The Journal of Development Studies, 2015
Vol. 51, No. 8, 1060–1077, http://dx.doi.org/10.1080/00220388.2015.1018901

Routledge
Taylor & Francis Group

If They Grow It, Will They Eat and Grow? Evidence from Zambia on Agricultural Diversity and Child Undernutrition

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ABSTRACT *In this article we address a gap in our understanding of how household agricultural production diversity affects the diets and nutrition of young children living in rural farming communities in sub-Saharan Africa. The specific objectives of this article are to assess: (1) the association between household agricultural production diversity and child dietary diversity; and (2) the association between household agricultural production diversity and child nutritional status. We use household survey data collected from 3,040 households as part of the Realigning Agriculture for Improved Nutrition (RAIN) intervention in Zambia. The data indicate low agricultural diversity, low dietary diversity and high levels of chronic malnutrition overall in this area. We find a strong positive association between production diversity and dietary diversity among younger children aged 6–23 months, and significant positive associations between production diversity and height for age Z-scores and stunting among older children aged 24–59 months.*

1. Introduction

Undernutrition in children is causally complex, and can result from a combination of insufficient quantity and quality of food, inadequate health services and hygiene, and inappropriate childcare and feeding practices (UNICEF, 1990). These *food, health and care* determinants of undernutrition have been recognised for several decades, but despite the acknowledgment that addressing all three elements is necessary if undernutrition is to be avoided (Bhutta et al., 2008), not all determinants have been given equal attention in nutrition policy, interventions or research. Due to a focus on direct, nutrition-specific interventions such as breastfeeding promotion and single-micronutrient delivery programmes, nutrition has found itself aligned most strongly with the health sector; however, recent international strategies for tackling undernutrition promote these direct interventions alongside broader, nutrition-sensitive programming and policies, including those supporting food-based strategies (Standing Committee on Nutrition, 2011).

Addressing the *food* determinant of undernutrition necessarily involves alignment of nutrition programmes with the agriculture sector to some extent, but to date the agriculture sector's focus on production of quantity (adequate calories per capita, when averaged across a population) has eclipsed the importance of quality (the composition of a population's diet in terms of essential nutrients) in agricultural programmes and policies. A high-quality diet is one which provides all essential nutrients in the right amounts at different stages of life; there is no single dietary model that is superior to others, but since different foods provide different nutrients, a range of diverse foods is required in order to achieve a quality diet. Achieving a diverse diet is particularly important for children, who require energy- and nutrient-dense foods for growth and development (Pan American Health Organisation and

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World Health Organisation, 2003), and for women in pregnancy. But diverse diets are particularly problematic in low-income countries, where cheap and filling starchy staple foods dominate and the range of nutrient-dense foods (such as fruits, vegetables, and animal-source foods) is limited in availability or affordability.

There is scant literature predicting dietary diversity in general; normally dietary diversity is itself used as a predictor variable for effects further 'downstream' in the pathways towards nutritional status. Dietary diversity has been shown to be associated with nutritional status in children as measured by anthropometry (Arimond & Ruel, 2004), and specifically in Zambia (Ali, Rawat, Subandaro, & Menon, 2012), and with diet quality in terms of micronutrient density (Arimond et al., 2010; Ruel, Harris, & Cunningham, 2014; Working Group on Infant and Young Child Feeding Indicators, 2006). Measurement of individual dietary diversity therefore tells us whether diets provide adequate micronutrient content for different populations and is associated with child nutritional status.

Although the linkages between agriculture and nutrition are ascendant as a topic of development interest, there remains little empirical evidence demonstrating these links at the household level, particularly for infants and young children. Agriculture is assumed to affect child nutrition through multiple pathways, including the production of food to be eaten by a household or sold for income and subsequent food- or health-related expenditure; through modulation of food prices and the food market environment, and therefore the incomes of net food sellers and the ability to access food for net food buyers; and through various gender-specific pathways including women's socioeconomic status, time use and energy expenditure (Gillespie, Harris, & Kadiyala, 2012; World Bank, 2007) (see Figure 1). But evidence is scant along the specific pathways by which effects may occur, even though a link is often presumed in policy and programming.

In subsistence farming systems, where the links between agriculture and nutrition are most direct and households are assumed to consume most of what they produce, it is supposed that increased diversity of agricultural production may be associated with increased diversity of foods eaten, and therefore onwards to improved diet quality. Several authors have postulated that increased biodiversity in general, including diversity of wild and cultivated foods, might lead to increased diversity of foods

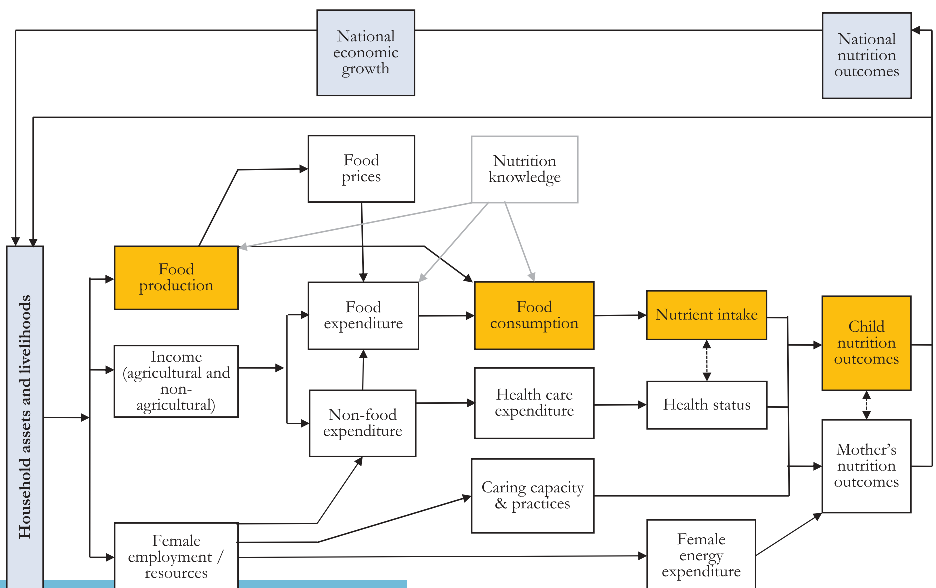

Figure 1. Pathways from agriculture.
Source: adapted from Gillespie, Harris, and Kadiyala (2012).

in the diet at a population level (Frison, Cherfas, & Hodgkin, 2011), though none has yet demonstrated this in an experimental setting, nor any impacts of biodiversity on nutritional status. Studies of homestead food production programmes have found improvements in production of targeted nutrient-rich foods within households (Dillon, Moreira, Olney, Pedehombga, & Quinones, 2012; Iannotti, Cunningham, & Ruel, 2009), but have not found impact on child nutrition. A critical intermediate step requiring assessment is whether production of these more diverse foods leads to their actually being eaten, improving the diversity and quality of children's diets in those households. Reviews of interventions aiming to increase the diversity of agricultural production and assess impact on diet and nutrition (Berti, Krasevec, & Sian, 2004; Masset, Haddad, Cornelius, & Isaza-Castro, 2011; World Bank, 2007) have found in general that the specific foods or food groups targeted by an intervention have tended to find their way into the diets of target beneficiaries, but have not demonstrated impact on nutritional status (anthropometry) – generally because the original evaluations were poorly designed or underpowered to show such an effect.

The few available economic studies that have looked specifically at the production-intake pathway have found linkages between household agricultural production and nutrition: Muller (2009) found significant association between production of staple and non-staple foods and adult Body Mass Index (BMI) in Rwanda, with increased production leading to increased BMI. And a recent study by Woldehanna and Behrman (2013) examines the determinants of dietary diversity among children using data from Ethiopia; they control for diversification of crops cultivated and find a positive significant association between crop diversification and dietary diversity from seven food groups (however, this association becomes insignificant when they account for fixed effects). Studies on links between agricultural production and subsequent diets and nutritional status of household members are therefore limited.

In particular, then, evidence is needed on the direct links between food production within a household, ingestion of that food by individual household members, and subsequent effects on nutritional status. This is the pathway investigated in this article. The motivation for this study is to address the gap in our understanding of how diversity of agricultural production affects the dietary diversity and nutritional status of children living in farming communities in sub-Saharan Africa, using household survey data from a rural district in central Zambia. Specific objectives are to:

(1) assess the association between household agricultural production diversity and child dietary diversity among children 6–23 months of age, controlling for various socio-economic, demographic, health and empowerment variables; and
(2) assess the association between household agricultural production diversity and child nutritional status, among younger (6–23 months of age) and older children (24–59 months of age), controlling as above.

2. Study Context

Zambia is among the countries struggling to meet Millennium Development Goal targets for undernutrition reduction to improve the health and productivity of its population. Nationally, 45 per cent of children aged under five are stunted (chronically malnourished, below standard recommendations for linear growth) (Central Statistical Office et al., 2009). The determinants of malnutrition all face challenges in Zambia, with limited infrastructure and public services, and huge income inequality: while urban poverty has reduced by almost half over the past 20 years, to around 26 per cent, rural poverty remains flat at almost 80 per cent, and infrastructure and markets are confined mostly to urban and peri-urban areas (Harris, Seco, Masi, & Haddad, 2014).

Around 75 per cent of Zambia's rural poor are small-scale farmers relying almost entirely on subsistence agriculture, and a further 20 per cent are classed as emergent, with some surplus available for sale but consuming a large proportion of what they grow (Food and Agriculture Organisation, 2009). Agriculture revolves around a few staple crops, and maize is predominant both in terms of production and consumption; in 2009, maize accounted for 86 per cent of cereal production and 49 per cent of total calorie availability per capita in the country; cassava, another starchy staple, accounted for a further 14 per cent of calories (FAO, 2014). Zambian agricultural policies revolve around large input subsidy programmes and large-scale government maize procurement through the Food Reserve Agency, promoting maize production to the exclusion of most other crops; although other crops have recently been incorporated into this system, and nutrition is gradually being written into high-level strategy documents within the agriculture sector, there is as yet little sign that the emphasis on maize is due to change soon in any practical sense (Harris & Drimie, 2012).

Because of this focus on staple food production and poor access to markets, rural Zambian diets are monotonous and generally lack the diversity required for good nutrition. Recognising this, several NGOs have initiated projects designed to improve access to nutritious foods, and this study takes advantage of one such project. We use data collected as part of the Realigning Agriculture for Improved Nutrition (RAIN) intervention in Zambia. The RAIN project is an agricultural intervention to increase year-round availability of and access to nutrient rich foods at the household level, in some areas accompanied by promotion of optimal health, nutrition and care-seeking behaviour through social behaviour change communication, all delivered to impact children during their early life when avoidance of undernutrition is most crucial. The RAIN project is delivered in poor rural parts of Mumbwa District, Central Province. The baseline survey data used for this article confirm that the area is defined by many of the agricultural constraints described above, and that children routinely consume poor diets lacking diversity; rates of stunting in the project area are similar to those seen nationally (Harris, Quabili, & Rawat, 2012).

3. Conceptual Framework

As noted in the introduction, there are several pathways through which agriculture affects nutrition. We focus on the pathway from household production to food intake, highlighted in Figure 1. To better understand the link between agricultural production and dietary diversity we consider an agricultural household (similar to Pitt and Rosenzweig [1985] and Rashid, Smith, and Rahman [2006]) with N members that maximise a household utility function given by:

$$U = U(X_f, X_{nf}, H, L) \tag{1}$$

where X_f is an $N \times F$ matrix of food items consumed by all members of the household. F is the total number of food items consumed which consists of j food items which the farm household produces and k food items which are purchased from the market ($F = j + k$), X_{nf} is the matrix of non-food items consumed by the household, H is a vector of health status of all members of the household and L is the vector of leisure time consumed by all members. The health status of each household member, i, is given by the following function:

$$H^i = H(N(X_f^i), E^i, D, c^i) \tag{2}$$

where $N(.)$ is the $1 \times n$ vector of nutrients consumed by member i, E^i are the non-food inputs such as health services, D are household characteristics that affect health and c^i are individual characteristics that affect health.

In the absence of missing markets or market imperfections, the household's production and consumption decisions can be separated (Singh, Squire, & Strauss, 1986) and the household can choose to produce only the profit-maximising crop or agricultural good and trade in other goods on the market. However, when markets are missing or there are sizeable transaction costs of purchasing food items from the market, the household's decision problem changes. In such a case, the household may produce all crops that are more profitable to produce on their own farm compared to buying them on the market (Taylor & Adelman, 2002). As described in Section 2, the rural Zambian context is closer to the missing/imperfect market scenario. The household produces j food items (each of which are determined by a production technology which we abstract from here):

$$X_f^h = (X_f^1, X_f^2, \ldots, X_f^j) \tag{3}$$

If we assume that households consume at least a portion of all food items they produce, then each household has a production motive and a consumption motive when deciding on the number of food items to produce. On the production side, the household would choose the optimal number of food items to produce to maximise profits. This profit maximisation exercise is determined by a number of factors such as available land, labour and other factors of production, quality of these inputs, ability of the farmer, access to markets, time and risk preferences, and food preferences. On the consumption side the household derives utility from greater variety in two ways – directly and indirectly through the effects of food intake on health.

In our analysis, we are interested in understanding whether greater household production diversity translates into greater household dietary diversity in the presence of missing markets. We begin our analysis by examining this link. To examine whether this trickles down to dietary diversity among young children, we study the relation between household production diversity and dietary among children aged 6–23 months. And finally, we also explore the link between production diversity and nutritional status of children aged 6–23 months and children aged 24–59 months.

We focus on the relationship between production diversity and dietary diversity among the younger children because it is widely recognised that the first 1,000 days from conception until a child's second birthday is the 'window of opportunity' to intervene, during which time chronic undernutrition can best be prevented (Bhutta et al., 2008); we assess this at 6–23 months because younger children are ideally exclusively breastfed. Global evidence suggests that the earlier children are exposed to nutrition interventions during their first two years of life, and the longer the exposure during this period, the more they are likely to benefit in terms of linear growth; there is also evidence that nutrition interventions beyond the first two years have much less impact on stunting than if delivered before 2 years of age (Victora, De Onis, Hallal, Blossner, & Shrimpton, 2010). In addition, although nutrition interventions should reach infants and young children during their first 2 years, the accrued benefits of these interventions should ideally be measured once this period of greatest potential to benefit is concluded (Bhutta et al., 2008); when examining the association between agricultural production variables and child nutritional status (particularly long-run phenomena such as stunting), it is therefore important to look at this in children ≥24 months of age. Measuring associations with stunting at an earlier age (<24 months of age) would likely underestimate the magnitude of the association because it would possibly truncate the full benefit that children could get from receiving interventions during the entire first 2 years of life, so nutritional status here is measured in children aged 24–59 months.

4. Empirical Strategy

We examine the determinants of dietary diversity and nutritional status with production diversity as the main variable of interest. We estimate the following reduced form equations:

$$DD_h = \alpha + \beta PD_h + \varphi HH_h + \varepsilon \tag{4}$$

$$DD_{ih} = \alpha + \beta PD_h + \gamma C_{ih} + \delta M_{ih} + \varphi HH_h + \varepsilon \tag{5}$$

$$A_{ih} = \alpha + \beta PD_h + \gamma C_{ih} + \delta M_{ih} + \varphi HH_h + \varepsilon \tag{6}$$

where DD_h is the household dietary diversity, PD_h is production diversity for household h, HH_h are household characteristics including head's age, gender and education, household size and age composition, socio-economic status index, monthly food expenditure, land area cultivated and ε is the error term. DD_{ih} is dietary diversity among children aged 6–23 months and A_{ih} is the anthropometric nutritional status of children aged 6–59 months (estimated separately for children aged 6–23 months and those aged 24–59 months), C_{ih} are the characteristics of child i including age, age squared, gender and morbidity, M_i are characteristics of child i's biological mother including age, height, education, economic activity and decision-making power. The reduced form model for dietary diversity is estimated using ordered logit when the dietary diversity variable is ordered and by marginal probit (dprobit) when the dietary diversity variable is an indicator variable. The reduced form equations for anthropometric status are estimated using ordinary least squares when the anthropometric status is measured by a continuous variable and by marginal probit when it is measured by an indicator variable.

Decisions regarding production diversity are complex and, among other things, are functions of amount of land and labour available, quality of land, risk and food preferences and access to markets (for inputs as well as outputs) and infrastructure. This poses an endogeneity concern in that any observed relationship between production diversity and the outcomes of interest may be due to any of these factors. We control for the factors that are observable and available in our data. However, there are other factors that remain unobservable – such as land quality and ability of farmer. We estimate extensions to the basic model to address some of these concerns. However, our ability to completely account for the endogeneity remains limited.

5. Data and Descriptives

For the analysis presented here we use baseline survey data collected as part of the cluster randomised evaluation of the RAIN project; clusters were defined as census supervisory areas, geographic sampling units used for census surveys that do not correspond to any administrative or village boundaries, but contain roughly similar numbers of inhabitants. This dataset consists of 3,340 households, selected using simple random sampling from a complete sampling frame of all eligible households in the project area developed for this survey. The only inclusion criterion was a household having a child aged 24–59 months of age, the age range for detecting impacts on stunting. In addition, to capture impacts of the RAIN project on key infant and young child feeding (IYCF) indicators including diet, questions about children between 6–23 months of age were also asked where households had a child of that age. The baseline survey gathered data using a detailed household questionnaire based on the UNICEF conceptual framework, designed to capture information on all levels of influence that contribute to child undernutrition. Data included anthropometry among all children 0–59 months of age, IYCF practices among children 6–23 months, health status and care practices, women's empowerment, and household-level demographics, food security, agricultural production. This was administered primarily to the primary care giver of the child 24–59 months; for several modules, questions could be asked of other household members if these individuals had appropriate knowledge (such as the agriculture module).

5.1. Variables

Stunting was the primary outcome measure in this study. This is measured in children under the age of 5 years and expressed as a Z-score (deviation from the mean of a reference population) (WHO Multicentre Growth Reference Study Group, 2006): height-for-age Z-score (HAZ) expresses a child's height for a given age; a Z-score of less than −2 denotes stunting, or growth faltering as a result of chronic undernutrition. Weight-for-height Z-score (WHZ) expresses a child's weight for a given height; a Z-score of less than −2 denotes wasting, or excess thinness due to acute malnutrition.

Infant and young child feeding (IYCF) is a key issue determining nutritional status, and has a defined set of indicators for measurement of both breastfeeding and complementary feeding facets (World Health Organisation, 2010); dietary diversity is a central indicator in this set. The diversity of children's diets is measured as the intake of discrete food groups among children aged 6–23 months of age over the previous 24 hours. The seven food groups considered are those with the most density of nutrients, and therefore those most important in a young child's diet: grains, roots and tubers; legumes and nuts; dairy products; flesh foods; eggs; vitamin A rich fruits and vegetables; and other fruits and vegetables.[1] Dietary diversity can be expressed as the mean number of food groups consumed within a population of children (aged 0–7), and as achieving minimum dietary diversity (consuming four or more food groups the previous day) (World Health Organisation, 2010).

In addition to individual-level dietary diversity for young children, we construct a dietary diversity measure for the household. While individual dietary diversity is a validated measure of the diet quality of an individual (Ruel et al., 2014), dietary diversity at the level of the household (household purchases) is a measure of household food access, and therefore of food security (Hoddinott & Yohannes, 2002). Household dietary diversity is most commonly constructed with 12 food groups as it does not focus solely on the most nutrient-rich foods (FAO, 2011).

From our data we also constructed an index on the caregiver's knowledge of IYCF practices, including recommended breastfeeding practices and the introduction of foods. We assign a value of 1 to each correct answer and sum the scores, such that the index can take values between 0 and 4 (inclusive). We also construct a health care index using positive responses to questions regarding immunisation, micronutrient supplementation and routine deworming medication. We construct a preventative health-seeking behaviour index using information from the most recent preventive health clinic visit, whether the child's height and weight were measured, and whether the caregiver was informed about the results, the growth pattern, and any specific advice or prescriptions. Each positive response was coded as 1 and summed across all the 10 responses giving a total score of 0–10 (inclusive).

Agricultural diversity can be measured by an index of number of crops planted and area of each crop (Winters, Cavatassi, & Lipper, 2006), but this does not take into consideration non-crop foods such as animal products which are particularly important to nutrition. Other estimation methods such as 'functional diversity' try more explicitly to bring in nutrient considerations (Remans et al., 2011), but require more intensive data collection methods. For this study, we use three different variables as indicators of production diversity: (1) the total number of crops (including field crops and fruits and vegetables) cultivated; (2) the total number of agricultural activities engaged in (production of field crops, production of fruits and fruits/vegetables, rearing animals and production of animal source foods); and (3) the production of seven different food groups that correspond to those groups used in the child dietary diversity index. Total agricultural production is expressed in the form of both total quantity of production, and total income derived from production. All agricultural variables were constructed from data recalled by the household head for the past three months (spanning the main maize harvest time in dry season).[2] To account for production diversity at the local level we construct a variable that reflects the maximum production diversity within a cluster which is represented by the largest value of household production diversity measured in that cluster.

Socio-economic status of households was estimated through creation of an index using principle components analysis (Filmer & Pritchett, 2001), derived from variables collected in the baseline survey (household fixed, durable and productive assets; household utilities and home building materials; and household demographic characteristics).

The household questionnaire also collected information on child characteristics such as age, gender and morbidity; mothers' age, height, economic activity, education, and empowerment; household head's characteristics; and household size and age composition, assets owned, land area owned and cultivated, and expenditure on specific food categories.

5.2. Descriptive Results

The nutritional status of children less than 5 years of age is presented in Table 1. Among all children 0–5 years of age, mean HAZ is low at −1.64 (±1.68). Mean WHZ is above the median of the reference data at 0.39 (±1.36) and deteriorates with age but does not dip below zero. Consistent with global evidence, in this sample, male children had consistently poorer outcomes for all three measures during

Table 1. Nutritional status outcomes and IYCF indicators, by age

Outcome	Mean	SD	Percent stunted, underweight, or wasted
Height-for-age Z-score (HAZ); stunting			
All	−1.64	(1.68)	43.4
0–5.9 months	−0.44	(2.14)	21.1
6–23.9 months	−1.45	(1.99)	44.2
24–59.9 months	−1.82	(1.41)	44.8
Weight-for-age Z-score (WAZ); underweight			
All	−0.64	(1.19)	10.4
0–5.9 months	−0.01	(1.43)	5.6
6–23.9 months	−0.44	(1.40)	12.9
24–59.9 months	−0.81	(0.99)	9.9
Weight-for-height Z-score (WHZ); wasting			
All	0.39	(1.36)	3.6
0–5.9 months	0.52	(2.01)	10.5
6–23.9 months	0.45	(1.52)	4.7
24–59.9 months	0.35	(1.22)	2.5
Core indicators for IYCF			
Early initiation of breastfeeding (within 1 hour of birth)	57.1		
Exclusive breastfeeding among children under 6 months	74.3		
Continued breastfeeding at 1 year (12–15 m)	94.8		
Introduction of solid, semi-solid or soft food (6–8 m)	85.1		
Minimum diet diversity (≥ 4 food groups)	27.3		
Minimum meal frequency [1]	51.7		
Minimum acceptable diet [2]	16.4		
Intake of iron-rich food [3]	55.4		
Minimum meal frequency, acceptable diet & intake of iron-rich food	13.5		

Notes: Standard deviations in parenthesis.
[1]Minimum is defined as: 2 times for breastfed infants 6–8 m; 3 times for breastfed children 9–23.9 m; 4 times for non-breastfed children 6–23.9 m. "Meals" include both meals and snacks and frequency is based on caregiver report.
[2]Acceptable diet is defined who had at least the minimum dietary diversity and the minimum meal frequency during the previous day.
[3]Iron-rich or iron-fortified foods include flesh foods, commercially fortified foods specially designed for infants and young children which contain iron, or foods fortified in the home with a micronutrient powder containing iron.

the first five years of life. Overall, the patterns reinforce what is known in the global literature on child growth (Victora et al., 2010): the first two years of life are a critical period within which growth-faltering is rapid, and mean HAZ falls steeply in the first 18 months here, and remains low. Mean WHZ remains above the median in this population. The overall prevalence of stunting is high at 43.4 per cent, approximately equivalent to the national average of 45 per cent (Central Statistical Office, Ministry of Health, Tropical Diseases Research Centre, University of Zambia, and Macro International Inc, 2009). The prevalence of wasting, an indicator of acute malnutrition, is 3.6 per cent, below the national average of 5 per cent, with prevalence highest in the youngest age group and decreasing progressively in older age groups; severe wasting, a strong risk factor for mortality, is less than 2 per cent.

In general, the majority of IYCF practices are sub-optimal in this population (Table 1), with complementary feeding-related practices faring worse than breastfeeding-related practices. Mean dietary diversity score is fewer than three food groups (2.8 food groups, ±1.2) among children aged 6–23 months. About a quarter of children meet the minimum dietary diversity criterion.

Summary statistics on agricultural production, diversity and market linkage are provided in Table 2. There are major gaps in the diversity of crops, fruits and vegetables, and animal products produced.

Table 2. Descriptive statistics on agricultural activities and production diversity among households

	Mean	S.D.
Average fraction of households that cultivate field crop	0.87	(0.34)
Average fraction of households that cultivate fruits/vegetables	0.31	(0.46)
Average fraction households that cultivate field crops and fruits/vegetables	0.31	(0.46)
Average fraction households that own any livestock	0.99	(0.10)
Average fraction households that produce animal products	0.68	(0.47)
Average number of field crops and fruits/vegetables cultivated	2.47	(1.87)
Average number of agricultural activities undertaken	2.6	(1.17)
Average household production diversity (7 food groups)	2.5	(1.63)
Log of average agricultural production in kilograms	12.68	(5.02)
Log of average agricultural income	11.44	(6.00)
Average percentage of households that sell more than half of production from any of its field crops	60.90	(48.8)
Average percentage of households that sell any proportion of their field crops outside the village	2.56	(15.8)
Average percentage of households that sell any proportion of their field crops to the government	48.55	(49.9)
Average percentage of households that sell more than half of production from any of its fruits/vegetables	8.34	(27.7)
Average percentage of households that sell any proportion of their fruits/vegetables outside the village	1.31	(11.4)
Observations	3033	

Notes: Standard deviations in parenthesis.

Overall, 87 per cent of households cultivated field crops, whereas only 31 per cent cultivated fruits and vegetables and just over half produced animal foods. Half of households kept all of their maize production and most kept all of their groundnut production for home consumption; most sold all of their cotton. Even though there is a large percentage of households selling field crops, a very small fraction sells outside the village and close to half sell to the government directly. A majority of the households own at least some livestock. Most of the livestock ownership is comprised of smaller animals such as poultry, with only about 40 per cent of households owning any milk producing animals. On average households are producing foods corresponding to at least two food groups. Household dietary diversity is 4.5 food groups, indicating poor food access overall.

6. Results & Discussion

We present results on household dietary diversity and household production diversity in Table 3. This shows that household dietary diversity is positively associated with all three measures of production diversity and this relation is statistically significant. This is what we would expect in a context where markets do not function properly and most households have to rely on own production to satisfy their food needs.

Next, we examine whether this holds true for individual dietary diversity among young children aged 6–23 months. We present results on the effect of diversity of agricultural production and total agricultural production on: (1) individual dietary diversity (both mean number of food groups and minimum dietary diversity) among infants and young children 6–23 months of age (Table 4, Panel A); (2) nutritional status among children 6–23 months of age (Table 4, Panels B and C); and (3) nutritional status among older children 24–59 months of age (Table 4, Panels A and B). All three production diversity variables are significantly associated with both dietary diversity outcomes, with similar magnitudes of association. Additionally, total agricultural production and agricultural income earned is also associated with dietary diversity. However, the coefficient estimates are much smaller as compared to those on the production diversity variables.[3] These results suggest that the diversity of diets consumed by infants and young children is directly related to diversity in agricultural production. This diversity in production is more strongly associated with dietary diversity than the total amount of

Table 3. Relation between household dietary diversity and household production diversity and agricultural production

	No. of field crops and vegetables cultivated	No. of agricultural activities	No. of food groups produced	Log of agricultural production	Log of agricultural income
	(1)	(2)	(3)	(4)	(5)
Household dietary diversity (7 food groups)	0.250***	0.451***	0.387***	0.078***	0.071***
	(0.028)	(0.046)	(0.034)	(0.013)	(0.009)
Observations	2,785	2,785	2,785	2,784	2,785
Psuedo R-squared	0.04	0.04	0.05	0.04	0.04

Notes: Robust standard errors in parentheses clustered at village level. *** p < 0.01, ** p < 0.05, * p < 0.1. All regression include controls for head's age, gender and education, household age composition, size and dependency ratio, socio-economic status index, land area cultivated, log of monthly expenditure and ward dummies. Models were estimated using ordered logit.

Table 4. Relationship between production diversity, total agricultural production, and dietary diversity and nutritional status among children 6–23 months

	No. of field crops and vegetables cultivated	No. of agricultural activities	No. of food groups produced	Log of agricultural production	Log of agricultural income
	(1)	(2)	(3)	(4)	(5)
Panel A: dietary diversity					
Dietary diversity (7 food groups)	0.217***	0.294***	0.263***	0.049***	0.042***
	(0.034)	(0.053)	(0.043)	(0.014)	(0.010)
Observations	1,298	1,298	1,298	1,298	1,298
Psuedo R-squared	0.06	0.06	0.06	0.05	0.05
Minimum dietary diversity (≥ 4 food groups)	0.053***	0.075***	0.067***	0.016***	0.014***
	(0.008)	(0.012)	(0.009)	(0.004)	(0.003)
Observations	1,288	1,288	1,288	1,288	1,288
Psuedo R-squared	0.10	0.09	0.11	0.09	0.09
Panel B: height for age Z-score and stunting prevalence					
Height for age Z-score	−0.083***	−0.097**	−0.058	−0.007	−0.000
	(0.030)	(0.049)	(0.036)	(0.014)	(0.011)
Observations	1,224	1,224	1,224	1,224	1,224
R-squared	0.126	0.124	0.123	0.122	0.122
Stunting (HAZ < –2)	0.006	0.014	0.007	0.002	0.004
	(0.009)	(0.014)	(0.010)	(0.004)	(0.003)
Observations	1,224	1,224	1,224	1,224	1,224
Psuedo R-squared	0.07	0.07	0.07	0.07	0.07
Panel C: weight for height Z-score and wasting prevalence					
Weight for Height Z score	0.025	−0.046	0.002	−0.011	−0.004
	(0.025)	(0.042)	(0.026)	(0.010)	(0.009)
Observations	1,222	1,222	1,222	1,222	1,222
R-squared	0.041	0.041	0.040	0.041	0.040
Wasting (WHZ < –2)	−0.010***	−0.002	−0.011***	0.002	0.002
	(0.003)	(0.005)	(0.004)	(0.001)	(0.001)
Observations	1,153	1,153	1,153	1,153	1,153
Psuedo R-squared	0.04	0.03	0.04	0.03	0.03

Notes: Robust standard errors in parentheses clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. All regression include controls for head's age, gender and education, household age composition, size and dependency ratio, socio-economic status index, land area cultivated, log of monthly expenditure, child characteristics, primary care giver's characteristics and ward dummies. Estimates for dietary diversity based on 7 food groups were estimated using ordered logit; those for minimum dietary diversity, stunting and wasting were estimated using dprobit; and; HAZ and WHZ were estimated using ordinary least scores.

agricultural production and the income derived from this production. Other key variables positively associated with child dietary diversity outcomes not reported here include, at the household level: socio-economic status; monthly food expenditure; and having a mother as an income earner and having greater influence over decision making; and at the level of the child: being female; age; and having a recent illness. Household ownership of cultivated land is inversely associated with dietary diversity. One plausible explanation for this finding may be that households with larger land holding may be engaged in cash cropping, particularly of maize and cotton.

In Table 4, Panels B and C, we present regression results on the association between production diversity and nutritional status among young children 6–23 months of age. There is no discernible pattern or noteworthy association between household production diversity and nutritional status in this young age range. Counterintuitively, the total number of crops produced and the total number of agricultural activities engaged in is inversely associated with HAZ (Panel B). Similarly, none of the agriculture production variables are associated with stunting. This pattern of results implies that the negative effect of total number of crops produced and the total number of agricultural activities engaged in is occurring among children who are in the higher end of the distribution of HAZ scores. We run quantile regressions to examine this further and find that the negative relationship between production diversity and HAZ is strongest (in magnitude and significance) for children who are in the 80th percentile or higher (or those with HAZ scores of 0 or higher).[4] The total number of crops produced and the total number of food groups produced is inversely associated with wasting, though, again, the magnitude of these associations are negligible (Panel C). The agriculture production variables are not associated with WHZ.

We also examined the association of agriculture production diversity and total production with nutritional status in older children (Table 5). The rationale behind stratifying these associations by children less than and greater than 24 months of age relates to the period of rapid growth faltering in

Table 5. Relationship between production diversity, total agricultural production, and nutritional status among children 24–59 months

	No. of field crops and vegetables cultivated	No. of agricultural activities	No. of food groups produced	Log of agricultural production	Log of agricultural income
	(1)	(2)	(3)	(4)	(5)
Panel A: height for age Z-score and stunting prevalence					
Height for age Z-score	0.033*	0.084***	0.036*	0.020***	0.017***
	(0.018)	(0.028)	(0.021)	(0.007)	(0.006)
Observations	2,385	2,385	2,385	2,385	2,385
R-squared	0.040	0.042	0.040	0.042	0.043
Stunting (HAZ < –2)	−0.008	−0.022**	−0.015**	−0.005*	−0.003
	(0.006)	(0.011)	(0.007)	(0.003)	(0.002)
Observations	2,385	2,385	2,385	2,385	2,385
Pseudo R-squared	0.05	0.05	0.05	0.05	0.05
Panel B: weight for height Z score and wasting prevalence					
Weight for height Z-score	0.003	−0.033	−0.013	−0.009	−0.009*
	(0.017)	(0.023)	(0.018)	(0.005)	(0.005)
Observations	2,385	2,385	2,385	2,385	2,385
R-squared	0.040	0.041	0.040	0.041	0.042
Wasting (WHZ < –2)	0.000	0.003	0.001	0.002**	0.001**
	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)
Observations	2,385	2,385	2,385	2,385	2,385
Pseudo R-squared	0.07	0.07	0.07	0.09	0.07

Notes: Robust standard errors in parentheses clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. All regression include controls for head's age, gender and education, household age composition, size and dependency ratio, socio-economic status index, land area cultivated, log of monthly expenditure, child characteristics, primary care giver's characteristics and ward dummies. Estimates for stunting and wasting were estimated using dprobit, and those for HAZ and WHZ were estimated using ordinary least scores.

the first two years of life, after which there appears to no subsequent catch-up period, particularly in terms of linear growth (Victora et al., 2010).

Unlike in younger children, there is a more consistent pattern between agricultural production diversity, total agricultural production and linear growth. All agricultural production variables are positively associated with HAZ scores and inversely associated with stunting in older children (Table 5, Panel A). While the magnitudes of these associations are very small, the consistency of these associations in older children compared to younger children is noteworthy. Similar to analysis undertaken for younger children, we run quantile regressions on the HAZ scores among older children to ascertain whether the relation between production diversity and HAZ scores varies at different points in the distribution of the HAZ score. We find that, among the older children, the positive relation between production diversity and HAZ score is strongest for children who are in the bottom end of the distribution. In other words, children who are in the 20th percentile (severely stunted with HAZ scores close to –3) are most likely to benefit from greater production diversity at the household level.[5]

Similar to our findings in younger children, agricultural production diversity is not associated with WHZ or wasting; there is, however, a very small positive association between total agricultural production and wasting (Table 5, Panel B). It is important to note that the total agricultural production variables have been log transformed, and after transformation these variables are only associated with a 0.1 percentage point increase in wasting.

Our finding of a significant association between the diversity of agricultural production and total agricultural production with linear growth in older children, but not younger children, is notable. One plausible explanation for this relates to the patterns discussed earlier: (1) younger children – due to their small stomachs – eat less of family foods and rely more on nutrients provided by breast milk; and (2) linear growth patterns are different at these different ages, and it is possible that the accrued benefits of household agricultural production diversity do not manifest until after children have been exposed fully to diverse diets during the critical 1,000-day 'window of opportunity' until 24 months of age. So, although production and dietary diversity should be promoted during the entirety of the 0–5 year age range, the benefits to linear growth may only be fully realised in later childhood. For our arguments to hold it is necessary that the production pattern observed in the baseline survey is a valid reflection of what food items were produced 2–3 years ago by the household, when the older children were in the relevant age group. Though we do not have the data to fully validate this, the study area selected for the RAIN intervention was one where no other agricultural/nutrition interventions were underway in the recent past and/or at the time of the baseline survey. This suggests that households in this area were not responding to any agricultural extension/nutrition behaviour change communication messages by changing production patterns in the last few years. Therefore, we believe that it is very likely food production during the time of data collection was similar to production over the previous 2–3 years.

6.1. Extensions to the Basic Model

Here we present a series of extensions to ensure that our core results are robust. The regressions models estimated are identical to those estimated in Table 4 with added control variables.

6.1.1. Testing the effect of access to a more diverse diet locally or via market accessibility. One pathway towards more diverse diets can be greater household access to more diverse foods. The greater access can be through own production or production by other households within the village. It is possible that each household does not produce all food groups but instead purchases them locally. If this is the case, then it is production diversity at village level that is critical. The results for the association between household production diversity and dietary diversity among children 6–23 months old controlling for maximum production diversity in the cluster are presented in columns (1) and (4) of Table 6 (which can be compared to corresponding coefficients in Table 4, Panel A[6]). For both dietary diversity and minimum dietary diversity, the point estimates are slightly smaller but remain significant.

Table 6. Access, production diversity and dietary diversity

	Dietary diversity (7 food groups)			Minimum dietary diversity (≥ 4 food groups)		
	(1)	(2)	(3)	(4)	(5)	(6)
No. of field crops and vegetables cultivated	0.197***	0.200***	0.184***	0.046***	0.049***	0.043***
	(0.035)	(0.035)	(0.036)	(0.008)	(0.008)	(0.008)
Observations	1,298	1,298	1,298	1,288	1,288	1,288
Pseudo R-squared	0.06	0.06	0.06	0.10	0.11	0.11
No. of agricultural activities	0.255***	0.255***	0.221***	0.062***	0.066***	0.054***
	(0.059)	(0.055)	(0.060)	(0.014)	(0.013)	(0.014)
Observations	1,298	1,298	1,298	1,288	1,288	1,288
Pseudo R-squared	0.06	0.06	0.06	0.10	0.10	0.10
No. of food groups produced	0.242***	0.241***	0.224***	0.061***	0.062***	0.057***
	(0.046)	(0.044)	(0.047)	(0.009)	(0.009)	(0.009)
Observations	1298	1298	1298	1,288	1,288	1,288
Pseudo R-squared	0.06	0.06	0.06	0.11	0.11	0.11
Controlling for local production diversity	Y	N	Y	Y	N	Y
Controlling for owing a mode of transport	N	Y	Y	N	Y	Y

Notes: Robust standard errors in parentheses clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. All regression include controls for head's age, gender and education, household age composition, size and dependency ratio, socio-economic status index, land area cultivated, log of monthly expenditure, child characteristics, primary care giver's characteristics and ward dummies. Estimates for dietary diversity based on 7 food groups were estimated using ordered logit, those for minimum dietary diversity were estimated using dprobit.

This indicates that dietary diversity among the younger children is primarily being driven by diversity of own production as compared to diversity of production at the village level.

It is possible that households within a cluster are producing very similar foods; therefore, they tend not to trade food with each other. However, it is still possible that these households go to nearby markets to buy foods that are not locally produced or produced at home. We do not have data on distance to nearest market or town, but we do have data on vehicle ownership. To the extent that households within the village have access to the same public transport facilities available, we can argue that households that own a mode of transport have better access to nearby markets. In columns (2) and (5) of Table 6 we include control for owning a mode of transport; however, the point estimates are essentially unchanged (again as compared to corresponding coefficients in Table 4, Panel A). However, we do find that owning a mode of transport by itself has a positive significant effect on the measures of dietary diversity.[7]

Columns (3) and (6) of Table 6 present results when we control for local production diversity as well as owning a mode of transport. The results are unchanged. We performed the same analysis for the nutritional status among younger (6–23 months) and the older (24–59 months) children and find results that are similar to our core results.[8]

6.1.2. Testing the effect of relative socioeconomic status. If we believe that local markets play a bigger role in determining dietary diversity than own production, then food prices will be important. Food prices may vary from market to market depending on the general wealth levels in nearby villages and towns. In such a scenario, relative wealth is more important in determining purchasing power rather than absolute wealth. Table 7 presents estimates for association between household production diversity and child dietary diversity and minimum dietary diversity, controlling for socio-economic tertiles based on the distribution of the socio-economic status index within the cluster. The point estimates are almost identical to those in Table 4, Panel A, indicating that production diversity is more important than relative socio-economic status in determining dietary diversity among young children.

Table 7. Relative socio-economic status, dietary diversity and nutritional status

Dietary diversity among children 6–23 months	No. of field crops and vegetables cultivated (1)	No. of agricultural activities (2)	No. of food groups produced (3)
Dietary diversity (7 food groups)	0.217***	0.294***	0.264***
	(0.034)	(0.053)	(0.042)
Observations	1,298	1,298	1,298
Pseudo R-squared	0.06	0.06	0.06
Minimum dietary diversity (≥ 4 food groups)	0.053***	0.076***	0.068***
	(0.008)	(0.012)	(0.009)
Observations	1,288	1,288	1,288
Pseudo R-squared	0.10	0.09	0.11

Notes: All regressions include dummies for socio-economic status tertiles within the cluster. Robust standard errors in parentheses clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. All regression include controls for head's age, gender and education, household age composition, size and dependency ratio, socio-economic status index, land area cultivated, log of monthly expenditure, child characteristics, primary care giver's characteristics and ward dummies. Estimates for dietary diversity based on 7 food groups were estimated using ordered logit, those for minimum dietary diversity were estimated using dprobit.

6.1.3. Testing the effect of caregiver's knowledge of infant and young child feeding practices. A child's caregiver's knowledge of feeding practices plays a large role in deciding what the child actually eats. Households that produce a large number of foods/food products may not feed their children a diverse diet if they are not aware of the kinds of foods children of certain age groups require for optimal growth. We re-estimate regressions reported in Table 4, Panel A, controlling for the index of care giver's knowledge of IYCF practices. These are presented in Table 8. The results here are almost identical to those in Table 4. This gives us more confidence in our estimates on production diversity and its link with dietary diversity.

Table 8. IYCF knowledge, dietary diversity and nutritional status

Dietary diversity among children 6–23 months	No. of field crops and vegetables cultivated (1)	No. of agricultural activities (2)	No. of food groups produced (3)
Dietary diversity (7 food groups)	0.217***	0.294***	0.263***
	(0.034)	(0.053)	(0.043)
Observations	1,298	1,298	1,298
Pseudo R-squared	0.06	0.06	0.06
Minimum dietary diversity (≥ 4 food groups)	0.053***	0.075***	0.067***
	(0.008)	(0.012)	(0.009)
Observations	1,288	1,288	1,288
Pseudo R-squared	0.10	0.09	0.11

Notes: All regressions include a score on IYCF practices (0–3). Robust standard errors in parentheses clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. All regression include controls for head's age, gender and education, household age composition, size and dependency ratio, socio-economic status index, land area cultivated, log of monthly expenditure, child characteristics, primary care giver's characteristics and ward dummies. Estimates for dietary diversity based on 7 food groups were estimated using ordered logit, those for minimum dietary diversity were estimated using dprobit.

Table 9. Infrastructure, preferences, dietary diversity and nutritional status

	Dietary diversity (7 food groups)		Minimum dietary diversity (> 4 food groups)	
	(1)	(2)	(3)	(4)
No. of field crops and vegetables cultivated	0.207***	0.093**	0.051***	0.048***
	(0.033)	(0.037)	(0.008)	(0.008)
Observations	1,298	1,298	1,288	1,288
Pseudo R-squared	0.07	0.07	0.12	0.12
No. of agricultural activities	0.296***	0.168**	0.075***	0.069***
	(0.052)	(0.067)	(0.013)	(0.013)
Observations	1,298	1,298	1,288	1,288
Pseudo R-squared	0.06	0.06	0.11	0.11
No. of food groups produced	0.254***	0.102**	0.065***	0.062***
	(0.042)	(0.046)	(0.009)	(0.009)
Observations	1,298	1,298	1,288	1,288
Pseudo R-squared	0.07	0.07	0.12	0.12
Controlling for child's immunisation and preventive health-seeking behaviour	Y	Y	Y	Y
Controlling for fraction of children with immunisation card and fraction children that visited a health clinic in the last 6 months in the cluster	N	Y	N	Y

Notes: Robust standard errors in parentheses clustered at village level. ***p < 0.01, **p < 0.05, *p < 0.1. All regression include controls for head's age, gender and education, household age composition, size and dependency ratio, socio-economic status index, land area cultivated, log of monthly expenditure, child characteristics, primary care giver's characteristics and ward dummies. Estimates for dietary diversity based on 7 food groups were estimated using ordered logit, those for minimum dietary diversity were estimated using dprobit.

6.1.3.1. Testing the effect of household preferences and local infrastructure. As mentioned in our conceptual framework, households have preferences over the health status of their household members, and these preferences can have implications for dietary diversity among household members. Although it is hard to measure preferences, we try to proxy them using data on child immunisation status and preventive health seeking behaviour, potentially good proxies for health preference as both these exercises are costly (in terms of time and money) and are largely proactive. However, these measures also capture health infrastructure to some extent and could be driven by the child being sick (even though information was sought for preventive visit only). Preventive health-seeking behaviour will also have a spill-over effect on neighbouring households within a cluster: if more households within a village get their children immunised, the probability of falling sick is lower and therefore infection levels are lower, leading to a positive spill-over to other households.

In Table 9, we control for the household's preventative health-seeking behaviour by including as covariates the immunisation index and the preventative health-seeking behaviour index in columns (1) and (3), and; also control for child immunisation and preventative health-seeking behaviour at the cluster level in columns (2) and (4) by including as covariates the fraction of households that have an immunisation card and fraction of households that visited a health clinic in the last six months. We find that controlling for household preventative health seeking behaviour does not change in the estimates by much (columns (1) and (3)). However, when we control for cluster level preventative health-seeking behaviour, the point estimates for dietary diversity (seven food groups) are much lower though still significant (column (2)).

7. Conclusion

While dietary diversity is recognised as an indicator of diet quality, associated with both micronutrient adequacy and nutritional status of children, it has been unclear whether diversity in agricultural production in subsistence households is a determinant of dietary diversity or nutritional status of children. This study has looked at various indicators of agricultural production diversity, diet quality and nutrition in order to improve our understanding of these processes. We have found that the three production diversity variables assessed are significantly associated with individual dietary diversity outcomes in young children aged 6–23 months. These results suggest that the diversity of diets consumed by infants and young children is directly related to diversity in agricultural production in these semi-subsistence households. Production diversity is not associated with nutritional status (as measured through anthropometry) in younger children, but in children over the age of 24 months (after the common growth-faltering stage at age 6–23 months) there is a more consistent pattern between agricultural production diversity and linear growth. In older children, agricultural production diversity are positively associated with HAZ scores and inversely associated with stunting. These associations, while small, are consistent, and are congruent with what is known about biological processes affecting children of different ages. Diversity of agricultural production can therefore be said to have an important impact on dietary diversity in young children in subsistence households, and subsequently on nutritional status as these children age.

Reductions in undernutrition can only be achieved through attention to the food, health and care determinants all at once, but often the agriculture sector has difficulty seeing how agriculture fits into a nutrition agenda without being completely subsumed; a potentially useful way to frame agriculture's contribution to nutrition is primarily around food and diets. We conclude that diversity of agricultural production can be an important predictor of dietary diversity (and therefore diet quality) in young children in subsistence households, and on nutritional status as these children get older. Agricultural programmes and policies aiming to have impacts on child undernutrition should promote diversity in agricultural production, rather than only increasing total quantity produced of select staple crops as is the case in Zambia – where large-scale fertiliser input subsidies and government maize procurement provide little incentive for farmers to diversify production. To our knowledge, no study to date (other than those in this collection) has assessed the impact of diversity of household-level agricultural production on the diversity of diets of children within these households, and the subsequent effects on nutritional status.

Acknowledgements

This research was supported by the CGIAR Research Program on Agriculture for Nutrition and Health (A4NH) led by IFPRI, and Concern Worldwide through the Realigning Agriculture to Improve Nutrition (RAIN) project. The RAIN project receives funding from Irish Aid and the Kerry Group. We thank Marie Ruel, Derek Headey, John Hoddinott, Benjamin Davis and two anonymous referees for helpful comments. All errors and omissions are our own.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes

1. Gold-standard nutritional methods of measuring dietary diversity such as weighed food intakes or 24-hour food recalls are complex and time-consuming, and are not appropriate for all research and programming contexts. Nor are they always necessary: Simpler dietary diversity scores, using a count of foods or food groups consumed by an individual over a reference period (usually 24 hours), have been constructed and validated for these contexts. Individual dietary diversity scores (World Health Organisation, 2010) predict diet quality in terms of micronutrient content, having been shown to be strongly and consistently associated with the micronutrient density of the diet in children under 2, in different populations and contexts, and independent of socio-economic and demographic factors (Ruel et al., 2014).
2. Agricultural production diversity was not collected with the diversity score in mind; this was therefore constructed from recalled production data at plot level, aggregated to household level. Foods produced were assigned to a group based on their known physical and nutritional properties corresponding to the different food groups available. One crop may be assigned to

more than one food group if it has multiple edible parts (for instance where both tubers and leaves are known to be consumed). It is possible that some vegetable crops were miscategorised due to the nutrient content of the exact variety grown; however, production diversity was so low in general within the study area, that this is unlikely to have affected results.
3. When log of agricultural income is included in the regression of dietary diversity on production diversity, the coefficients production diversity variables remain similar in magnitude and significance as reported here, and the coefficient on log of agricultural income is much smaller in magnitude as compared with the coefficient on production diversity. This shows that even when we include measures of production diversity and agricultural income in the same regression we find that the correlation of the production diversity measure with dietary diversity is much stronger, reflecting that it is not the greater income that may be associated with greater production diversity that is causing the greater dietary diversity, but the greater production diversity itself which is driving this.
4. Results from quantile regressions not reported here. They can be provided upon request by the authors.
5. Results from quantile regressions not reported here. They can be provided upon request by the authors.
6. The maximum production diversity at the cluster level could be correlated with the household's production diversity due to agro-climatic reasons, as well as if neighbours imitate each other.
7. Results not reported here. They can be provided upon request by the authors.
8. We find that the point estimates are slightly smaller and standard error unchanged. As a result some estimates lose significance.

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