Crop Diversification and Nutrition Outcomes in Smallholder Households: Panel Data Evidence from Southwestern and Northern Uganda

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Crop Diversification and Nutrition Outcomes in Smallholder Households: Panel Data Evidence from Southwestern and Northern Uganda

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Abstract

This study examined the effect of adopting crop diversification on nutrition outcomes of smallholder households in southwestern and northern Uganda. We constructed three models of correlates of household dietary diversity, minimum dietary diversity for women, and stunting of children aged 6–59 months. A three-year panel multi-topic dataset collected in 2012, 2014 and 2016 by USAID's Feed the Future Nutrition Innovation Laboratory in southwestern and northern Uganda was utilized. Crop diversification was found to be positively and strongly associated with household dietary diversity, and with the probability of achieving the minimum dietary diversity for women, although the effect sizes were rather small. There was no clear association found between crop diversification and child stunting. Our findings point to an integrated approach that simultaneously addresses increasing crop diversification, access to improved farm production technology, access to nutritional knowledge, increasing formal education of mothers, increasing opportunities to do off-farm work, livestock diversification and food security to improve the nutritional outcomes of smallholder households.

Key words: Crop diversification, dietary diversity, stunting, panel data, Uganda

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1. Background

Malnutrition arising from an inadequate intake of energy and nutrients is still a major public health problem in sub-Saharan Africa. Most households affected by malnutrition are in rural areas and mainly depend on agriculture for their livelihood. Since the 1990 UNICEF conceptual framework and the 1992 International Conference on Nutrition that called for a multi-sectoral approach to tackling undernutrition, national governments in developing countries have been addressing population nutrition issues by intervening in various sectors. Due to its impact pathways, the agriculture sector demonstrates a higher potential than other sectors to influence nutritional outcomes in developing countries (Ruel et al, 2018; Ruel and Alderman, 2013). Regional bodies such as the African Union have called on governments, through the Comprehensive Africa Agriculture Development Programme, to prioritize nutrition interventions in their agriculture investment plans. The Food and Agricultural Organization (FAO, 2014) identifies three nutrition-sensitive agricultural production implementation avenues. The first avenue relates to increasing agricultural production so that food can be accessed by all households at affordable prices. Second, food can be made more diverse through deliberate crop production diversity undertaken by farm families. Third, food can be made more nutritious by means of micronutrient fortification at the processing stage or biofortification at the breeding stage and by improving soil quality. Given these avenues, there are a range of policy options emanating from the agricultural sector that could influence the nutritional outcomes of a population largely dependent on agriculture. This study broadly focuses on the role crop production diversity plays in achieving the nutrition objectives of Uganda's 2013 National Agriculture Policy (NAP).

Policy context

Uganda has incorporated explicit nutrition objectives in its agriculture policy and national development plan. The goal of Uganda's 2013 NAP is "to achieve food and nutrition security and improve household incomes" (MAAIF, 2013). The first specific objective of this policy requires that all households and individuals are food and nutrition secure in Uganda. One strategy to achieve this objective relates to farm production diversification whereby the Government of Uganda promotes: "the production of nutritious foods to meet household needs and for sale…" (MAAIF, 2013). Accordingly, in operationalizing this strategy, 12 food commodities were prioritized for investment in the areas of research, extension, provision of quality inputs, pest, vector and disease control, post-harvest handling, and improving market access and value addition. The 12 food commodities are: bananas, beans, maize, rice, cassava, Irish potatoes, tea, coffee, fruit and vegetables, dairy, fish, and livestock. In a complementary strategy, the policy supports the consumption of diversified nutritious foods through promotion of the production of bio-fortified foods, including indigenous foods, at household and community levels. The second objective of the policy identifies farm diversification as one of the strategies that would lead to an increase in farming households' incomes. Additionally, the policy provides for the development of extension systems through which farmers acquire new knowledge and information on good agricultural practices. Diversified farm production systems are a component of the recommended agricultural practices included in training manuals of extension systems, whereby farmers are taught to intercrop and plant micro-nutrient rich varieties. Clearly, production diversification is recognized as a policy instrument that is expected to influence household nutrition directly and indirectly. Uganda's NAP is operationalized by the Agricultural Sector Strategic Plan and is being implemented by state and non-state actors such as donor agencies who work in partnership with Uganda's Government. An example of this partnership was the USAID–Uganda Community Connector Project, which supported the implementation of the 2010–2015 Agricultural Sector Development Strategy and Investment Plan in Uganda.

USAID's Community Connector Project in Uganda

This project was a Feed the Future initiative with the objective of improving the nutrition, health and livelihood of poor rural households dependent on subsistence farming, through integrated agricultural and nutrition interventions. The project that began in 2012 and lasted five years was implemented in 15 districts in northern and southwestern Uganda. USAID worked with local governments in these districts to implement evidence-based interventions that would improve agricultural production and livelihood activities, household nutrition, hygiene practices and gender equitable practices. Beneficiary households were expected to adopt 10 intervention components (Fhi360, USAID/Uganda Community Connector (CC) Project, 2016) that comprised: creating homestead gardens with nutritious foods such as pumpkin, amaranth and other traditional vegetables; at least a pawpaw tree, an avocado tree or other fruit tree near the homestead; an agricultural income-generating activity; rearing of goats, keeping chickens or having an apiary; acquisition of production assets such as hoes, ox-ploughs, watering cans, and spray pumps; availability of water, sanitation and hygiene facilities; clean and neat homestead compounds; family members supporting each other in production and feeding decisions; stocks of enough food to last up to three months in the garden or store; and women or family who are saving. The mid-term review report of the project indicated that these intervention components had been widely adopted by the beneficiary households (Fhi360, USAID/Uganda Community Connector (CC) Project, 2016).

2. Problem statement

Nutritional outcomes in Uganda are still at undesirable levels. The 2016 Uganda Demographic Health Survey report showed that child stunting had reduced by 4% between 2011 and 2016. Stunting, however, remained higher in rural areas (30%) than in urban areas (24%). The poor nutrition outcomes were also unevenly distributed within the regions of the country. As the 2006, 2011 and 2016 Uganda Demographic Health Survey reports show, the prevalence of stunting has consistently been higher in the southwestern and northern regions. Intermediate nutritional outcomes such as household dietary diversity, which are known to have a positive influence on the nutritional status of children and adults (Arimond and Ruel, 2004; Ruel, 2002), are also still at undesirable levels in Uganda. A study by Ecker et al (2010) found that farmers' diets in Uganda and other East African countries were dominated by grains and tuber-based staples with little or no consumption of vegetables and fruit. Additionally, an analysis of the food consumption module of the 2009/2010 Uganda National Panel Survey data shows that starchy staples and grains contributed, on average, to about 70% of calories consumed nationally (Namulondo, 2016). Based on the guidelines in Smith and Subandoro (2007), such a high proportion of starchy staples and grains in the diet is an indicator of low dietary diversity and micronutrient adequacy.

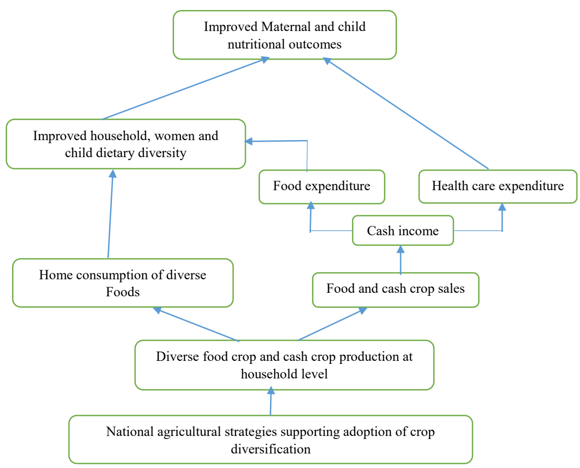
Agriculture is one of the sectors at the forefront in implementing interventions to curb undernutrition in Uganda. This study aims at investigating the effect of food-crop diversification (a NAP intervention) on nutrition outcomes of smallholder households in southwestern and northern Uganda. This study has two hypotheses: i) a higher level of crop diversification is associated with a higher level of household dietary diversity and increases the probability of achieving the minimum dietary diversity for women; and ii) the risk of stunting for children aged 6–59 months is lower in households with a higher level of crop diversification.

3. Literature review

Conceptual Framework: the effect of a crop diversification strategy on household nutrition outcomes

The UNICEF conceptual framework (UNICEF, 1991), which explains the causes of malnutrition, forms the theoretical basis of our analysis. As it highlights the linkages between agriculture and nutrition, this framework implies that the complex and multiple causes of malnutrition require broader strategies to be integrated with nutrition interventions to curb the malnutrition problem in developing countries. Kadiyala et al (2014) and Headey et al (2011) modified the UNICEF conceptual framework for malnutrition and provided specific pathways that explain the linkages between agriculture and nutrition. These were mainly: consumption of own production; income earned from agricultural-related activities that are used to acquire nutritious foods and healthcare; and women's socioeconomic status and autonomy in household decision-making.

Figure 1: Pathways of the effect of a crop diversification strategy on household nutrition outcomes



Source: Adapted from Kadiyala et al (2014) and Headey et al (2011)

We expect that households who diversify their crop production to include staple grains and tubers, legumes, vegetables and cash crops will have a diverse diet from own production and can use income earned from sales of surplus food and cash crops to acquire other nutrient dense foods from the market. Income earned can also be used to access health services. The improvement in dietary diversity and health status of the household and of individuals that results will lead to an improved nutritional status.

Findings from related studies

The findings of the various studies that have examined the association between farm production diversification and better nutrition outcomes for developing countries are mixed. Pandey et al (2016) identified two levels of nutrition outcome indicators, namely intermediate nutrition outcomes, which include dietary diversity, calorie intake and micronutrient intake, while final nutrition outcomes include anthropometric measures and disability adjusted life years, where adequate dietary intake can reverse years of life to be lost or lived with disability. Jones et al (2014) estimated dietary diversity outcomes of crop diversity using Malawian household-level cross-sectional data and concluded that farm production diversity had the potential to increase household dietary diversity. Herforth (2010) demonstrated a positive association between the number of crops grown and the farm households' dietary variety measured by the number of different foods in the diet in the East African countries of Kenya and Tanzania. Sibhatu et al (2015) used household cross-sectional data from Indonesia, Kenya, Ethiopia and Malawi and found a positive association between on-farm production diversity and household dietary diversity. However, the same study showed that market access was more effective than production diversity in increasing households' diet diversity. In a similar study finding, Koppmair et al (2016) indicated that the effect of farm diversity on households', mothers' and children's dietary diversity was smaller than that of market access and agricultural technology adoption in Malawi. Chegere and Stage (2020) also reported that diversifying agricultural production increases the dietary diversity of households in Tanzania, although effect sizes are small. Kavitha et al (2016) concluded that crop diversity alone does not improve household dietary diversity in the semi-arid regions of India.

A separate strand of studies investigated the association between farm diversification and children's nutritional status. Kumar et al (2015) found a negative association between production diversity and stunting of children aged 24–59 months in Zambia. Similarly, Lovo and Veronsi (2019) found a positive, albeit small, effect of crop diversification on child height-for-age Z-scores for subsistence farm households in Tanzania. Evidence from Nepal (Shively and Sununtnasuk, 2015) showed positive correlations between the consumption of own production and better outcome indicators of child stunting and child height-for-age Z-scores.

Within this context, this study adds to the body of research that aims to understand the influence of crop diversification on nutrition by utilizing a household panel dataset that captures the changing behaviour of smallholders, and holds information on dietary patterns from 24-hour food recalls. Existing panel-data studies concerning this research question assess dietary diversity using food consumption modules of household surveys where data are not collected for dietary purposes. A notable limitation is that these data do not consider food acquired and then stored (Smith and Subandoro, 2007). Consequently, a misrepresentation of dietary patterns might arise if acquired food was not wholly consumed daily or was consumed after the recall period. While we acknowledge that each dietary assessment methodology has limitations, collecting 24-hour food recall data on at least two non-consecutive days provides reliable information regarding the average dietary patterns of households (FAO, 2018). Twenty-four-hour food recall data also considers intra-household food allocation, which is essential for understanding the dietary patterns of vulnerable members of a household such as women and children under five.

Furthermore, several previous studies have concluded that farm diversification alone is not enough to improve dietary diversity, and compared the importance of farm diversification vis-à-vis market access. However, the evidence on the importance of markets in delivering dietary diversity for farm households in predominantly subsistence production is mixed. There is also limited evidence on the role of agricultural technology in improving nutrition outcomes for small farm households. Further research is therefore necessary to clarify the factors that are important for improving nutrition outcomes other than farm diversification for predominantly subsistence farm households.

4. Materials and methods

Data description

The data for this study were collected as part of the Community Connector Project by Feed the Future Innovation Lab for Nutrition in Uganda. Panel surveys were conducted in 2012, 2014 and 2016 in six districts in southwestern and northern Uganda (Fhi360, USAID/Uganda Community Connector (CC) Project, 2016). A multi-stage sampling framework was employed to identify 3,597 households with a caregiver/mother of a child 0–23 months old, or a woman of reproductive age (18–49 years) as the main respondent in the baseline survey. Of these households, 3,302 and 3,196 were surveyed in 2014 and 2016, respectively. The sampling framework involved randomly selecting 17–25 parishes from each of the six districts and then randomly selecting 5–8 villages from each selected parish. Households were then randomly selected from a list generated for each selected village. This was a multi-topic survey covering household characteristics such as diet intake in a 24-hour recall period for mothers and children under five, sanitation, breastfeeding, health status of the caregiver and children under 5 years of age, food security, crop and livestock production, income and expenditure, gender and decision-making, and anthropometric measurements of mothers and children under five. The low attrition rate of 8% and 7% between the survey waves was assumed to be random and was addressed by controlling for household demographics in the estimation models.

This study examined the effect of crop diversification on nutrition outcomes of farm households following a methodology similar to that in studies where a dietary diversity score or child anthropometrics is regressed on indexes of farm production diversity and control variables of socioeconomic characteristics, market access and participation indicators, and farm characteristics. Three outcome variables were considered: Household Dietary Diversity (HDD), Minimum Dietary Diversity for Women (MDD-W) and the anthropometric indicator of stunting in children under five scores. Hoddinott and Yohannes (2002) and Ruel (2002) define household dietary diversity as the number of different foods or food groups consumed by a household at a point in time. According to Ruel (2003), food items are grouped together when they have similar nutrients and have the same role in the diet. In this study, the HDD score was calculated based on 12 categories of foods consumed by the household in a 24-hour recall period, i.e., cereals; white tubers, roots and plantain; vegetables; fruit; meat; eggs; fish and other seafood; pulses; nuts and seeds; milk and milk products; oils and fats; and sugar, condiments and beverages.

MDD-W measures the number of food groups consumed by women of reproductive age out of the following 10 food groups (FAO and FHI 360, 2016): Grains, roots, tubers and plantain (starchy staples); pulses (beans, peas, lentils); nuts and seeds; dark green leafy vegetables; other Vitamin A-rich fruit and vegetables; other fruit; other vegetables; meat, poultry and fish; eggs; and dairy (milk and milk products). Thus, while the HDD score measures access to a diverse diet, the MDD-W with a cut-off of five food groups reflects the micronutrient adequacy of the diet of women of reproductive age in a household. Data on food intake were gathered from households based on a 24-hour recall period and the respondent was a caregiver/mother, aged 18–49 years, who prepared and served the meals.

Stunting is a widely used indicator of child nutritional status. From our conceptual framework, child nutritional status is depicted as a final outcome influenced by crop diversification via the mechanism of a child's consumption of diverse foods from own production and household food expenditure on diverse foods. We, therefore, focused on young children who were assumed to have started complementary feeding and older children below five years of age. The stunting variable was constructed based on the height-for-age Z-scores in the dataset, which were calculated using growth standards compiled by the World Health Organization. A 6–59-month-old child was considered stunted if her/his height-for-age Z-score was two or more standard deviations below the median height of the reference population (WHO, 2006). The analysis used data on an index child of 6–59 months old from 2,060 households.

Crop diversification was the main independent variable in our analyses. The crop diversity score, an indicator of crop diversification, was constructed by summing the number of diverse crop families produced. Accordingly, the following six food crop families were constructed: (1) grains (2) roots, tubers and plantain (3) legumes (4) fruit (5) vegetables; and (6) oil seeds.

Estimation models

A fixed-effects Poisson model with standard errors clustered at the household level, and thus robust to heteroscedasticity, was estimated for the count dependent variable of the HDD score with the following specification:

$$Y_{it} = \alpha_0 + \alpha_1 CD_{it} + \alpha_2 X_{it} + T_t + \omega_i + u_{it} \quad (1)$$

Where Y_{it} is the HDD score for household i at time t. CD_{it} is the crop diversity score of household i at time t, and X_{it} is a vector of control variables that includes socioeconomic characteristics, market access and participation indicators, and farm characteristics of household i at time t. ω_i is the time-invariant unobserved heterogeneity of household I, and u_{it} is an error term. The parameters to be estimated are represented by α .

Equations 2 and 3 are random-effect probit models estimated for the MDD-W and child stunting binary outcomes.

$$P(Y_{ait} = 1) = F(\alpha CD_{it} + \beta X_{ait} + \mu_{ai} + \varepsilon_{ait}) \quad (2)$$

$$P(Y_{bit} = 1) = F(\alpha CD_{it} + \gamma X_{bit} + \mu_{bi} + \varepsilon_{bit}) \quad (3)$$

Where $Y_{ait} = 1$ if the woman in household i at time t had met the MDD-W and 0 otherwise; $Y_{bit} = 1$ if a child i at time t was found stunted and 0 otherwise; F represents the cumulative distribution of a standard normal distribution function; CD_{it} represents the crop diversity score; X_{ait} is a vector of control variables that could influence the MDD-W, while X_{bit} represents a vector of child, maternal and additional socioeconomic characteristics of household i at time t that could influence stunting of children aged 6–59 months. μ_{ai} and μ_{bi} are random effects assumed to be uncorrelated with the explanatory variables in the respective models, and ε_{ait} and ε_{bit} are error terms with a standard normal distribution and a mean of 0 and variance 1. Parameters to be estimated are represented by α, β and γ.

5. Results and discussion

Descriptive results

Table 1 presents the summary statistics of variables used in the study and other household characteristics. The analysis included a total of 3,365 households aggregated from the northern and southwestern regions of Uganda.

Table 1: Selected characteristics of households and caregivers

	Pooled		Wave 1	Wave 2	Wave 3
	N	Mean	Mean	Mean	Mean
Household dietary diversity score	7,739	4.35 (1.46)	4.46 (1.60)	4.14 (1.37)	4.40 (1.34)
Women's dietary diversity score	7,739	3.14 (1.09)	3.31 (1.20)	3.00 (1.02)	3.06 (0.98)
Minimum dietary diversity for women achieved (1=Yes, 0=No)	7,739	0.11 (0.31)	0.15 (0.36)	0.08 (0.27)	0.07 (0.26)
Sex of household head (1= Female, 0=Male)	7,739	0.03 (0.17)	0.03 (0.16)	0.04 (0.19)	0.03 (0.17)
Household size	7,739	6.65 (2.47)	6.00 (2.57)	6.89 (2.28)	7.23 (2.34)
Years of schooling of caregiver/ mother	7,739	4.02 (3.05)	4.04 (3.08)	3.98 (3.08)	4.02 (3.00)
Main woman has autonomy over income use (1=Yes, 0=No)	7,739	0.99 (0.09)	0.99 (0.10)	0.99 (0.10)	0.99 (0.08)
Distance to nearest agricultural input/output market (Km)2	7,739	3.86 (3.11)	3.75 (3.00)	3.45 (2.71)	4.41 (3.50)
Share of output sold	7,739	0.24 (0.22)	0.26 (0.23)	0.24 (0.23)	0.23 (0.20)
Household had off-farm income (1=Yes, 0=No)	7,739	0.80 (0.40)	0.74 (0.44)	0.84 (0.37)	0.83 (0.37)
Agricultural income ('000 UGX)1	7,739	556.2 (664.5)	562.4 (661.9)	455.3 (605.0)	646.7 (708.2)
Food secure (1=Yes, 0=No)	7,739	0.16 (0.36)	0.18 (0.39)	0.16 (0.37)	0.12 (0.32)
Accessed nutrition information (1=Yes, 0=No)	7,739	0.59 (0.49)	0.71 (0.45)	0.52 (0.50)	0.51 (0.50)
Accessed a clean water source (1=Yes, 0=No)	7,739	0.66 (0.47)	0.64 (0.48)	0.66 (0.47)	0.69 (0.46)
Crop species count	7,739	5.76 (2.73)	5.74 (2.62)	5.00 (2.48)	6.52 (2.89)
Crop diversity score (crop families)	7,739	3.39 (1.09)	3.34 (1.05)	3.21 (1.10)	3.64 (1.09)
Size of land cultivated (acres)	7,739	2.73 (1.88)	2.90 (1.94)	2.65 (1.94)	2.60 (1.70)
Household cultivated vegetables (1=Yes, 0=No)	7,739	0.27 (0.44)	0.21 (0.41)	0.26 (0.44)	0.35 (0.48)
Livestock diversity score3	7,739	1.91 (1.26)	1.81 (1.26)	1.89 (1.22)	2.05 (1.27)

Used improved seed variety (1=Yes, 0=No)	7,739	0.26 (0.44)	0.30 (0.46)	0.22 (0.41)	0.25 (0.43)
Used chemical fertilizer (1=Yes, 0=No)	7,739	0.04 (0.19)	0.03 (0.17)	0.04 (0.20)	0.05 (0.21)
Household is in southwestern region (1=Yes, 0=No)	7,739	0.31 (0.46)	0.33 (0.47)	0.30 (0.46)	0.31 (0.46)

Source: Calculated based on Feed the Future Innovation Lab for Nutrition panel data 2012, 2014 and 2016 (Fhi360, USAID/Uganda Community Connector (CC) Project, 2016).

Note: Values are means with standard deviation in parentheses.

1 Exchange rate of 1 US$=3700UGX.

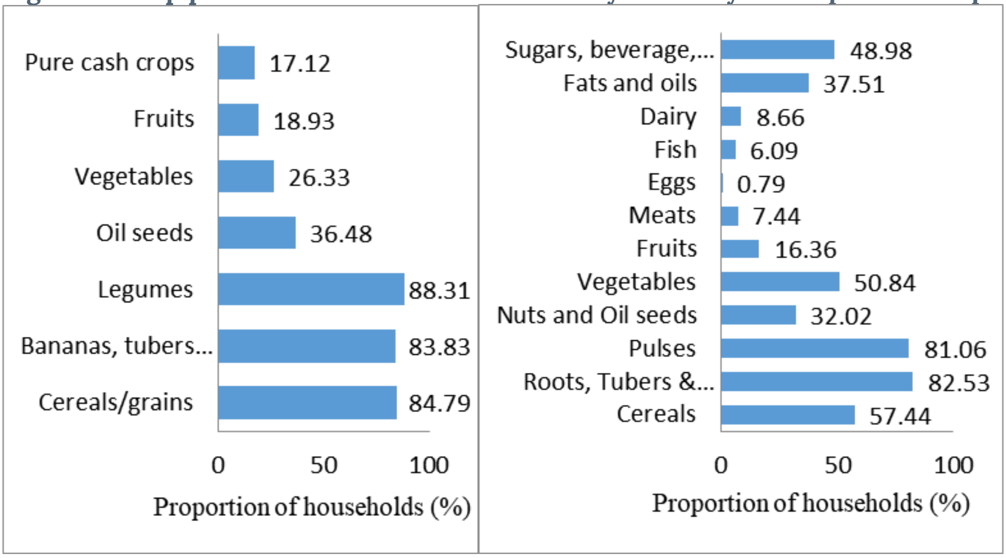
2 Data for distance to the nearest market were collected only in the 2016 wave; a proxy of distance to the household's nearest source of healthcare was used for survey waves 1 and 2, and when household information was missing median values calculated at either the village level or parish level were used.

3 Livestock diversity score was constructed as a sum of the number of livestock categories kept by a household. Accordingly, the following 7 categories of livestock were considered in constructing the score: cattle, sheep, goats, poultry, pigs, rabbits, and fish.

Dietary diversity and crop production

In the 24 hours that preceded the survey, households consumed an average of about 4 food groups out of 12 across the three waves. There was a small variation in the HDD score arising from agricultural income-group differentials (high, medium and low), with households in the high-income group having a higher score (4.60) than those in the low income group (3.93). We found an average MDD-W score of 3.14 out of 10 food groups, which corresponds to only 11% of households who met the MDD-W in the overall sample. The average number of different crop species produced was five to six crops, which translates to an average crop diversity score of 3.39 out of six food-crop families cultivated on an average land size of less than three acres. In Figure 2, we present both the household production and consumption by food group. Figure 2a shows that over 80% of households produced legumes, cereals/grains and bananas/tubers/roots crop families, while a smaller proportion of households produced vegetables (26.33%) and fruit (18.93%). Figure 2b shows that over 80% of households consumed the roots, tubers and plantain food group. Pulses formed the second-most highly consumed food group, followed by cereals. Only about 50% consumed vegetables while less than 20% of the households consumed fruit, meat, fish and dairy. Eggs was the least consumed food group. This pattern of food consumption is indicative of a diet with limited diversity, on average, and supports the finding of a low average HDD score. Figure 2 also gives the impression that households' food consumption patterns are dependent on the food groups they produce. Households sold only 25% of their crop output, on average, indicating both low market participation and predominantly subsistence production. In addition, an average market distance of about four kilometres is rather high for households to buy daily food from the market, which suggests high dependence on own production.

Figure 2: Crop production and household dietary diversity of the pooled sample



a. Crop families produced **b. Food groups consumed in 24-hour recall period**

Source: Calculated based on Feed the Future Innovation Lab for Nutrition panel data 2012, 2014 and 2016 (Fhi360, USAID/Uganda Community Connector (CC) Project, 2016) .

Other household characteristics

The average household size increased from 6 members in 2012 to about 7 members in 2016, and only 3% of the households were headed by a female. Caregivers/mothers had an average of only 4 years of schooling completed, while over 98% of women reported to have participated in household decision-making on income use. A moderately high proportion of over 60% of households had access to a clean water source (piped water, public tap, borehole, protected well/spring and bottled water). Dissemination of nutrition and dietary knowledge is critical to influence nutritional outcomes as households and individuals are known to demand food items based not only on affordability, but also their knowledge of the nutritional values of the foods. The proportion of households that accessed nutrition information through media exposure, visits to health care facilities or visits of extension agents to households was higher in 2012 (71%) and reduced by about 20 percentage points in the subsequent waves.

The bulk of households were food insecure as less than 20% reported to have had enough food to eat. Food insecurity increased over the survey years. Technologies that enhance productivity for smallholder farmers can result in food and nutrition security at the household level. The use of improved seed varieties and chemical fertilizer are shown in Koppmair et al (2016) to be important determinants of dietary diversity for farm-households. In our sample, less than 30% of households used improved seed varieties while only about 4% reported to have used chemical fertilizers. An average annual household agricultural income of about UGShs 550,000 was recorded and over 70% of households had at least one member involved in an off-farm income-related activity. Households reared an average of approximately two livestock categories out of the seven categories considered. About 65% of the households in the analyses were from the Northern region.

Table 2 shows some characteristics of children aged 6–59 months from 2,022 households whose data were used for our analysis. About 50% of the children were male and about 95% of them had a birth weight of at least 2.5 kilogrammes. Over 85% of the children were still breastfeeding at the time of the surveys. Most children (86%) included in the analysis had a diet that fell below the minimum acceptable level of at least four food groups and 25% of the children were stunted. Over 90% of the children had received at least a measles or diphtheria vaccination. About 60% of the mothers reported they had received antenatal care at least four times in the overall sample.

Table 2: Selected characteristics of children 6–59 months and their mothers

	Pooled		Wave 1	Wave 2	Wave 3
	N	Mean	Mean	Mean	Mean
Male child (1=Yes, 0=No)	2,738	0.51 (0.50)	0.50 (0.50)	0.54 (0.50)	0.49 (0.50)
Weight at birth >=2.5 kg (1=Yes, 0=No)	2,738	0.95 (0.21)	0.96 (0.20)	0.95 (0.21)	0.94 (0.23)
Child was breastfeeding (1=Yes, 0=No)	2,738	0.87 (0.34)	0.86 (0.34)	0.88 (0.32)	0.88 (0.33)
Child's diet was below minimum acceptable1 (1=Yes, 0=No)	2,738	0.86 (0.35)	0.83 (0.37)	0.90 (0.30)	0.88 (0.32)
Received at least one vaccination (1=Yes, 0=No)	2,738	0.91 (0.29)	0.87 (0.33)	0.93 (0.25)	0.95 (0.21)
Stunted (1=Yes, 0=No)	2,738	0.25 (0.43)	0.25 (0.43)	0.23 (0.42)	0.26 (0.44)
At least 4 antenatal care visits reported by mother (1=Yes, 0=No)	2,738	0.61 (0.49)	0.56 (0.50)	0.67 (0.47)	0.66 (0.47)

Note: Standard deviations are in parentheses.

1 Based on a child dietary diversity score, calculated using seven food groups, namely: grains, roots, tubers and plantain; legumes and nuts; dairy products; meat and fish; eggs; vitamin A-rich fruit and vegetables; and other fruit and vegetables. A minimum acceptable diet of at least four food groups consumed was considered (WHO, 2008).

Econometric results of association between crop diversification and nutrition outcomes

In Table 3 we present the Poisson estimator results. The bivariate model results show a strong positive association between crop diversification and household dietary diversity. An increase in crop diversification by one food-crop family increases the number of food groups a household consumes by 6.5%. The inclusion of control variables marginally reduces the size of this effect, which remains larger than that of other statistically significant variables. Moreover, keeping one more livestock category is associated with a 1.1% increase in the number of food groups a household consumes. We found no significant association between HDD and the market participation indicator of share of marketed output. Further, no association was found between HDD and the market access indicator of distance to an agricultural market. Our finding is comparable to that of Chegere and Stage (2020), but differs from that of Sibhatu et al (2015) and Koppmair et al (2016), who report a strong association between geographical access to markets and household dietary diversity. The crop diversity score x market distance interaction term was also insignificant, which indicates that the importance of market access vis-à-vis crop diversification in influencing HDD did not vary by how far a household was located from an agricultural market. Conversely, we interpreted the positive statistically significant effect of having an off-farm income to mean that markets still had a role in increasing the number of food groups consumed by farm households in predominantly subsistence production. Our finding of a strong association between adopting agricultural technology and HDD compares to that of Koppmair et al (2016). In our study, the use of improved seeds leads to a 5.4% increase in the number of food groups a household consumes. Literature shows that improved seeds increase crop productivity, which provides a surplus that subsistence households can sell. This implies that households can access markets to sell their output, and buy food items that they do not produce. Table 3 also shows that a caregiver's years of schooling, access to nutrition information and being food secure were all positively associated with HDD as expected.

Table 3: Association between crop diversification and 24-hour HDD (fixed-effects Poisson model)

	Bivariate model		Multivariate model	
Variable	**Coefficient**	**Robust SE**	**Coefficient**	**Robust SE**
Crop diversity score	0.063***	0.005	0.058***	0.007
Livestock diversity score			0.011**	0.005
Distance to agricultural input/output market (km)			0.002	0.005
(Crop diversity score) x distance to agricultural input/output market			-0.0004	0.001
Share of output sold			-0.012	0.025
Household used improved seed (Yes=1)			0.053***	0.011
Household size			0.003	0.003
Years of schooling completed by caregiver/mother			0.008**	0.003
Main woman had adequate autonomy on income use (Yes=1)			0.055	0.039
Caregiver received nutrition information (Yes=1)			0.025**	.0097
Household was food secure (Yes=1)			0.028**	0.013
Agricultural income (UGX)			1.40e-08	9.12e-09
Household had off-farm income source (Yes=1)			0.040**	0.013
Model Prob > chi2	0.0000		0.0000	
Number of observations	7,161		7,161	

Note: Standard errors are clustered by household. Both models included household and year fixed effects.
*p<0.1, **p<0.05, ***p<0.01.

The results in Table 4 show that crop diversification has a strong positive effect on the probability of achieving MDD-W. The bivariate and multivariate model results show that an increase in crop diversification by one food-crop family increases the probability of achieving MDD-W by 3.7% points and 2.8% points, respectively. However, a woman's access to nutrition information and living in a household with enough food to eat had a larger influence on increasing the probability of achieving the MDD-W than crop diversification. Unlike the case of HDD, we found a negative statistically significant effect of market distance on the probability of achieving MDD-W. This implies that market access is important for individual dietary diversity. Markets might provide food crops consumed by a larger proportion of households although not produced by them, such as vegetables. Figure 2 shows that while only about 26% of households produced vegetables, a higher proportion (more than 50%) reported to have consumed vegetables in the previous 24 hours. Our results show that a 10 kilometre decrease in market distance is associated with a 3.5% point increase in the probability of achieving MDD-W. Relatedly, as improved market access may arise from having off-farm work, our findings indicate that women in households with an off-farm income opportunity were more likely to meet the MDD-W. Similarly, the positive correlation between agricultural income and the probability of achieving MDD-W implies that incomes are used to access markets to buy food items not produced on the farm. As expected, a woman's years of schooling and livestock diversification were positively correlated with the probability of achieving the MDD-W.

Table 4: Marginal effect of crop diversification on 24-hour minimum dietary diversity for women (random-effect probit model)

	Bivariate model		Multivariate model	
Variable	**Coefficient**	**Robust SE**	**Coefficient**	**Robust SE**
Crop diversity score	0.0366***	0.0034	0.0281***	0.0035
Livestock diversity score			0.0111***	0.003
Distance to agricultural input/output market (km)			-0.0035***	0.0012
Share of output sold			0.0067	0.0181
Household used improved seed (Yes=1)			0.0150*	0.008
Household size			-0.002	0.0016
Years of schooling completed by woman			0.0065***	0.0012
Main woman had adequate autonomy on income use (Yes=1)			-0.0216	0.0396
Woman received nutrition information (Yes=1)			0.0306***	0.0069
Household was food secure (Yes=1)			0.0364***	0.0101
Agricultural income (UGX)			1.69e-08***	5.57e-09
Household has off-farm income source (Yes=1)			0.0214**	0.0085
Number of observations	7,739		7,739	

Note: Standard errors are clustered by household.

**p*<0.1, ***p*<0.05, ****p*<0.01.

Table 5 presents the results of a binary probit model of the effect of crop diversification on child stunting. The results show a strong negative effect when crop diversification is the only strategy followed to reduce child stunting. However, crop diversification has no effect on stunting with the inclusion of control variables. In its place, livestock diversification is strongly associated with a lower risk of stunting. An increase of one livestock group reduces the probability of stunting by 3.1% points. Households that keep cattle or poultry have access to animal source protein in the form of meat, milk and eggs, which enhance a child's diet and increase nutrient adequacy. Consumption of these food items is shown in the literature to be associated with a lower risk of child stunting (Khamis et al, 2019). Also, livestock ownership provides a source of income that households can use to acquire nutrient-dense foods for young children. We further controlled for the effect of diets and found a strong influence of both child and mother/caregiver's dietary diversity on stunting. Our findings indicate that a diet below minimum child diet diversity increases the probability of stunting by 4.8% points while achieving the MDD-W reduces the probability of stunting by 6.8% points. This confirms the results of previous research (Khamis et al, 2019 and Hasan et al, 2019), which shows that achieving the minimum dietary diversity for a child or mother is associated with reduced child stunting.

In line with previous studies' findings (Ali et al, 2019; Khamis et al, 2019; Torlesse et al, 2016; Fekadu et al, 2015), we found that a mother's years of schooling, at least fourantenatal care visits, household size and a household's access to an improved water source were associated with a lower risk of stunting. In addition, children who had been breastfed, children who weighed at least 2.5kg at birth and male children were less likely to be stunted.

Table 5: Marginal effect of crop diversification on stunting (random-effect probit model)

	Bivariate model		Multivariate model	
Variable	Coefficient	Robust SE	Coefficient	Robust SE
Crop diversity score	-0.0238***	0.0074	-0.0052	0.0077
Livestock diversity score			-0.0314***	0.0068
Distance to agricultural input/ output market (km)			0.0006	0.0026
Diet below 24-hour minimum child dietary diversity (Yes=1)			0.0485**	0.0218
Child's sex (Male=1)			-0.1675***	0.0158
Child received at least one basic vaccination (Yes=1)			0.0241	0.0282
Child's weight at birth (>=2.5 kg) (Yes=1)			-0.1291***	0.0428
Child was breastfed (Yes=1)			-0.0632**	0.026
Mother met Minimum Dietary Diversity for women (Yes=1)			-0.0678***	0.0235
Years of schooling completed by mother /Caregiver			-0.0063**	0.0027
Mother had adequate autonomy on income use (Yes=1)			0.0946	0.0726
Mother reported at least 4 antenatal care visits (Yes=1)			-0.0528***	0.0166
Household size			-0.0061*	0.0034
Household used an improved water source (Yes=1)			-0.0441**	0.0175
Number of observations	2,738		2,738	

Note: Standard errors are clustered by household. *p<0.1, **p<0.05, ***p<0.01.

6. Conclusion and policy implications

The conventional wisdom is that when small farmers integrate vegetables, legumes and fruit into their farming systems, dietary diversity and diet adequacy of their households improve. We found statistically significant associations between food-crop diversification and household dietary diversity, and between food-crop diversification and achieving minimum dietary diversity for women. As crop diversification is an existing strategy of the NAP to improve household incomes and nutrition outcomes, our findings serve as reassurance for the policy and agricultural programmes in Uganda. However, due to the small effect size of crop diversification observed, our results point at an integrated approach that simultaneously addresses increasing crop diversification, access to improved farm production technology, access to nutritional knowledge, increasing the formal education of mothers, increasing opportunities to do off-farm work, livestock diversification, and food security of households to improve the nutritional outcomes of smallholder households.

With an average of 5–6 food-crop species cultivated (composed mostly of staples of grains, plantains, tubers and legumes) households need to be sensitized to diversify along food-crop families to produce vegetables and fruit in addition to the food-crop families that are largely produced. The use of improved seed varieties increases crop productivity and provides a surplus that can be sold. The positive association between the use of improved seeds and household dietary diversity implies that incomes realized, due to increased crop productivity and by extension increased crop sales, would be utilized by households to buy diverse foods. Similarly, incomes from off-farm work would be used to acquire diverse foods. The formal education of mothers/caregivers would improve their health practices and access to and use of nutrition information needed to prepare diverse diets for household members. The positive effect of food security on diet diversity indicates that households only begin to consider the quality of their diets if there is enough food to eat for every household member. With livestock diversification, subsistence households can increase their access to animal-source foods, hence diversifying their diets.

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