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Nutrition-sensitive agricultural interventions, agricultural diversity, food access and child dietary diversity: Evidence from rural Zambia

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ABSTRACT

We study a nutrition-sensitive agricultural program in low-income rural Zambia between 2011 and 2015. Using a pre-post design with a control group, we measure program effects along established pathways connecting agriculture to nutrition: diversity of agricultural production, crop sales, household food access and child and maternal diets. The program increased diversity in crops grown and the number of months in which various food groups were harvested. In particular, the program substantially increased the percentage of households producing three nutritious crops it promoted (groundnuts, rape and tomatoes). As a consequence there were modest increases in household access to diverse food groups. Despite modest increases in the proportion of children consuming pulses, legumes and nuts, ultimately there were no significant improvements in the overall dietary diversity of young children or their mothers. A nutrition-sensitive agricultural program can increase diversity in agricultural production and to a lesser extent access to nutritious foods, but this may not always be sufficient to improve child diets or nutrition.

1. Introduction

Childhood undernutrition in sub-Saharan Africa is a public health crisis. Thirty-five percent of the region's children under five years of age are stunted (significantly short for their age), with height-for-age z-scores (HAZ) two standard deviations or more below the World Health Organization reference (Black et al., 2013). Such stunting is a marker for chronic undernutrition and linked to increased morbidity and mortality for children (Black et al., 2008, 2013) and lower levels of education, cognitive ability and wages for adults (Hoddinott et al. 2013).

Substantial evidence exists regarding the effectiveness of *nutrition-specific* interventions—those that treat the immediate or proximate determinants of undernutrition (diet and disease), for example micronutrient supplementation (Bhutta et al., 2013). Many nutrition-specific interventions have been demonstrated to reduce the stunting burden, though often only modestly. Consequently, the complementary implementation of broader *nutrition-sensitive* interventions—those that more directly address the underlying causes of poor nutrition (summarized as food, health and care by UNICEF [1990])—may accelerate progress in regions where the burden is most severe (Ruel and Alderman, 2013; Ruel et al., 2017). One class of these nutrition-sensitive programs with promise, particularly in rural settings, are those focusing on the links between agriculture and nutrition, or nutrition-sensitive *agricultural* programs (Ruel and Alderman, 2013; Ruel et al., 2017). In this paper, we evaluate one such program in rural Zambia, examining its effects on a range of outcomes linking the program's operation to dietary diversity.

The nutrition literature has demonstrated that diversity of foods and food groups is the foundation of a healthy diet that provides adequate calories, fats, proteins and micronutrients (World Health Organization, 2010). Observational studies show that better-nourished children generally eat a more diverse diet (Arimond and Ruel, 2004; Azzarri et al., 2015; de Brauw et al., 2015; Shively and Sununtnasuk, 2015) and that

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such diets provide a wider, more adequate range of micronutrients (Ruel et al., 2014). Therefore, nutrition-sensitive agricultural programs—including the one examined in this paper—often specify an increase in dietary diversity as an intermediate goal.

The archetypal agricultural household model (Singh et al., 1986) illustrates three channels through which an agricultural program might increase dietary diversity: (i) increasing total income through increased productivity or production; (ii) shifting preferences toward more varied and nutritious foods; and (iii) increasing diversity of agricultural production.[1] Increasing income, although neither necessary nor sufficient, can lead to improved diets (Dillon et al., 2015). Shifting preferences can lead households to prefer consumption bundles with more varied and nutritious foods.[2] Where households face incomplete markets or high transactions costs—as is often the case in rural settings (e.g., Udry, 1996; LaFave and Thomas, 2016; Dillon and Barrett, 2017)—the diversity of own production also can play an important role. Insufficient markets for sellers or high transactions costs can constrain households, leading them to consume more of their own production. (Hoddinott et al., 2015). All three channels may be important whenever markets exist but are imperfect.

Although hundreds of programs aim to improve agriculture in areas of high malnutrition, relatively few are deliberately nutrition-sensitive, for example specifying improved nutrition as an explicit goal or incorporating particular components related to nutrition (Berti et al., 2004; Arimond et al., 2011; Stewart et al., 2015; Pandey et al., 2016). Moreover, most studies of programs that are explicitly nutrition-sensitive have been limited by their methodology (Masset et al., 2011; Girard et al. 2012), with low internal validity and limited measurement of relevant outcomes (Webb and Kenndey, 2014) so that much of the evidence of their impact on nutrition has been inconclusive (Ruel and Alderman, 2013; Ruel et al., 2017).

Nevertheless, there is a small emerging body of rigorous research along the pathways from agriculture to nutrition in low-income settings. These include increased household production of, and access to, nutritious foods; improvements in the status of women in agricultural households; improved diets and nutrient intakes of household members; and improvements in aspects of nutritional status (Leroy et al., 2008; Olney et al., 2009; Azzarri et al., 2015; Carletto et al., 2015; de Brauw et al., 2015; Dillon et al., 2015; Hoddinott et al., 2015; Slavcheka, 2015). For example, Dillon et al. (2015) use weather shocks and representative data on rural Nigerian farmers to estimate the elasticity of dietary diversity to crop revenue (0.18) and to agricultural production diversity (0.24) in a dynamic agricultural household model. In addition, a two-year program in Burkina Faso integrating household agriculture and behavior change communication targeted to women reduced anemia, wasting and diarrhea among young children, and decreased the proportion of mothers who were underweight (Olney et al., 2015; Olney et al., 2016).

We add to the literature on pathways from agriculture to nutrition in low-income settings by examining the effects of a nutrition-sensitive agricultural program implemented in rural Zambia (Harris et al., 2011), with our analysis focused on pathways through agriculture, food security and dietary diversity. The program included several components designed to improve three aspects hypothesized together to contribute to improved nutrition: diversity in household agricultural production; women's input into and control over household, agricultural and child feeding decisions; and women's nutritional knowledge. These components directly address two of UNICEF's (1990) broad determinants of undernutrition—food and care—but only indirectly address the third determinant, health. The multifaceted program was implemented in a setting where the correlations among agricultural production diversity, child dietary diversity and child nutritional status were positive and strong (Kumar et al., 2015). A related study of the same program—following pathways through women's empowerment and knowledge to nutrition—reported that the program had beneficial effects on aspects of women's empowerment, knowledge of infant and young child feeding practices and acute child malnutrition (wasting, as measured by weight-for-height z-scores), but no impact on child feeding practices or chronic malnutrition (stunting) (Kumar et al., 2018).

Our paper contributes to the literature in two ways. First, we provide new evidence on the effects of a nutrition-sensitive agricultural program offered at scale for four years to households in a small geographic region in rural Zambia. In particular, using a pre-post design with a control group we implement a difference-in-difference (DD) estimator to recover the effects of the program on all households, and an instrumental variables estimator for the effects on the sub-population of compliers. Second, we take a comprehensive approach examining effects along the nutrition-sensitive agricultural program impact pathways, including agricultural production, sales and consumption from own production, household food access and maternal and child diets.

We find a large and significant increase in yearly diversity of agricultural production: an average increase of one food group produced per year among all households eligible for treatment, and two per year for those who participated, a near doubling of baseline production. In particular, the intervention increased the percentage of households producing groundnuts, rape (a local green leafy vegetable) and tomatoes by about 20 percentage points each. Although some of this new production was sold, it was primarily used for own consumption. Only the increase in groundnut production is reflected in child diets, however, and there is no apparent effect of the program on child consumption of the other crops or on overall child or maternal dietary diversity.

Our results demonstrate that a nutrition-sensitive agricultural program can increase diversity in agricultural production and to a lesser extent access to nutritious foods, but that there may be further barriers to improving the diets of household members. Results for this program reported in Kumar et al. (2018) show that in this setting and for this program as implemented, the increased access to nutritious foods was linked to improvements in short-term nutritional status measures, but did not lead to improvements in chronic nutritional status.

2. Program and evaluation design

2.1. The RAIN program

Concern Worldwide, in collaboration with the International Food Policy Research Institute (IFPRI), designed and implemented the Realigning Agriculture to Improve Nutrition (RAIN) program between 2011 and 2015 in four governmental administrative areas (known as Wards) of Mumbwa District. Located in Zambia's Central Province, this rural district is two hours west of Lusaka along one of Zambia's main highways. Off the highway, however, transportation and energy infrastructure is poor. In 2010, only 10 percent of the homes in Mumbwa District had access to electricity or any type of piped water and 75 percent had a dirt floor.[3] The overall poverty rate in the district was 64 percent (de la Fuente et al., 2015). Most households practice smallholder agriculture—typically dedicated to maize for consumption (80 percent of households) and cotton for sale (50 percent)—and have only indirect access to food markets (FEWSN, 2014). The emphasis on maize is consistent with past government policy and programs that heavily

[1] Recent extensions to the agricultural household model also include gender-sensitive pathways, such as women's control of agricultural income and decision-making (Kadiyala et al. 2014).

[2] A variety of interventions can modify preferences or the expression of preferences in the household, including education and information provision as well as programs improving women's power in household bargaining. Such preferences may differ by gender (Thomas 1994).

[3] Based on authors' calculations using the 2010 Zambian national census.

promote it; food security in Zambia is often equated with "maize security" (Smale and Jayne, 2009).

This emphasis on staple crops, alongside relatively poor access to markets, contributes to monotonous diets that lack the diversity required for good nutrition. Chronic undernutrition in the area is common, affecting nearly half of children under 5, and the stunting rate in Mumbwa and surrounding districts has consistently been above the national rate (DHS, 2001, 2007, 2013), itself above the average rate for sub-Saharan Africa (Black et al., 2008, 2013). The stunting rate was above 45 percent for children 24–48 months of age in the program Wards in 2011.

The initial design for RAIN included two variants of nutrition-sensitive programming, one layered on top of the other (Harris et al., 2012; Kumar et al., 2018). For reasons outlined below, however, including their substantial content overlap, we treat both variants as a single intervention in our main analysis. Both variants received equal promotion of the main elements of the intervention, comprised of homestead gardening, food crop production and animal rearing—all emphasizing nutritious foods—alongside interventions designed to improve female empowerment. All interventions were delivered through the formation of local women's groups specific to the RAIN program.[4] One variant also received an additional nutrition education behavior change communication (BCC) component focused on the promotion of optimal infant and young child feeding knowledge and practices, health seeking behaviors and hygiene.[5] Concern Worldwide implemented all components on top of existing government services, including agricultural extension.

The RAIN women's groups were at the core of the intervention and served a twofold purpose: to strengthen the role of women in the community and to provide the platform for most other components of the interventions, including promotion of home food production and nutrition education BCC. All women in the treatment areas who were pregnant or had a child under age two at any point over the course of the four-year intervention were eligible to join the RAIN women's groups, and they could remain a member until the program ended. Over the four program years, there were nearly 4500 beneficiaries.

The RAIN women's groups enabled the delivery of program components at monthly meetings.[6] To connect group members with RAIN staff and government extension workers, each group designated one member as a liaison, known as a smallholder model farmer (SMF), to receive additional training. The liaisons were then responsible for passing on that training as well as the physical inputs from the program to their groups at meetings and follow-up visits to individual households. RAIN provided inputs to women with the intent of increasing female control over their use in accordance with women's own preferences (Doepke and Tertilt, 2014). Physical inputs were provided to women in their first two years of membership while they had infant children. These included (i) twice-yearly deliveries of seeds for nutritious vegetables, legumes and tubers; (ii) one-time provision of agricultural tools; and (iii) one-time distribution of chickens and goats to a subset of group members, with the condition that offspring would be passed to other group members.

In areas receiving the RAIN variant with the layered nutrition education BCC component, RAIN women's groups also were assigned local community health volunteers (CHVs), who served a role parallel to the SMF. CHVs constitute a formal body of volunteers across Zambia trained and deployed by the Zambian Ministry of Health to extend health and nutrition services to rural areas (Zambia Ministry of Health 2011). RAIN-connected CHVs received additional training from the Zambian Ministry of Health on maternal, infant and young child feeding practices in accordance with existing government guidelines. In addition, RAIN-connected CHVs provided health and nutrition counseling at the RAIN women's group meetings and carried out follow-up visits to individual households.

Broadly, RAIN implemented its home food production component as intended, including distribution of inputs, tools and small animals (albeit with occasional shortages). The nutrition education BCC was also implemented widely, but there is evidence of two departures from the original design, suggesting there was little substantive difference between the two program variants on the ground (see also Kumar et al., 2018).[7] First, implementation of the layered nutrition education BCC component appears to have been incomplete—only 45 percent of women in RAIN women's groups matched with a CHV reported presence of a CHV at the most recent meeting. In contrast, 90 percent reported the presence of the SMF at the most recent meeting. Second, the nutrition education BCC component appears to have spilled over to households in treatment areas not assigned to receive it, as almost 40 percent of women in these areas reported a CHV in attendance at the most recent RAIN meeting.[8] In addition to these leakages, the use of standardized government materials for training CHVs suggests that the information provided as part of the nutrition education BCC component may have been duplicated in part by their usual government training. Indeed, all CHVs, regardless of type of treatment area, scored similarly on a mid-program test of infant and young child feeding knowledge (Harris et al., 2013).

The program impact pathway clarifies that outcomes relating to the diversity of agricultural production and diets among all household members were not hypothesized to differ between the two variants of the RAIN program (Harris et al., 2012; Kumar et al., 2018). Thus, among the outcomes considered in this paper, only child and maternal dietary diversity were expected to possibly differ between the two variants.

2.2. RAIN evaluation, sampling and survey design

The RAIN evaluation was carried out in all four Wards receiving the program and in two additional neighboring Wards used as the control. The evaluation area covers roughly 4000 square kilometers and is home to approximately 75,000 people living in 12,000 households. Poverty rates in the six Wards were remarkably similar in 2010, ranging from 69 to 74 percent (de la Fuente et al., 2015).

Assignment of treatment status for the evaluation followed a two-part process prior to program start (Harris et al., 2012; Kumar et al., 2018). First, one of three pairs (of two contiguous Wards each) was selected as the control, continuing to receive standard government services but none of the RAIN-specific interventions.[9] The two control

[4] The other key common element of both variants of the program was a gender sensitization campaign with the objective of reducing gender inequality in agriculture and childcare and increasing female involvement in community leadership structures. The campaign comprised annual training sessions in each community with discussions centered on gender roles, as well as methods for recognizing and overcoming potentially deleterious cultural practices. Given the important roles of mothers and other female caregivers in the nutrition of children, this component strengthens the sense in which RAIN was a nutrition-sensitive agricultural program. See Kumar et al. (2018) for further details.

[5] Kumar et al. (2018) refer to these two variants as the agriculture, gender equity and women's empowerment (Ag-G) and the agriculture, gender equity and women's empowerment plus nutrition BCC intervention groups (Ag-G-BCC).

[6] The monthly meeting schedule of RAIN women's groups was occasionally interrupted by seasonal rainfall and the agricultural calendar.

[7] BCC components of nutrition-sensitive agricultural interventions can be operationally difficult to implement, and their improvement is an area of interest in the nutrition literature (Ruel et al. 2017).

[8] This share would be zero if the layered nutrition-education component had been implemented as intended. Additionally, 20 percent of households in treatment areas not assigned to receive nutrition BCC report having received a home visit from a CHV, which also would have been zero if implemented as intended.

[9] While selection of the one Ward-pair control from the three possible was "random," there are too few pairs for this to be statistically meaningful.

Wards had 15 pre-specified survey clusters for fieldwork, each comprised of 1–3 census standard enumeration areas (SEA, a unit of area used for the Zambian census). Second, stakeholders from the remaining four Wards selected for treatment publicly drew paper lots to randomly assign one of the two variants of RAIN (with and without the nutrition education BCC component) in equal proportion across 26 survey clusters. In total, the six Wards used for evaluation include 41 survey clusters covering 131 SEAs, with 42 SEAs assigned to control and 89 assigned to treatment.

In our evaluation of the RAIN program, we pool all treatment survey clusters together, and do not exploit the experimental variation of program variant. This decision reflects the conclusions in Section 2.1 that the intended differences between the two variants were neither fully realized nor hypothesized to affect most outcomes we consider.[10] In addition, endline participation in RAIN across the two variants was nearly identical—33 (36) percent of households in the variant without (with) the additional nutrition education BCC. Similar participation rates suggest that the two variants were seen as beneficial by similar shares of households.

The principal data we use are the repeated (2011 and 2015) cross-sectional RAIN evaluation surveys (Harris et al., 2012; Harris et al., 2016).[11] The 2011 baseline survey was conducted prior to treatment assignment and several months before the interventions began. The 2015 endline survey followed after four years of continuous program implementation as specified by the evaluation design, notwithstanding a period of program setup and learning in the first year. To control for seasonality, both cross-sectional surveys were administered between July and August, just after the end of the maize harvest. RAIN collected comprehensive individual- and household-level information with nearly identical questionnaires in both rounds.[12]

Teams of specially trained and experienced field enumerators carried out the sampling for RAIN across the 131 SEAs. In each round, a team first conducted a census of all households in the SEA, identifying those (i) with at least one child between 24 and 60 months or (ii) with at least one child between 24 and 60 months *as well as* with at least one child under 24 months. For the sample, supervisors then drew randomly from the second set of households with at least one child in both age cohorts before proceeding, if necessary, to draw from households with a child only in the older cohort.[13] Consequently, all households in the sample have at least one child between 24 and 60 months, and more than one-half of them have a child younger than 24 months.

3. Methodology

3.1. Estimation methods and identification

We examine both the intent-to-treat (ITT) and treatment-on-the-treated (TOT) effects of RAIN on a range of individual- and household-level outcomes (Angrist et al., 1996; Duflo et al., 2008). For the ITT, we first use the two repeated cross sections to implement a difference-in-difference (ITT-DD) estimator of the average effect of the intervention on all individuals (or households) eligible for the program: those living in the treatment areas at endline, regardless of their actual participation. Given the program and sampling designs, all the households we observe in the treatment area at endline were eligible for the program at some point during the prior four years of program implementation. Although not panel data, a high sampling proportion (one-fourth of all households and more than one-half of households with a child between 24 and 60 months) ensures large and representative samples before and after program implementation. For the TOT, we use eligibility as an instrument for membership in a RAIN women's group, our indicator of program participation, to implement a two-stage least squares (2SLS) estimator. This estimate is the effect of the intervention on a well-defined subgroup of interest, those who participated in the intervention because of their assignment, i.e., the compliers (Angrist et al., 1996). The TOT estimates are particularly important for understanding the effectiveness of RAIN since only one third of eligible households participated.

For the ITT-DD, we estimate the following model:

$$y_{ict} = \beta_0 + \beta_1 RAIN_c + \beta_2 POST_t + \delta_{DD} RAIN_c \times POST_t + u_{ict} \quad (1)$$

where y_{ict} is an outcome for household (or individual) i living in SEA c, and interviewed during the cross-sectional survey in year t. $RAIN_c$ is a dummy variable indicating whether the household lives in an area assigned to the RAIN intervention and $POST_t$ is a dummy variable indicating whether an observation is from the 2015 endline cross-sectional survey, after nearly four years of program operation. In addition to this model, we also present specifications that adjust for time-invariant geographic characteristics by including fixed effects for each SEA, c.

The coefficient of interest is δ_{DD}, the DD estimator of the average program effect. As we do not condition on actual household participation in Eq. (1), this estimator captures the ITT effect. Its validity relies principally on the assumption of common trends—absent treatment, average conditions in the treatment and control areas would have changed over time in similar fashion. Support for the common trends assumption comes from the nature of the study area, which is geographically compact and contiguous with similar starting levels of poverty, as well as the evidence that at baseline many, though not all, characteristics of the treatment and control are well-balanced (described in Section 4.1). Common trends are further suggested by similarities of inherently time-varying characteristics between treatment and control. Both areas experienced similar exposure to the operation of various development programs *other* than RAIN and to a variety of possible socioeconomic shocks over the study period.

For the TOT, we first restrict analysis to individuals and households from the endline survey and, for the same outcomes, implement a 2SLS estimator. Going from a DD estimator in a model with two periods to a 2SLS estimator using only the single follow-up period leads to different estimates for two reasons: (i) the exclusion of information from baseline and (ii) the estimation of a different underlying theoretical parameter, the treatment on the treated. To help quantify these differences, we first consider a single-difference (SD) estimator of the treatment effect in the following model restricted to the endline survey:

$$y_{ic,2015} = \beta_0 + \delta_{SD} RAIN_c + u_{ic,2015} \quad (2)$$

The estimates from this intermediate model are the reduced form of the 2SLS system, or the ITT-SD. In general, where there is good baseline balance we expect the two estimates of δ_{SD} and δ_{DD} to be relatively similar, but for variables that differ across treatment and control at baseline these two estimates will also differ.

For the TOT, we estimate the following model using 2SLS:

$$y_{ic,2015} = \beta_0 + \delta_{TOT} Participation_{ic,2015} + u_{ic,2015}, \quad (3)$$

where $Participation_{ic}$ is a dummy variable treated as endogenous and the

[10] There were few substantive or statistical differences between program effects for the two treatment variants in arm-specific models we estimated utilizing the cluster-level randomization. This alternative analysis also preserves the direction, statistical strength and qualitative interpretation of our primary results.

[11] The evaluation design uses repeated cross-sectional, rather than longitudinal, surveys to measure the attributes of comparable cohorts of children below age 5, and their households, in 2011 and 2015.

[12] The questionnaire design drew on the UNICEF (1990) framework for undernutrition and past surveys covering agriculture and nutrition, including the Zambian Demographic and Health Surveys and the World Bank Living Standards Measurement Survey (Harris et al. 2012).

[13] Sample sizes were set to draw equal numbers of households from each of the 41 survey clusters and equal numbers of households from SEAs within each cluster (Harris et al. 2012). Selection of households from the census list was performed using a table of random numbers.

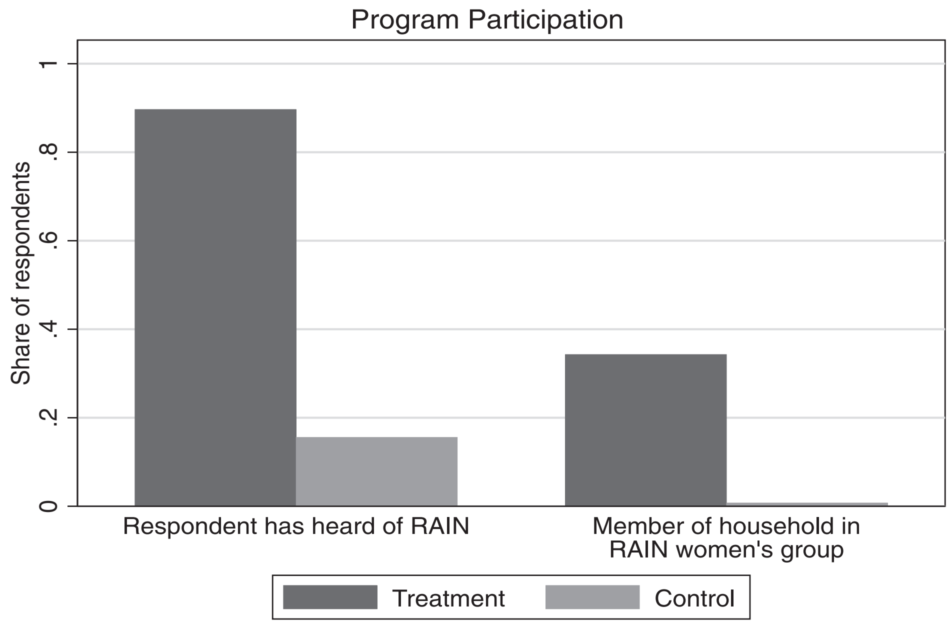

Fig. 1. Program Participation. Note: Figure shows the share of households participating in the program at endline. Dark columns represent all households assigned to treatment. Light columns represent all households assigned to control. Additional participation statistics are available in the Supplementary Appendix.

exogenous program assignment indicator, $RAIN_c$ is the first-stage excluded instrument used to predict it. A household (and its individual members) is considered a participant if it reported any member of the household to be a member of a RAIN women's group; Fig. 1 shows an overall average participation rate of 34 percent in treatment areas. The estimate of δ_{TOT} is the estimate of the ITT-SD scaled by program participation, or the Wald statistic (Duflo et al., 2008).

The validity of the TOT results rests on several assumptions that are difficult to verify empirically (Duflo et al., 2008). By design, program assignment was exogenous. Although according to the survey 15 percent of households in the control area were aware of the program by 2015, only eight control households, less than one percent, reported participating in RAIN, indicating negligible direct contamination (Fig. 1). Nevertheless, as in many interventions of this nature, it is a strong assumption that the assignment of a household to the treatment only affects the outcome through the household's actual participation in the program, even for households *within the treatment area.* For example, a beneficiary household that receives seeds from the program could share them with an eligible neighbor who does not directly participate herself. Alternatively, the program may induce participants to purchase or use more agricultural inputs (other than seeds), in turn influencing prices and access for eligible non-participants.[14] In general, a positive spillover (such as sharing seeds or production information) will attenuate the TOT estimate; the reverse holds for negative spillovers. Many theories can generate violations of the exclusion restriction that push the bias in either direction, but the economic development literature typically emphasizes underestimation due to positive spillovers (Miguel and Kremer, 2004; Duflo et al., 2008). Given the central role of the information and demonstration dimensions of the program, as well as the possibility that inputs could be shared, we argue that net positive spillovers seem more likely in this context, and consequently that estimated TOT results are, if anything, probably conservative.

Based on the sample selection procedures (Section 2.2), the error term u_{ict} in each model is assumed independent between the 131 SEAs (though possibly correlated within them). Therefore, in all models, we adjust standard errors for clustering within the SEA.[15] To account for potential inference errors from individual estimates of multiple related outcomes, we present summary indicators and in some cases seemingly unrelated regression estimation (SURE) results for families of outcomes (Kling et al., 2007). We set statistical significance at P-value < 0.05.

3.2. Main outcome measurements

Because a nutrition-sensitive agricultural program like RAIN incorporates a number of activities, its assessment requires measurement of a comprehensive set of outcomes. We examine program effects on measures of (i) household agricultural production diversity; (ii) crop production, sale and consumption from own production; (iii) household food access; and (iv) maternal and child diet diversity. As described above, our measure of participation for the TOT estimates is an indicator of whether a woman in the household was a RAIN women's group member; 34 percent reported participation.

There are several possible measures of household agricultural production diversity and each measure captures different aspects of diversity (Baumgartner, 2006; Magurran and McGill, 2013). The RAIN evaluation survey measured agricultural production diversity principally along the extensive margin (i.e., the number of different crops produced rather than the intensity of some crops compared to others), by delineating all of the agricultural goods being produced. Examples of so-called richness indices include counts of individual food items, different agricultural activities and food groups.[16] Kumar et al. (2015)

[14] This type of negative spillover is a clarifying example, and not likely to be important in this context as less than half of households use purchased inputs such as fertilizer or herbicides.

[15] All individual-level samples utilize only one individual per household per survey year. Moreover, because of the specified age ranges and the cross-sectional nature of the data, an individual child *i* can appear in only one of the two cross-sections. A household (or mother), however, might appear in both rounds although we cannot identify when that occurs. The repeated random samples of approximately one-third of all households suggest about one-third of the sample of households overlap.

[16] This is in contrast to an approach enabling comprehensive assessment along the intensive margin, which would emphasize the proportions of different products in the overall production mix. Common applications of these so-called abundance indices provide estimates of diversity in the amount of total production and land allocation among crops (Winters et al. 2006). For aggregation across different activities like farming and animal husbandry, as done in our

demonstrate that such indices were positively correlated with child dietary diversity and child anthropometric status at baseline. Building on their work, we construct similar measures for each household in each survey using information covering the entire previous 12-month agricultural season. More specifically, we construct a count of four possible agricultural activities (production of field crops, production of fruits or vegetables, rearing of animals and production of animal-sourced foods) and, separately, categorize foods produced into seven food groups known to be nutritionally-relevant for young children. The seven food groups are: (i) grains, roots and tubers; (ii) pulses, legumes and nuts; (iii) vitamin-A rich fruits and vegetables, (iv) other fruits and vegetables; (v) dairy products; (vi) eggs; and (vii) meat and fish. These seven food groups can be aggregated to calculate the Individual Dietary Diversity Score (IDDS) for children 6–24 months (World Health Organization, 2010). Each food group contains at least one food item commonly produced and/or consumed in Mumbwa District. Additionally, we construct a count of the number of months in which specific food groups are harvested or produced. This last measure goes beyond the extensive margin capturing in part the intensive margin of production over a full 12-month period.

For each agricultural crop and animal product, the survey collected information on production, sales and consumption from own production. We calculate gross cash revenues from sales for each item and sum them to obtain total cash revenue from agriculture. We also consider revenues from relevant subcategories including food versus non-food. All cash revenues are inflated to 2014 Kwacha and truncated at the 99th percentile. We also examine what underlies these aggregates by focusing on decisions regarding the production, sale and consumption from own production of six nutritious foods promoted by RAIN: groundnuts, rape, tomatoes, orange flesh sweet potatoes, dairy and eggs.

We measure food access at the household level in two ways. First, using a 24-hour recall of all foods eaten in the home by any household member, we construct binary variables indicating any consumption for each of the seven food groups used to measure agricultural production diversity. While this is a departure from some more standard categorizations of household food access (such as the Household Dietary Diversity Score [HDDS] using 12 food groups in Kennedy et al., 2013), it has the benefit in this study of better aligning our measures across all outcomes of interest.

Our second approach to measuring food access at the household level uses as designed the three-item Household Hunger Scale (HHS) and nine-item Household Food Insecurity Access Scales (HFIAS) (Coates et al., 2007; Ballard et al., 2011). The full complement of questions for the HFIAS is available only in the endline survey. The HFIAS scale reflects perceptions of food insecurity rather than the more objective household food access measure and consists of nine items (scaled from 0 to 3) using a 30-day recall period. It is designed to reflect three universal domains of the experience of inadequate household-level food access: (i) anxiety about household food supply; (ii) insufficient quality of food, which includes variety and preferences; and (iii) insufficient quantity of food supply, the quantity consumed and the physical consequences of insufficiency. The HHS scale reflects the third, and most severe, of the HFIAS domains. We calculate the HHS score ranging from 0 to 6 and create three discrete categories of household hunger: none or mild, moderate and severe. We calculate the HFIAS score ranging from 0 to 27. We also create four discrete categories of household food insecurity: food secure, and mild, moderate and severely insecure. All scoring and discretization follows the validated schemes in Coates et al. (2007) and Ballard et al. (2011).

To measure child diet quality, we use the IDDS for children 6–24 months, an age group for which dietary diversity is essential (Arimond and Ruel, 2004). IDDS is a common dietary richness index for young children that counts the consumption of seven different food groups during the previous day (24 hr recall)—the same we use to measure agricultural diversity above (World Health Organization, 2010). Individual diets with four or more food groups per day are considered to have adequate diversity. The index gives equal importance to each food group in the diet regardless of the quantity consumed. Measures of micronutrient density along the intensive margin, such as weighed food intakes, are the gold standard in assessing nutrient intakes, and they are accurately predicted by the IDDS for children under two around the world (World Health Organization, 2010) independent of demographic characteristics and socioeconomic status (Ruel et al., 2013).

We measure maternal diet quality on the same scale as children using the IDDS. This minor departure from validated measures better aligns our measures across outcomes of interest, in the same way it does for household food access.[17]

4. Results

4.1. Descriptive statistics

In this section, we further characterize the study population and assess baseline balance across the treatment and control areas (Table 1). Given the design, we do not expect, nor do we find, perfect balance for all variables. Nevertheless, consistent with the study area being geographically compact and relatively homogeneous, household characteristics over a range of demographic, economic and food security variables show similar levels and few statistical differences. There are some small significant differences, however, with respect to agriculture. The initially higher average levels of agricultural activity in the control Wards underscore the importance of examining both the DD and SD estimators.

The principal sample we use at the household level includes all households: 3044 (2003 in treatment and 1041 in control) in the 2011 cross-section and 3536 (2456 in treatment and 1080 in control) in the 2015 endline cross-section.[18] At the child (and corresponding mother) level, analyses include all children 6–24 months of age (or their mothers) with completed dietary recall data, a subsample of all households including 1524 (938 in treatment and 586 in control) in the 2011 cross-section and 1343 (841 in treatment and 502 in control) in the 2015 cross-section.[19] The first two columns of Table 1 present the treatment and control means at baseline in 2011, and the third the standardized

(*footnote continued*)
analysis, abundance indices require more detailed information than richness indices. A third approach, with even more demanding data requirements, is the so-called functional index that captures diversity in the composition of *nutrients* for a household by converting crops and other foods into their nutrient profiles (Remans et al. 2011). The conversion produces the best description of household agriculture as a nutritional system. It also can complicate interpretation, however, and clear policy prescriptions require mapping back to the individual source inputs.

[17] With the available data it is possible to construct the minimally different, but validated, Women's Dietary Diversity Score (WDDS) (Kennedy et al. 2013). The nine food groups comprising the WDDS are identical to those in the IDDS except that dark green leafy vegetables are separated from vitamin A rich fruits and vegetables and organ meat is separated from meat and fish.

[18] As the description of sampling makes clear (Section 3), the sample is not a simple random sample of children between 24 and 60 months. For the 2015 endline survey where the necessary information is available, we calculated inverse probability weights (Solon et al. 2015). Likely in part because of the high sampling proportions, results with these weights are nearly identical to those without weights, so throughout we present only results without weights since we do not have the information needed to construct them for the 2011 baseline.

[19] Although prioritized in the sampling strategy, of course not all households in our primary sample had a child in this age range, so the resulting sample for these outcomes is smaller.

Table 1
Baseline summary statistics.

	(1) Treatment	(2) Control	(3) T-C standardized difference
Panel A: Household demographics			
Number of household members	6.868	7.326	−0.146*
	(2.840)	(3.142)	
Number of children < 60 months	1.868	2.062	−0.237*
	(0.734)	(0.815)	
Youngest child is 6–24 months	0.468	0.563	−0.191*
Mother is married	0.846	0.841	0.014
Mother's age (years)	30.779	30.692	0.010
	(15.899)	(9.144)	
Household head is female	0.165	0.175	−0.027
Household head age (years)	37.904	38.328	−0.032
	(21.190)	(13.484)	
Household head schooling (grades)	7.082	6.999	0.028
	(2.995)	(2.937)	
Panel B: Household economic well-being			
Housing characteristics index score	−0.085	−0.103	0.010
	(1.726)	(1.712)	
Home assets index score	0.195	0.283	−0.045
	(1.964)	(1.969)	
Productive assets index score	−0.171	0.004	−0.135
	(1.571)	(1.295)	
Received external assistance in past year	0.358	0.388	−0.062
Experienced a negative shock in past year	0.199	0.266	−0.153*
Panel C: Household agriculture			
Has a plot	0.843	0.934	−0.366*
Has an animal	0.817	0.875	−0.175
Has a plot and animal	0.779	0.855	−0.216*
Grows maize	0.792	0.885	−0.291*
Number of agricultural activities (of 4)	2.495	2.742	−0.229*
	(1.226)	(1.075)	
Number of food groups produced (of 7)	2.372	2.617	−0.159
	(1.645)	(1.534)	
Total number of food crops grown	2.203	2.647	−0.250*
	(1.714)	(1.775)	
Grow seed cotton	0.520	0.504	0.032
Number of months with *any* food group produced	4.997	5.093	−0.023
	(4.305)	(4.154)	
Panel D: Individual dietary diversity and household food access and security			
Total number of food groups in child's diet (24 hr)	2.950	2.934	0.014
[Treatment N = 925, Control = 575]	(1.151)	(1.192)	
Total number of food groups in mother's diet (24 hr)	3.130	3.108	0.022
[Treatment N = 925, Control = 575]	(0.949)	(1.004)	
Total number of food groups eaten in household (24 hr)	4.343	4.389	−0.031
	(1.505)	(1.511)	
Mild or no household hunger (HHS)	0.918	0.910	0.028
Moderate household hunger (HHS)	0.067	0.078	−0.044
Severe household hunger (HHS)	0.015	0.012	0.036
Maximum number of households, except where noted	2003	1041	3044

Note: Table reports means (and standard deviations for non-binary variables) for households assigned to treatment and the control at baseline in 2011. The standardized difference is the difference between the treatment and control means divided by the control standard deviation. The indices used in Panel B are produced from principal component analyses of mutually exclusive sets of binary indicators for household characteristics and assets (see Supplementary Appendix). The four agricultural activities in panel C include: (1) Production of field crops; (2) Production of fruits or vegetables; (3) Rearing of animals; and (4) Production of animal source foods. The seven food groups in Panel C include: (1) Grains, roots and tubers; (2) Pulses, legumes and nuts; (3) Vitamin A rich fruits and vegetables; (4) Other fruits and vegetables; (5) Dairy products; (6) Eggs; and (7) Meat and fish. The food groups in the child's and mother's diet are reported for the youngest child in the household when that child is between 6 and 24 months of age. The number of households on which these statistics are based is given in the last row of the table unless otherwise noted. Due to incomplete reporting, the exact number of observations is as many as 10 observations lower than the reported maximum. Exact sample sizes are in the Supplementary Appendix. * indicates a difference between the means at $p < 0.05$ when accounting for geographic clustering within the 131 SEAs used for sampling.

difference between treatment and control, measured in control standard deviations.

Apart from modestly larger households and 0.15 more children under 5 years of age in the control areas, average household demographics including characteristics of the mother and household head are similar across the treatment and control areas (Table 1, Panel A). To assess and compare economic well-being, we use principal components analysis to construct three indices measuring housing characteristics (e.g., condition of the floor, roof, etc.), home assets (e.g., ownership of durable goods such as radio, television, etc.) and productive assets (e.g., agricultural tools) (Filmer and Pritchett, 2001). There are no significant differences for these indices across treatment and control (Table 1, Panel B and see Supplementary Appendix for details of index construction). The fraction of households that report receiving external assistance (e.g., from government or other programs) in the past year is similar across treatment and control although the latter report having experienced modestly more negative economic or other shocks during that same period.

Unsurprisingly for rural Zambia, agriculture is central to the livelihoods of the residents in the sample and most are smallholder farmers, with median total plot area per household of roughly three hectares. More than 80 percent of households in each area have a plot of land or an animal for agricultural purposes, and most households have both, though the proportions are modestly higher in the control (Table 1, Panel C). Consequently, households in the control undertake more agricultural activities, grow more crops and produce more food groups. Conditional on having a plot, however, the differences in crop production disappear, suggesting that differences in agriculture could reflect access to inputs like land (Supplementary Appendix). If access to land is a binding constraint, then these baseline differences suggest there may be less potential for RAIN to shift crop production or even home gardening. On the other hand, if such constraints do not bind and it is possible to obtain (additional) land, then the initially lower agricultural activity in the treatment Wards might indicate greater potential for program impact.

We probe further into agricultural practices related to the study in the two areas to explore if they differ in other ways. In particular, we examine the number of food groups produced (of seven) by month over the 12-month season covered in the baseline survey, shown in Fig. 2 for treatment and control separately. The figure makes clear that the two areas follow remarkably similar production patterns over the year. We interpret this as evidence that despite some differences the control is a good counterfactual for agriculture. In the ITT impact analyses, we consider both single- and double-difference results; the slight imbalances in agricultural activities at baseline have the implication that the former are generally smaller and consequently more conservative.

Individual dietary diversity and household food access and food security are also quite similar across the two areas (Table 1, Panel D). Child and mother dietary diversity are similar, and a full food group below the minimum recommended for an adequate diet. The average number of food groups consumed across all members of the household

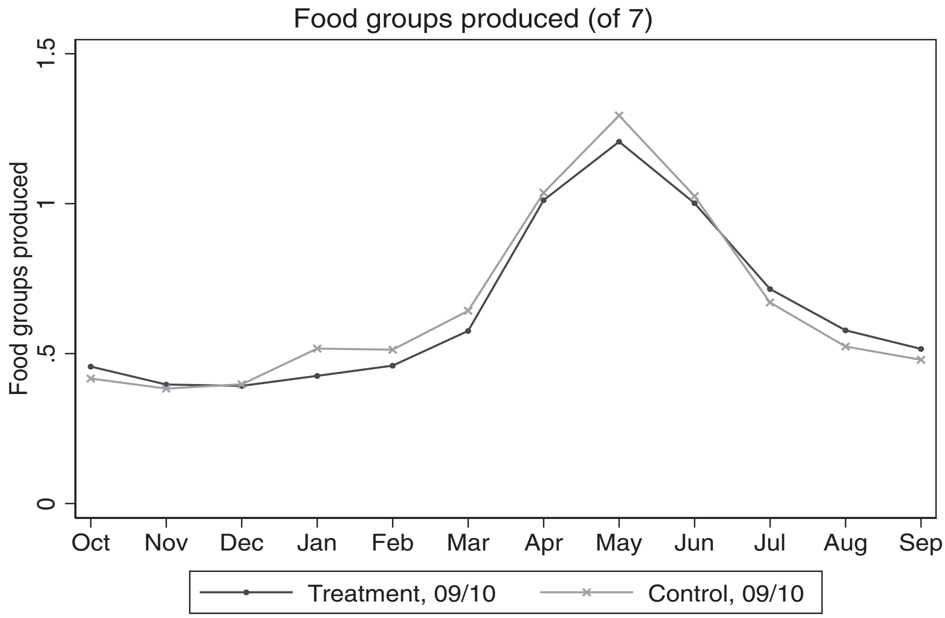

Fig. 2. Food groups produced (of 7). Note: Figure shows the average number of food groups produced in the 2009–2010 agricultural year. This is the completed agricultural year nearest the baseline cross-sectional survey in 2011. The dark line represents the average of households assigned to treatment and the light line the average of households assigned to control.

in the 24 h before the survey was just over four (out of seven), also demonstrating relatively poor access to diverse foods (Table 1, Panel D). Around 20 percent of households reported having at least one member go to bed hungry during the past 30 days and 8 percent of households demonstrate moderate or severe hunger according to the HHS.[20]

Overall, the evidence indicates that RAIN was implemented in an area with high rates of smallholder agriculture, poverty and childhood stunting and low levels of diversity in economic activity (with the vast majority in agriculture) and in individual diets. Moreover, while there are some statistically significant differences across treatment and control areas, most are relatively small in magnitude, supporting the interpretation of the results we present next as reflecting the causal effects of RAIN using the control areas as the counterfactual.

4.2. ITT and TOT estimated effects

We first examine the effect of RAIN on household agricultural production, sales, consumption from own production and food access. We then explore its effects on maternal and child dietary diversity. Estimates at the household level are reported in Tables 2–5 and at the individual level in Table 6. For all but Table 4, each row corresponds to a specific outcome. The first two columns present the control mean at baseline in 2011 and the standardized difference between treatment and control. (The second column, therefore, is a Z-score and on its own not directly comparable to the others.) Except for Table 4, the next two columns present estimates from Eq. (1)—column (3a) contains the basic ITT-DD estimate without any controls and column (3b) the ITT-DD estimate controlling for the 131 SEA-level fixed effects. These control for all time-invariant factors at this small geographic level, such as characteristics related to the suitability of the local conditions (including soil, water or available land) for specific agricultural practices (and their diversity) that differ across space in the study area. The next column shows the results for Eq. (2), the SD estimator of the ITT treatment effect in 2015, yielding the ITT-SD estimate. In the final column, we present the TOT results corresponding to Eq. (3) estimated by 2SLS.[21]

4.2.1. Household-level agricultural production and sales

Despite modestly lower agricultural activity in treatment areas at baseline, the estimates in the first row of Table 2 credit RAIN with a large and unambiguous increase in the number of agricultural activities carried out during the year. The ITT-DD estimates are statistically significant and sizable, indicating an average increase of about half an activity over a baseline of 2.7. There is almost no difference between (3a) without controls and (3b) with SEA-level fixed effects, a pattern that holds across all outcomes we explore. This suggests that estimated program effects may not suffer from substantial locality-specific time-invariant omitted variable bias in models (2) and (3) where we are unable to control directly for such time-invariant factors. Due to the initial differences, the estimated increase when comparing treatment with control households using just the endline survey (4) is only half as large as (3a), though it remains significant. In the final column, the TOT estimate is three times the size, larger than all of the ITT estimates and reflecting the one-third participation rate in the program.[22]

A similar pattern of relative magnitudes and significance levels appears across the estimation approaches for the other measures of annual agricultural production diversity: the number of different food groups harvested or produced (out of seven total) and the number of unique food crops grown (excluding animal products). As with agricultural activities, even the most conservative estimates (the ITT-SD) represent substantial increases over baseline values, by at least one third of the baseline standard deviation of the outcome of interest. Comparing these with the TOT estimates, the evidence indicates that RAIN increases diversity in agricultural production in the treatment areas and that the increase is driven by participating households. In the fourth row, we present a SURE analysis using an index of all three of

[20] Kumar et al. (2018) further demonstrate baseline balance across treatment and control areas for various measures of child nutritional status.

[21] For both the individual- and household-level estimates, the first stage F-statistic on the excluded instrument $RAIN_c$ exceeds 100 (Bound et al. 1995). For the household-level model, the estimated coefficient on $RAIN_c$ in the first stage is 0.335 (standard error 0.025). Because the model has no additional controls, this is equal to the average fraction participating.

[22] We also explored whether the inclusion of an additional set of household-level controls (including household head characteristics, housing characteristics and assets and demographics) in the various models we estimate altered any of the substantive findings. Estimated effects were very similar. We present results from the more parsimonious models without these additional controls to ease interpretation and avoid possible endogeneity of controls to the multifaceted RAIN program (as shown in Section 4.2.1 for productive assets).

Table 2
Program effects on household-level diversity in agriculture and food production.

	(1) Control 2011	(2) T-C standardized difference	(3a) ITT-DD	(3b) ITT-DD	(4) ITT-SD	(5) TT-2SLS
Panel A: Agricultural production diversity						
Number of agricultural activities (of 4)	2.742	−0.229*	0.544**	0.536**	0.298**	0.881**
	(1.075)		(0.133)	(0.133)	(0.073)	(0.203)
Number of food groups produced (of 7)	2.617	−0.159	0.931**	0.929**	0.687**	2.042**
	(1.534)		(0.177)	(0.179)	(0.101)	(0.277)
Total number of food crops grown	2.646	−0.250**	1.357**	1.361**	0.913**	2.716**
	(1.775)		(0.170)	(0.172)	(0.112)	(0.260)
Agricultural diversity family of outcomes (Z-score)	0.621	−0.264*	2.058**	2.052**	1.364**	4.053**
	(2.959)		(0.343)	(0.345)	(0.194)	(0.494)
Panel B: Number of months (of 12) during which harvested/produced food group						
Grains, roots, and tubers	3.138	−0.196**	1.138**	1.087**	0.599**	1.776**
	(2.748)		(0.239)	(0.241)	(0.173)	(0.477)
Pulses, legumes, and nuts	1.694	−0.147*	1.726**	1.695**	1.322**	3.939**
	(2.756)		(0.215)	(0.219)	(0.159)	(0.459)
Vitamin A rich fruits and vegetables	0.980	−0.138*	1.218**	1.230**	0.874**	2.604**
	(2.494)		(0.210)	(0.215)	(0.148)	(0.374)
Other fruits and vegetables	1.991	−0.206**	1.747**	1.716**	1.079**	3.213**
	(3.243)		(0.293)	(0.296)	(0.247)	(0.674)
Dairy products	1.26	0.001	0.660**	0.618**	0.662**	1.973**
	(3.271)		(0.205)	(0.208)	(0.132)	(0.431)
Eggs	3.117	0.110	0.153	0.135	0.637*	1.891*
	(4.388)		(0.432)	(0.440)	(0.274)	(0.839)
Meat and fish	0.781	0.266*	−0.241	−0.204	0.456*	1.356
	(2.619)		(0.304)	(0.304)	(0.230)	(0.696)
Harvested/Produced food group family of outcomes (Z-score)	0.478	−0.082	2.483**	2.440**	2.101**	6.254**
	(4.693)		(0.466)	(0.474)	(0.327)	(0.932)
Any food group	5.093	−0.023	0.935*	0.886*	0.838**	2.485**
	(4.154)		(0.424)	(0.429)	(0.242)	(0.722)
Sampling zone fixed effects	No	No	No	Yes	No	No
Number of households	1041	3044	6580	6580	3536	3535

Note: Table reports program effects on diversity in agricultural production. Column (1) reports the control mean in 2011 and the standard deviation in parentheses. Column (2) reports the difference between treatment and control means in 2011 divided by the control standard deviation in 2011. The stars in column (2) correspond to the results of a hypothesis test for equality between the two means in 2011 when accounting for geographic clustering within the 131 SEAs used for sampling. Columns (3a) and (3b) report ITT double-difference estimated effects from Eq. (1). Column (4) reports the 2015 ITT single-difference estimated effects from Eq. (2). Column (5) reports the 2015 2SLS TT estimated effects from Eq. (3). Standard errors shown in parentheses allow for geographic clustering within the 131 SEAs used for sampling. The agricultural activities in Panel A include: (1) Production of field crops (2) Production of fruits or vegetables (3) Rearing of animals; and (4) Production of animal source foods. The seven food groups in Panel B include: (1) Grains, roots and tubers; (2) Pulses, legumes and nuts; (3) Vitamin A rich fruits and vegetables; (4) Other fruits and vegetables; (5) Dairy products; (6) Eggs; and (7) Meat and fish. We define a family of outcomes by taking the evenly weighted average of all demeaned and standardized variables in Panel A and all seven individual food groups in Panel B. Statistically different from 0: * $p < 0.05$, ** $p < 0.01$.

these agricultural production measures, indicating that the results are robust to their treatment as a family of related outcomes (Kling et al., 2007).

An outcome especially indicative of the potential efficacy of a nutrition-sensitive agricultural intervention in areas with incomplete markets is the number of food groups a household is able to produce *throughout* the year. The agricultural household model suggests that an increase in annual production of diverse foods has the potential to lead to an increase in the availability of diverse foods year-round, particularly for crops that are difficult to store. The ITT-DD and TOT point estimates in Panel A credit the program with household production of one or more new food groups per year. This represents a substantial increase in annual diversity over the average 2.6 food groups produced per household at baseline.

We go beyond these summary measures of annual diversity by examining changes in the number of months throughout the year during which individual food groups were produced (Table 2, Panel B). RAIN appears to increase the number of months with production of six of the seven food groups. The TOT estimates suggest a 1–3 month increase in the availability of each of these foods groups. There is no apparent increase, however, in the production of meat and fish. The family of outcomes combining all seven groups into a Z-score clearly indicates large and positive significant effects.

Last, we consider whether the additional months during which different food groups are produced coincide or lead to even larger increases in the number of months with at least one food group produced over a 12-month season. The program effect on the number of months with *any* food group produced is approximately the average of the effects of the individual food groups (final row in Panel B). This pattern indicates that the additional months in which each food group is produced largely overlap with one another, possibly due to heavy reliance on rain-fed agriculture. While the overall additional months of production are large compared to the baseline average of five months, it is notable that they are not sufficient to extend food group production across all months of the year. Without adequate storage or purchases, the remaining gaps in availability may leave individuals without adequate food for several months and hamper year-round improvements in dietary diversity.

Before disaggregating the effect of the program on production and sales, we consider the possibility that by promoting agricultural activities RAIN stalled otherwise preferable household exit from such pursuits. For many of the agricultural outcomes in Table 2, the ITT-SD (column 4) is smaller than the ITT-DD (columns 3a and 3b). This indicates that some of the improvements reflected in the larger ITT-DD estimates are due to declines in the outcome in the control area over time. As is apparent in the ITT-SD estimates, any such declines are not completely driving the estimates, though for some outcomes they comprise approximately 50 percent of the gain. These declines may therefore reflect a protective effect of RAIN that helps at-risk households in the agricultural livelihood system. However, they also may

Table 3
Program effects on household economic status.

	(1) Control 2011	(2) T-C standardized difference	(3a) ITT-DD	(3b) ITT-DD	(4) ITT-SD	(5) TOT-2SLS
Panel A: Economic well-being						
Housing characteristics index score	−0.103	0.010	0.020	−0.0001	0.038	0.114
	(1.711)		(0.160)	(0.160)	(0.137)	(0.406)
Home assets index score	0.283	−0.045	0.190	0.173	0.101	0.302
	(1.969)		(0.124)	(0.122)	(0.087)	(0.256)
Productive assets index score	0.004	−0.135	0.604**	0.572**	0.429**	1.279**
	(1.295)		(0.135)	(0.132)	(0.066)	(0.204)
Panel B: Gross revenue						
All crops and animal products	2822	0.031	−54.02	−148.7	89.70	260.8
	(4700)		(279.1)	(285.1)	(188.7)	(558.5)
Non-food agriculture	1153	0.214*	−39.97	−90.82	380.2**	1,135**
	(1962)		(151.9)	(155.1)	(93.71)	(275.9)
Food-based agriculture	1520	−0.053	−98.10	−138.9	−276.3*	−831.7
	(3353)		(180.5)	(184.6)	(139.5)	(430.5)
RAIN-targeted crops	166.5	−0.114**	145.8**	145.1**	51.95**	154.8**
	(826.6)		(32.20)	(34.10)	(17.92)	(52.69)
Sampling zone fixed effects	No	No	No	Yes	No	No
Maximum number of households	1041	3044	6580	6580	3536	3536

Note: Table reports program effects on economic well-being and gross revenue from the sale of own-produced agricultural products. Column (1) reports the control mean in 2011 and the standard deviation in parentheses. Column (2) reports the difference between treatment and control means in 2011 divided by the control standard deviation in 2011. The stars in column (2) correspond to the results of a hypothesis test for equality between the two means in 2011 when accounting for geographic clustering within the 131 SEAs used for sampling. Columns (3a) and (3b) report ITT double-difference estimated effects from Eq. (1). Column (4) reports the 2015 ITT single-difference estimated effects from Eq. (2). Column (5) reports the 2015 2SLS TT estimated effects from Eq. (3). Standard errors shown in parentheses allow for geographic clustering within the 131 SEAs used for sampling. The indices used in Panel A are produced from principal component analyses of mutually exclusive sets of binary indicators for household characteristics and assets (see Supplementary Appendix). Gross revenue in Panel B is denominated in 2014 Kwacha and truncated at the 99th percentile. The RAIN-targeted crops are groundnuts, rape, tomatoes and sweet potatoes. Due to incomplete reporting, the exact number of observations is as many as 25 observations fewer than the reported maximum for variables in Panel A and 183 lower for variables in Panel B. Exact sample sizes are provided in the Supplementary Appendix. Statistically different from 0: * $p < 0.05$, ** $p < 0.01$.

Table 4
Program effects on RAIN-targeted agricultural items, ITT-DD.

	(1) Control 2011, produce	(2) T-C standardized difference, produce	(3) Produce	(4) Sell any	(5) Consume any from own production	(6) Consume half or more from own production
Panel A: Crops						
Groundnuts	0.356	−0.149*	0.279**	0.097**	0.263**	0.192**
	(0.479)		(0.038)	(0.022)	(0.038)	(0.034)
Rape	0.315	−0.213**	0.249**	0.166**	0.242**	0.153**
	(0.465)		(0.035)	(0.029)	(0.036)	(0.030)
Tomatoes	0.128	−0.116*	0.164**	0.098**	0.156**	0.108**
	(0.334)		(0.027)	(0.019)	(0.028)	(0.022)
Sweet potatoes	0.036	−0.041	0.019	0.014**	0.019	0.012
	(0.185)		(0.011)	(0.004)	(0.011)	(0.011)
Maize	0.885	−0.291**	0.046	0.041	0.025	0.024
	(0.320)		(0.034)	(0.038)	(0.035)	(0.042)
Seed cotton	0.504	0.032	0.181**	0.162**	–	–
	(0.500)		(0.042)	(0.042)		
Panel B: Animal products						
Eggs	0.524	0.047	0.054	−0.007	0.073	0.056
	(0.500)		(0.057)	(0.015)	(0.054)	(0.044)
Dairy	0.170	0.013	0.077**	0.010	0.084**	0.092**
	(0.376)		(0.025)	(0.018)	(0.025)	(0.023)
Sampling zone fixed effects	No	No	Yes	Yes	Yes	Yes
Maximum number of households	1041	3044	6580	6580	6580	6580

Note: Table reports program effects on the production, sale and consumption of RAIN-targeted agricultural items. Each row corresponds to a single agricultural item. Column (1) reports the control mean in 2011 and the standard deviation in parentheses. Column (2) reports the difference between treatment and control means in 2011 divided by the control standard deviation in 2011. The stars in column (2) correspond to the results of a hypothesis test for equality between the two means in 2011 when accounting for geographic clustering within the 131 SEAs used for sampling. Columns (3)–(6) report estimates of the ITT-DD estimated impacts from Eq. (1) with SEA fixed effects on the share of households producing, selling, eating and eating at least half of their own production of an agricultural item. Standard errors shown in parentheses allow for geographic clustering within the 131 SEAs used for sampling. Panel A presents results for the four crops that were targeted by RAIN in addition to maize and seed cotton. Panel B presents results for animal-source foods. Due to incomplete reporting, the exact number of observations is as many as 59 observations fewer than the reported maximum. Exact sample sizes and results from different estimators are provided in the Supplementary Appendix. Statistically different from 0: * $p < 0.05$, ** $p < 0.01$.

Table 5
Program effects on household-level food access and insecurity.

	(1) Control 2011	(2) T-C standardized difference	(3a) ITT-DD	(3b) ITT-DD	(4) ITT-SD	(5) TOT-2SLS
Panel A: Household member food group consumption (24 hours)						
Grains, roots, and tubers	0.997	−0.021	−0.008	−0.008	−0.009	−0.028
	(0.054)		(0.005)	(0.005)	(0.005)	(0.014)
Pulses, legumes, and nuts	0.521	−0.053	0.125**	0.137**	0.099**	0.296**
	(0.500)		(0.046)	(0.047)	(0.028)	(0.086)
Vitamin A rich fruits and vegetables	0.623	−0.152	0.067	0.076	−0.007	−0.021
	(0.485)		(0.040)	(0.040)	(0.015)	(0.043)
Other fruits and vegetables	0.793	−0.041	0.032	0.039	0.015	0.045
	(0.405)		(0.035)	(0.035)	(0.021)	(0.064)
Dairy products	0.337	0.062	0.028	0.0267	0.057	0.170
	(0.473)		(0.049)	(0.050)	(0.036)	(0.107)
Eggs	0.337	−0.062	0.072	0.079	0.043	0.129
	(0.473)		(0.051)	(0.052)	(0.025)	(0.074)
Meat and fish	0.781	0.172*	0.009	0.016	0.080**	0.238**
	(0.414)		(0.035)	(0.035)	(0.026)	(0.0818)
Total number of food groups in household	4.389	−0.031	0.325	0.366*	0.278**	0.829**
	(1.511)		(0.176)	(0.177)	(0.086)	(0.269)
Panel B: Household perceptions (30 days)						
Household hunger scale (0–6)	0.365	0.006	0.150	0.148	0.155	0.463
	(0.856)		(0.122)	(0.122)	(0.100)	(0.298)
Moderate or severe household hunger (HHS > 1)	0.090	−0.028	0.065	0.063	0.057	0.169
	(0.286)		(0.037)	(0.037)	(0.031)	(0.093)
Household Food Insecurity (0–27)	–	–	–	–	0.404	1.206
					(0.409)	(1.217)
Moderate or Severe Household Food Insecurity	–	–	–	–	0.069*	0.207*
					(0.035)	(0.104)
Sampling zone fixed effects		No	No	Yes	No	No
Maximum number of households	1041	3044	6580	6580	3536	3536

Note: Table reports program effects on household food access and insecurity. Column (1) reports the control mean in 2011 and the standard deviation in parentheses. Column (2) reports the difference between treatment and control means in 2011 divided by the control standard deviation in 2011. The stars in column (2) correspond to the results of a hypothesis test for equality between the two means in 2011 when accounting for geographic clustering within the 131 SEAs used for sampling. Columns (3a) and (3b) report ITT double-difference estimated effects from Eq. (1). Column (4) reports the 2015 ITT single-difference estimated effects from Eq. (2). Column (5) reports the 2015 2SLS TT estimated effects from Eq. (3). Standard errors shown in parentheses allow for geographic clustering within the 131 SEAs used for sampling. The seven food groups at the top of Panel A are dummy variables indicating whether anyone in the household consumed any food in that food group over the past 24 hours. The total number of food groups is the sum of the seven food group indicators. The 30-day recall-based measures in Panel B are the Household Hunger Scale (HHS) and Household Food Insecurity Access Scale (HFIAS). We discretize the HFIAS responses according to Coates et al. (2007) to measure moderate or severe household food insecurity. The data needed to construct the HFIAS measure are only available for 2015. Due to incomplete reporting, the exact number of observations is as many as 25 observations fewer than the reported maximum. Exact sample sizes are provided in the Supplementary Appendix. Statistically different from 0: * $p < 0.05$, ** $p < 0.01$.

demonstrate a restrictive effect that prevents households from shifting toward more profitable economic activities outside of agriculture, with potentially negative longer-term consequences.

We indirectly examine this possibility by assessing program effects on three economic measures of well-being. Improvements in economic well-being due to RAIN would be consistent with a protective effect on balance, whereas deterioration would suggest that those households more likely to shift out of the types of agricultural activities promoted by RAIN were faring better. The intervention significantly increased productive assets but apparently had no significant effect on housing characteristics or home assets, though point estimates are positive (Table 3, Panel A). These findings provide evidence against a restrictive role for the program that prevents households from making decisions that may have been beneficial to overall household economic well-being. At the same time, they are consistent with the program implementation design, in which an explicit component was the distribution of agricultural tools, strengthening the plausibility that the results reflect RAIN program effects.

We further test for the possibility that households could have profitably shifted away from agriculture by examining revenues from the sale of agricultural products. If agricultural revenues in control households fell dramatically relative to the treatment areas, it would be evidence that households had left agriculture to pursue different, possibly more profitable, economic activities. Panel B of Table 3 shows this is not the case. Estimates of the effect of RAIN on total revenues are small relative to the control mean and, though imprecise, provide little evidence of an average impact, either positive or negative.[23] This is not surprising as the program focused on nutrition-related production activities for women, rather than the production and sale of cash crops. Since agricultural cash revenues are a principal source of total income for households in this region (IAPRI, 2016), these findings suggest that RAIN is not operating through the income channel of the agricultural household model.

This null result for total revenue, however, masks differences in the effects of RAIN on revenues from different types of agricultural production. While holding total revenue constant, RAIN modestly induces households to substitute revenue from food items for revenue from non-food (principally cotton) agriculture. Separating the two, a pattern emerges in which small increases in revenue from cash crops offset decreases in revenue from food crops and animal products. Moreover, within revenues from food crops and animal products, RAIN induces households to shift toward revenue from crops specifically targeted by the program's agricultural interventions.

In Table 4, we explore what underlies the substitution patterns in sources of agricultural revenue by examining the production, sale and

[23] It is not possible with the data to impute total agricultural income due to insufficient information on price and quantity.

Table 6
Program effects on diet of children 6-24 months their mothers (24-hour recall).

	(1) Control 2011	(2) T-C standardized difference	(3a) ITT-DD	(3b) ITT-DD	(4) ITT-SD	(5) TOT-2SLS
Panel A: Child individual food groups						
Grains, roots and tubers	0.967	−0.016	−0.007	−0.003	−0.010	−0.029
	(0.178)		(0.013)	(0.015)	(0.008)	(0.023)
Pulses, legumes and nuts	0.151	−0.115	0.109**	0.114**	0.063*	0.181*
	(0.403)		(0.039)	(0.040)	(0.029)	(0.086)
Vitamin A rich fruits and vegetables	0.602	0.011	0.008	0.0001	0.013	0.036
	(0.460)		(0.040)	(0.042)	(0.023)	(0.067)
Other fruits and vegetables	0.116	0.052	−0.045	−0.043	−0.024	−0.069
	(0.404)		(0.040)	(0.041)	(0.025)	(0.073)
Dairy products	0.081	0.070	0.005	0.002	0.031	0.089
	(0.378)		(0.045)	(0.045)	(0.040)	(0.115)
Eggs	0.101	−0.074	0.045	0.051	0.018	0.051
	(0.368)		(0.043)	(0.044)	(0.032)	(0.092)
Meat and fish	0.388	0.072	−0.003	−0.006	0.033	0.094
	(0.499)		(0.042)	(0.044)	(0.032)	(0.093)
Total number of food groups in child's diet	2.327	0.014	0.105	0.111	0.121	0.349
	(1.192)		(0.129)	(0.134)	(0.092)	(0.268)
At least four food groups	0.156	−0.016	0.042	0.048	0.034	0.099
	(0.460)		(0.051)	(0.051)	(0.040)	(0.116)
Panel B: Mother's aggregated food groups						
Total number of food groups in mother's diet	3.108	0.022	0.045	0.068	0.067	0.193
	(1.004)		(0.121)	(0.123)	(0.0936)	(0.271)
At least four food groups	0.313	0.014	0.014	0.027	0.020	0.058
	(0.464)		(0.057)	(0.056)	(0.044)	(0.127)
Sampling zone fixed effects	No	No	No	Yes	No	No
Maximum number of individuals	586	1524	2867	2867	1343	1343

Note: Table reports program effects on the dietary diversity of children 6–24 months and their mothers. Column (1) reports the control mean in 2011 and the standard deviation in parentheses. Column (2) reports the difference between treatment and control means in 2011 divided by the control standard deviation in 2011. The stars in column (2) correspond to the results of a hypothesis test for equality between the two means in 2011 when accounting for geographic clustering within the 131 SEAs used for sampling. Columns (3a) and (3b) report ITT double-difference estimated effects from Eq. (1). Column (4) reports the 2015 ITT single-difference estimated effects from Eq. (2). Column (5) reports the 2015 2SLS TT estimated effects from Eq. (3). Standard errors shown in parentheses allow for geographic clustering within the 131 SEAs used for sampling. Estimates in Panel A include dummy variable controls for age of the child in quarters. The individual food groups in Panel A are dummy variables indicating consumption of that food group in the prior 24 hours. The total number of food groups is the sum of the seven food group indicators, and at least four food groups is a dummy variable indicating that this sum is four or greater. The aggregates are constructed identically for mothers in Panel B. Due to incomplete reporting, the exact number of observations is as many as 37 observations fewer than the reported maximum. Exact sample sizes are provided in the Supplementary Appendix. Statistically different from 0: * $p < 0.05$, ** $p < 0.01$.

consumption from own production decisions for individual crops and animal products. The table presents the ITT-DD estimates for outcomes measured as binary indicators (results for the other estimators are provided in the Supplementary Appendix). The program markedly increases the production of three RAIN-targeted crops (groundnuts, rape and tomatoes) as well as of seed cotton, without decreasing production of the others. Overall, the effects are consistent with households in the treatment area having potential to expand agricultural activities, despite initial differences in land access. As there is no significant impact on whether a household has a plot (not shown), gains were mostly on the intensive margin, that is for households already with some land. Items showing the largest gains in production were those already commonly planted in the area; sweet potatoes on the other hand, uncommon at baseline (< 4 percent), had little traction. Seed cotton was not distributed directly as part of RAIN, and it is unclear exactly why production of this cash crop increased.

Additional production creates the potential for sales and revenue. Indeed, conditional on production, sale of (at least) some portion of food crops and food items was common at baseline. For example, among households producing groundnuts, sweet potatoes or dairy products, one-third had sales. Among those growing rape, tomatoes or maize, it was more than 50 percent. For each of the RAIN-targeted crops, the effects on the probability of selling at least some of the production are between one-third and two-thirds the increases in production (Table 4, Column 4). It appears that between one and two of every three new households producing a RAIN-targeted crop sold (at least) some of that crop. There are only insignificant effects on maize, however, given its already ubiquitous production. The increase in the sale of seed cotton is virtually identical to its increase in production, as expected for a non-food cash crop. These results show that RAIN shifts the basket of goods households produce and bring to market in a manner that is consistent with the substitution patterns in agricultural revenue observed in Table 3.

We now examine whether there is a parallel shift in consumption from own production, consistent with a possible effect of the program on preferences for more varied and nutritious diets or with market imperfections. The results on sales make clear that households are not fully constrained to consume from own production as would be the case with completely missing markets, though there still may be important transaction costs or other market imperfections. Since less than two-thirds of households producing a RAIN-targeted crop due to the program sell any of it, approximately one-third consume all of their new production. Columns (5) and (6) directly examine whether households themselves consumed any of their own production and, separately, whether they consumed half or more of their own production. Nearly all of the households producing a RAIN-targeted crop because of the program consumed some of it, and about two-thirds consumed half or more. We conclude that increased production of RAIN-promoted crops was primarily, though not exclusively, used for own consumption.

The data do not permit a conclusive test to distinguish the channels through which RAIN might be influencing dietary diversity.[24] We

[24] We do not observe full income nor comprehensive food item expenditures, and therefore cannot test direct implications of all channels implied by the agricultural household model.

speculate, however, that the pattern of findings is more consistent with transmission through changing preferences and imperfect markets than through the income channel.

4.2.2. Household food access and individual dietary diversity

Last, we consider whether RAIN changed the foods eaten in households or by mothers and their young children in the 24 h prior to survey administration. We focus on the same seven food groups examined on the production side above. Of course, for such consumption to occur it is not necessary that the food item came from household production. Consequently, this outcome is a measure of food access and diet quality rather than just consumption from own production. Since the recall period is different, both in length and in calendar period (previous day versus past agricultural season), evidence of increased access from the dietary recall would be consistent with persistence of the program's effects on agriculture over time.

RAIN increased the share of households with a member eating pulses, legumes and nuts in the past 24 h (Table 5, Panel A). All but one of the other food group categories indicate small positive but insignificant increases. Relatedly, the overall total number of food groups significantly increases, indicating slightly improved household food access.[25]

Results for the same food group categories for the youngest household member between 6 and 24 months of age, in which we add indicator controls for age in quarters, are similar though less strong (Table 6, Panel A). They also indicate increases in pulses, legumes and nuts, suggesting the household-level result may be due to child consumption. However, the increase in total food groups (IDDS) is not significant, and there is no increase in the fraction of children consuming the four or more food groups considered adequate for a nutritious diet. There were no significant effects for mothers (Table 6, Panel B).[26]

The effect on pulses, legumes and nuts for household and child measures suggests a direct connection between RAIN and the diets of at least some members of participating households. RAIN distributed seeds for crops in this food group, and the treatment increased the number of months in which these crops were harvested. Not only did production increase, but consumption from own production increased as well. Moreover, in contrast to highly perishable fruits and vegetables which also saw increased production, foods from this group require minimal processing to keep shelf stable and are amenable to longer storage periods. Production data indicate that there were fruits and vegetables available during the survey months, but it may be that the 24-hour dietary recall period was too short to detect changes in the consumption of some of these more perishable items. Despite these modest improvements, however, there is no evidence that RAIN reduced food insecurity at the household level. The results for HHS and HFIAS scores (Table 5, Panel B) are generally insignificant or even suggest slight increases in food insecurity.

5. Conclusion

A complex of factors cause childhood undernutrition. Consequently, nutrition interventions must simultaneously address multiple potential causes to be effective. Using a pre-post design with a control group and different conservative estimators, we assessed a nutrition-sensitive agricultural program designed to address several potential causes of child undernutrition. These included low diversity in agricultural production, limited access to nutritious foods, imbalance in gender roles and poor knowledge about nutrition and child feeding. In this study we examined outcomes along the multiple potential pathways from food production to improved child diets.

RAIN significantly increased diversity in agricultural production on the extensive margin (e.g., types of crops grown per year and number of food groups) as well as on the intensive margin (e.g., the number of months in which a food group is harvested). In particular, the percentage of households producing three RAIN-promoted nutritious crops (groundnuts, rape and tomatoes) increased substantially, on the order of 20 percentage points each. Moreover, these RAIN-promoted crops were primarily, though not exclusively, used for own consumption. There were modest increases in household food access measured as household diet diversity, but not in household perceptions of food security. Within the framework of the agricultural household model, this pattern of findings from production to consumption is more consistent with changes in preferences and imperfect markets than with changes in income. Despite modest increases in the proportion of children consuming pulses, legumes and nuts, ultimately there were no significant improvements in the overall dietary diversity of young children or their mothers. Evidently there were further barriers to improving diets in this context beyond lack of own production.

Overall, the findings of limited conversion of diverse agricultural production into child dietary diversity are consistent with results from Kumar et al. (2018), who examined other program pathways and assessed the impact of RAIN on child nutritional status. They demonstrate that RAIN was linked to improvements in aspects of women's empowerment and knowledge of infant and young child feeding practices alongside decreases in acute child malnutrition, consistent with improved current food access. RAIN had no impact, however, on child feeding practices or chronic malnutrition, which may have been due to incomplete implementation of the nutrition education BCC component or have required more consistent food access and greater dietary diversity alongside interventions fully addressing the health and care determinants of child undernutrition (Ruel et al., 2017). This underscores the difficulty of reducing chronic undernutrition, even when a program achieves gains in agricultural production diversity.

Our results support the emerging consensus that nutrition-sensitive agricultural programs should focus on improving diets, rather than stunting, as their primary goal (Global Panel on Agriculture and Food Systems for Nutrition, 2016; Ruel et al., 2017). To achieve this goal, programs need to stimulate agriculture and food access, and ensure that gains are transferred downstream to diet quality, especially for young children and their mothers. We show that this transfer does not occur automatically, and recommend it as a priority for the design and evaluation of future nutrition-sensitive agricultural programs. Only by connecting agriculture to diets can nutrition-sensitive agricultural programs address the health and development challenges of the 21st century.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.foodpol.2018.07.008.

[25] There is a similar small and significant increase if we instead use the more standard 12-item HDDS designed and validated against calorie consumption in households.

[26] There is a similar small and insignificant effect if we instead use the WDDS designed and validated for women.

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