291.58***	2,794.26***	4,372.02***	1,706.00***

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Appendix G: FPD Impact Pathways towards Daily Household Zinc Intake Using Simultaneous Equations

Variables	Zinc (Milligrams) (1)	Daily per AE Consumption via Markets (UGX) (2)	Daily per AE Consumption from Home production (UGX) (3)	Farm Production Diversity (biodiversity index) (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***	67.35***	
		(21.70)	(1.940)	
Distance to nearest market (kilometers)	-0.011**	-0.547		
	(0.005)	(1.133)		
Head uses mobile phone (dummy)	-4.276***	1,466***	-289.8***	
	(1.277)	(340.0)	(22.34)	
Household size (Adult Equivalents)	0.383***	-235.3***	-14.10***	0.423***
	(0.107)	(16.49)	(1.947)	(0.0202)
Male heads (dummy)	-0.079	63.01	-17.38***	0.655***
	(0.185)	(42.80)	(5.614)	(0.0994)
Age of head (years)	-0.025	-2.308	-1.748***	0.0167***
	(0.025)	(2.095)	(0.178)	(0.00294)
Age squared of head (years)	0.0001			
	(0.0002)			
Education of head (years)	-0.058	42.68***	4.838***	0.027**
	(0.067)	(11.63)	(1.059)	(0.011)
Education squared of head (years)	0.003			
	(0.005)			
Shock experience (dummy)	-0.799***	103.2***	-14.59***	0.435***
	(0.189)	(38.62)	(4.894)	(0.092)
Land size (GPS meters)	0.002		-0.681***	0.017***
	(0.013)		(0.137)	(0.003)
Land size squared (GPS meters)	-1.9e-5			
	(2.1e-5)			
Year 2010	-0.793***	178.0***	81.95***	-0.913***
	(0.204)	(54.43)	(5.906)	(0.108)
Year 2011	-2.386***	520.4***	36.75***	0.605***
	(0.292)	(58.77)	(6.526)	(0.109)
Urban household (dummy)		774.5***		
		(102.0)		
Productive assets (UGX)			1.3e-7***	-1.4e-9***
			(2.6e-8)	(4.7e-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	5,121***	-336.5***	6.427***
	(1.677)	(206.4)	(24.78)	(0.345)
Observations	8,490	8,490	8,490	8,490
Chi2 value	432.04***	2,791.94***	4,372.63***	1,706.12***

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Appendix H: FPD Impact Pathways towards Daily Household Vitamin A Intake Using Simultaneous Equations

Variables	Vitamin A (RAE – micrograms) (1)	Daily per AE Consumption via Markets (UGX) (2)	Daily per AE Consumption from Home production (UGX) (3)	Farm Production Diversity (biodiversity index) (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***	67.38***	
		(22.01)	(1.940)	
Distance to nearest market (kilometers)	1.862***	-0.604		
	(0.696)	(1.137)		
Head uses mobile phone (dummy)	223.8	1,444***	-289.6***	
	(168.2)	(342.1)	(22.35)	
Household size (Adult Equivalents)	-63.20***	-235.5***	-14.12***	0.423***
	(14.11)	(16.51)	(1.947)	(0.020)
Male heads (dummy)	-6.315	62.77	-17.40***	0.655***
	(24.06)	(42.81)	(5.614)	(0.099)
Age of head (years)	0.246	-2.454	-1.747***	0.017***
	(3.303)	(2.109)	(0.178)	(0.003)
Age squared of head (years)	0.002			
	(0.032)			
Education of head (years)	-17.96**	43.19***	4.829***	0.027**
	(8.908)	(11.66)	(1.059)	(0.011)
Education squared of head (years)	1.991***			
	(0.600)			
Shock experience (dummy)	-24.47	102.1***	-14.59***	0.435***
	(24.54)	(38.66)	(4.894)	(0.092)
Land size (GPS meters)	1.435		-0.682***	0.017***
	(1.715)		(0.137)	(0.003)
Land size squared (GPS meters)	-0.003			
	(0.003)			
Year 2010	-56.89**	181.7***	81.97***	-0.913***
	(26.53)	(54.77)	(5.906)	(0.108)
Year 2011	-57.21	522.6***	36.71***	0.605***
	(38.15)	(58.90)	(6.526)	(0.109)
Urban household (dummy)		785.0***		
		(103.5)		
Productive assets (UGX)			1.3e-7***	-1.4e-9***
			(2.6e-8)	(4.7e-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	3,435***	5,110***	-336.8***	6.409***
	(221.6)	(207.3)	(24.78)	(0.346)
Observations	8,490	8,490	8,490	8,490
Chi2 value	234.77***	2,791.83***	4,373.51***	1,705.59***

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1