Farm-Level Agricultural Biodiversity in the Peruvian Andes Is Associated with Greater Odds of Women Achieving a Minimally Diverse and Micronutrient Adequate Diet

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Farm-level agricultural biodiversity in the Peruvian Andes is associated with greater odds of women achieving a minimally diverse and micronutrient adequate diet

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Abstract:	Background: The extent to and mechanisms by which agricultural biodiversity may influence diet diversity and quality among women are not well understood. Objective: We aimed to: 1) determine the association of farm-level agricultural biodiversity with diet diversity and quality among women of reproductive age in Peru; and 2) determine the extent to which farm market orientation mediates or moderates this association. Methods: We surveyed 600 households using stratified random sampling across three study landscapes in the Peruvian Andes with diverse agroecological and market conditions. Diet diversity and quality of women were assessed using quantitative 24-hour dietary recalls with repeat recalls among 100 randomly selected women. We calculated a 10-food group diet diversity score (DDS), the Minimum Dietary Diversity for Women (MDD-W) indicator, probability of adequacy (PA) of nine micronutrients using a measurement-error model approach, and mean probability of adequacy (MPA) (mean of PAs for nutrients). Agricultural biodiversity was defined as a count of crop species cultivated by the household during the 2016-2017 agricultural season. Results: In regression analyses adjusting for sociodemographic and agricultural characteristics, farm-level agricultural biodiversity was associated with a higher DDS (incidence-rate ratio from Poisson regression: 1.03; P<0.05), and MPA (OLS

coefficient: 0.65; P<0.1), and higher odds of achieving a minimally diverse diet (MDD-W: OR (95% CI) from logistic regression: 1.17 (1.11, 1.23)), and a diet that met a minimum threshold for micronutrient adequacy (MPA >60%: 1.21 (1.10, 1.35)). Farm market orientation did not consistently moderate these associations, and in path analyses, we observed no consistent evidence of mediation of these associations by farm market orientation.

Conclusions: Farm-level agricultural biodiversity was associated with moderately more diverse and more micronutrient-adequate diets among Peruvian women. This association was consistent across farms with varying levels of market orientation though agricultural biodiversity likely contributed to diets principally through subsistence consumption.

Additional Information:

Question	**Response**
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Author Comments:

June 15, 2018

Professor Teresa A. Davis
Editor-in-Chief
Journal of Nutrition

Dear Professor Davis,

Re: Re-submission of original research article entitled "Farm-level agricultural biodiversity in the Peruvian Andes is associated with greater odds of women achieving a minimally diverse and micronutrient adequate diet"

Thank you for the opportunity to re-submit a revised version of the manuscript "Farm-level agricultural biodiversity in the Peruvian Andes is associated with greater odds of women achieving a minimally diverse and micronutrient adequate diet" to the Journal of Nutrition.

My co-authors and I have carefully and comprehensively addressed each of the peer reviewers' comments, and we believe the revisions have helped to strengthen the clarity of the presentation of the findings and the methodology, as well as the motivation for the work.

Thank you in advance for your consideration of our manuscript. We have not submitted this manuscript elsewhere for publication and will not do so while it is under consideration by the Journal of Nutrition.

We look forward to hearing from you.

Sincerely,

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Farm-level agricultural biodiversity in the Peruvian Andes is associated with greater odds of women achieving a minimally diverse and micronutrient adequate diet

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Short running head: Agricultural biodiversity and diet quality

Abbreviations: Dietary Species Richness (DSR); Diet Diversity Score (DDS); Estimated Average Requirements (EAR); Incidence-Rate Ratios (IRR); Latin American and Caribbean Food Security Scale (ELCSA); Low- and Middle-Income Countries (LMICs); Mean Probability of Adequacy (MPA); Minimum Dietary Diversity for Women (MDD-W); Ordinary Least Squares (OLS); probability of adequacy (PA); Recommended Nutrient Intakes (RNI)

ABSTRACT

Background: The extent to and mechanisms by which agricultural biodiversity may influence diet diversity and quality among women are not well understood.

Objective: We aimed to: 1) determine the association of farm-level agricultural biodiversity with diet diversity and quality among women of reproductive age in Peru; and 2) determine the extent to which farm market orientation mediates or moderates this association.

Methods: We surveyed 600 households using stratified random sampling across three study landscapes in the Peruvian Andes with diverse agroecological and market conditions. Diet diversity and quality of women were assessed using quantitative 24-hour dietary recalls with repeat recalls among 100 randomly selected women. We calculated a 10-food group diet diversity score (DDS), the Minimum Dietary Diversity for Women (MDD-W) indicator, probability of adequacy (PA) of nine micronutrients using a measurement-error model approach, and mean probability of adequacy (MPA) (mean of PAs for all nutrients). Agricultural biodiversity was defined as a count of crop species cultivated by the household during the 2016-2017 agricultural season.

Results: In regression analyses adjusting for sociodemographic and agricultural characteristics, farm-level agricultural biodiversity was associated with a higher DDS (incidence-rate ratio from Poisson regression: 1.03; $P<0.05$), and MPA (OLS β coefficient: 0.65; $P<0.1$), and higher odds of achieving a minimally diverse diet (MDD-W: OR (95% CI) from logistic regression: 1.17 (1.11, 1.23)), and a diet that met a minimum threshold for micronutrient adequacy (MPA >60%:

1.21 (1.10, 1.35)). Farm market orientation did not consistently moderate these associations, and in path analyses, we observed no consistent evidence of mediation of these associations by farm market orientation.

Conclusions: Farm-level agricultural biodiversity was associated with moderately more diverse and more micronutrient-adequate diets among Peruvian women. This association was consistent across farms with varying levels of market orientation though agricultural biodiversity likely contributed to diets principally through subsistence consumption.

Keywords: Agricultural biodiversity, agrobiodiversity, women’s diet diversity, micronutrient adequacy, farm market orientation

INTRODUCTION

Agricultural biodiversity refers to the biological diversity within agriculture and food systems. This diversity includes variability of crop and livestock species, intraspecific diversity (i.e., varieties, breeds), associated wild species, as well as the different agroecosystems that farmers manage (1). Smallholder farmers typically manage agricultural biodiversity for a range of reasons, including for yield stability, risk avoidance, soil conservation, and pest and disease management. Agricultural biodiversity is also valued as a genetic resource needed to provide new resistance genes and functional traits in response to pests, pathogens and climate change (2). Yet, agricultural biodiversity is also essential for supplying the diverse foods needed to sustain healthy diets and prevent malnutrition in all its forms (3). Diverse diets, comprised of different foods and food groups, are widely recognized as essential for optimum nutrition and health (4-6).

A recent comprehensive synthesis of the empirical evidence underlying the relationship between agricultural production diversity and diet diversity in low- and middle-income countries (LMICs) found that more diverse family farms were consistently associated with more diverse household diets (7). The association was small, ranging from 0.1 to 0.25 additional food groups in household diets for each additional crop species cultivated on farms. While the consistency of this positive association across studies is striking, the evidence underlying this relationship is limited by: 1) the limited generalizability of the findings (i.e., studies were undertaken almost exclusively in Sub-Saharan Africa); 2) the near absence of quantitative, individual-level dietary intake estimates; and, 3) limited assessments of the potential market-related mechanisms underlying the observed associations between agricultural biodiversity and diets (7). While subsistence production of diverse food crops has been hypothesized as the principal mechanism linking agricultural production diversity with diets (8, 9), market-oriented mechanisms have also been proposed (e.g., income is generated through the sale of diverse agricultural products, which in turn is used to purchase more diverse foods) (10). Yet, our understanding of the extent to which earnings from sold agricultural production may mediate or moderate the association between agricultural biodiversity and diets remains limited.

The specific aims of this study were to: 1) determine the association of farm-level agricultural biodiversity with diet diversity and quality among women of reproductive age in central Peru; and 2) determine the extent to which market orientation of agricultural production mediates or moderates this association. We further examined characteristics of households with differing levels of agricultural biodiversity to provide context for interpreting results related to the second specific aim. We hypothesized that greater farm-level agricultural biodiversity would be associated with more diverse diets among women and diets that are more likely to meet women's micronutrient requirements. Focusing on women's diets in particular is especially important given that women's social status, control over resources, and health and nutrition are central to many of the pathways linking agriculture and nutrition (11). We further hypothesized that earnings from agricultural production would not mediate the association between agricultural biodiversity and diet outcomes, but that the magnitude of the association between agricultural biodiversity and diet outcomes would be diminished among households with a greater market orientation of agricultural production.

SUBJECTS AND METHODS

Study design and data collection

The study was conducted in the Huánuco region of the central Peruvian Andes. Three study regions, or landscapes, across a transect were selected from information gathered through site visits, key informant interviews, and analysis of municipal data and topographic maps. These intra-regional landscapes were representative of socio-environmental variation in the explanatory variables of the study (i.e., farm-level agricultural biodiversity; market access and orientation of agricultural production; and agroecological conditions). The geographic extents of the landscapes, each encompassing 150-250 km^2, were estimated initially using Google Earth and were later mapped and measured using ArcMap 10.5.1 and geocorrected using Sentinel 2 satellite imagery (31 May 2017). Population data from the 2007 National Census of Peru (12), cross-referenced with municipal-level data, were used to identify all communities within each landscape boundary to establish a community sample frame. We applied a stratified random sampling procedure to select ten communities in each landscape. Selection was stratified across elevation zones based on terciles of intra-landscape elevation distributions.

A census was conducted in each selected community and in randomly selected replacement communities to accurately enumerate the number of eligible households in each community based on the following inclusion criteria: 1) household members are permanent residents of the household; 2) a woman of reproductive age (18-49 years) is a member of the household; and, 3) field and/or garden crops were cultivated by at least one member of the household during the 2016-2017 agricultural season. In total, 82% of censused households cultivated at least one field or garden crop in the 2016-2017 agricultural season. Field and garden crops were defined as domesticated plants cultivated in production areas recognized locally as fields (i.e., *chacras*, *parcelas*) and gardens (i.e., *huertos*, *huertas*), respectively (13). Twenty households in each community were randomly selected for participation in the study. Our target sample size was calculated based on previous research indicating that cultivation of two additional crop species on smallholder farms—a difference we anticipated observing across terciles of crop species richness in this population—is associated with a mean (SD) difference in diet diversity of 0.6 (2.1) using a diet diversity score similar to that used in this study (see below) (14). Assuming a design effect of 1.5 to account for within-community correlations, we calculated we would need a sample of at least 579 households to observe such a difference in our outcome variable across households with differing crop species richness. Among the 600 households we sampled in this study, an in-person, multi-module household survey was conducted during an eight-week period between April to June 2017 corresponding to the local harvest season. On average, four days were required per community in each region to complete the administration of the household survey (including dietary assessments).

In addition to the multi-module household survey questionnaire, a separate team of trained nutritionists conducted a comprehensive assessment of index women's diets applying a quantitative 24-hour recall of food intake. An index woman in each household was identified as the wife of the male head of household if aged 18-49 years, or, if this criterion did not apply, the woman in the household between 18-49 years of age with the most responsibility for household management. Households wherein a respondent was not available after three separate visits on subsequent days were replaced with a randomly selected eligible replacement household from the community. For communities in which surveys were not completed with 20 households after exhausting the replacement household list, one or more replacement communities were randomly selected within the same study landscape-elevation zone for completion of the 20 requisite interviews.

One half of the households interviewed within each community were randomly selected for participation in a substudy aimed at characterizing and quantifying the agricultural biodiversity of each household using participatory mapping and plot-level sampling of each field. The methodology was applied to all fields and crops that were cultivated by the household at the time of sampling. Tailored, intra-plot sampling methods were used for fields characterized by the following predominant crops: 1) Andean root and tuber crops (including potatoes); 2) maize fields including interspecific mixtures with pulses, vegetables, and grains; and 3) home gardens. These sampling methods have been previously validated in analogous field systems for determining total species and varietal diversity, relative abundance of species and varieties, as well as land use patterns and the spatial distribution of agricultural biodiversity (15-17).

Measurement of variables

Women's diet diversity and diet quality were the principal dependent variables examined in this analysis. Indicators of both variables were constructed using data from quantitative 24-hour dietary recall interviews. The interviews were conducted using the multiple-pass method (18). We randomly selected 100 women to receive a second dietary survey on a non-consecutive day following the first interview.

A Dietary Diversity Score (DDS) was calculated for each woman based on the food group diversity reported in the first administered 24-hour recall. The DDS was based on 10 food groups that contribute most strongly to the micronutrient adequacy of women's diets (19). The food group was coded as 1 if the woman reported consuming at least 15 g of a food from the food group, and 0 otherwise (19, 20). The scores were then summed across individual food groups to yield the DDS. Based on the DDS, the Minimum Dietary Diversity for Women (MDD-W) indicator was also calculated defined as 1 if the woman consumed five or more food groups in the previous 24 hours, and 0 otherwise (19). Dietary Species Richness (DSR), a count of the number of different plant and animal species consumed by an individual (21), was also calculated using day-one 24-hour recall data. Only foods that were categorized into one of the 10 food groupings used to generate the MDD-W were incorporated into calculations of the DSR. For example, maize, potato, and wheat—species that were categorized into the "starchy staple foods" grouping of the DDS—were counted as distinct species for purposes of calculating the DSR. Distinct species of animals (e.g., chickens, goats, sheep) were also counted and contributed to the DSR.

We further calculated the probability of adequacy (PA) for nine micronutrients (i.e., thiamin, riboflavin, niacin, folate, vitamin C, vitamin A, calcium, iron, and zinc) for each individual. We converted each day of food intake data to nutrient intakes using food composition tables of the Instituto de Investigación Nutricional (IIN) that include data from other Latin American countries as well as the U.S. Department of Agriculture (22). Values for the nutrient content of varieties of foods that were not included in IIN food composition tables were identified from published catalogues for potatoes (23, 24), the La Molina National Agrarian University (UNALM) (for analyses of Andean grains), and from Internet searches. Where nutrient values were not available for a specific variety, the nutrient content of a similar food item was imputed.

Then, using variables that we power transformed to approximate normal intake distributions, we calculated individual and population means for the intakes of each nutrient, as well as within- and between-person variances for the transformed variables based on data from the subsample of women with two days of intake data (25). The best linear unbiased predictor of each respondent's usual intake was calculated using a measurement-error model approach (26), and from those predictors, the PA for each nutrient was calculated. PA was defined as the probability that a respondent's usual intake met the WHO/FAO micronutrient requirement distributions based on the woman's physiological status (27). Estimated Average Requirements (EAR) were back-calculated from Recommended Nutrient Intakes (RNI) as previously described (28). The Mean Probability of Adequacy (MPA) was calculated as the mean of the PAs for all nine nutrients. Limitations in the available food composition table data meant that we were unable to calculate additional PAs for vitamins B6 and B12 as was done for the validation study of the MDD-W indicator. However, we used the same threshold as this prior study to define "better" MPA, namely, a cut-off of >60% MPA (28).

The principal independent variables used in analyses were crop species richness, and crop and livestock species richness. Crop species richness was defined as a count of the number of different crop species cultivated by the household on any field that was cultivated or owned by the household during the 2016-2017 agricultural season. The general household survey collected plot-level data on the specific crops grown on each field during the 2016-2017 agricultural season. The current number of different livestock species owned or raised by the household was added to the crop species richness of field crops to generate the crop and livestock species richness variable. Respondents were explicitly asked about 12 species of livestock and were prompted to list additional species.

Sociodemographic data for each household were collected, and an asset-based wealth index was calculated for each household using data on the ownership of 23 assets. Using weights assigned to these assets from a principal components analysis, we generated standardized asset scores, and calculated quintiles of this score based on the sample-specific distribution (29). We used the Latin American and Caribbean Food Security Scale (ELCSA) to assess household food insecurity and defined food secure, mildly food insecure, moderately food insecure, and severely food insecure households using established cut-off values (30).

We calculated several additional agricultural variables including 1) total agricultural land area; 2) total production and yields during the 2016-2017 agricultural season; 3) proportion of harvest destined for sale and earnings from sold crops (i.e., indicators of market orientation of farms); 4) whether a household cultivated a garden, specific field crops, or produced any milk, cheese or eggs from their own production in the previous 12 months; 5) livestock units (31); and, 6) whether households earned income from non-agricultural sources.

Statistical analyses

All analyses were carried out using the Stata statistical software package, version 15.1. (2018; StataCorp, College Station, TX, USA). We compared sociodemographic, agricultural, and agricultural biodiversity characteristics of households by terciles of crop species richness using ANOVA for comparisons of continuous variables and Pearson’s chi-squared tests for comparisons of proportions. The Pearson product-moment correlation coefficient (r) was used to assess the association between crop species richness as measured based on survey recall and plot-level sampling of each field, respectively.

We used multiple regression analysis to examine the associations of measures of agricultural biodiversity and production (i.e., crop species richness; crop and livestock species richness; production of specific groupings of crops and livestock) with indicators of diet diversity and quality (i.e., DDS, MDD-W, DSR, MPA and MPA >60%). Given the discrete, bounded nature of the DDS and DSR variables, Poisson regressions were fit to models that included DDS and DSR as dependent variables. Values are reported as incidence-rate ratios (IRR). These models were adjusted for covariates that are hypothesized determinants of women's diet diversity and quality, and potential confounding factors of the relationship between agricultural biodiversity and women's diet outcomes. Similar sets of covariates have been used in previous studies examining these relationships (10, 14). These covariates included: household size; sex of head of household; the age, pregnancy, marital and education status of the index woman; household wealth quintiles; household food security status; agricultural land area of the household; livestock units (excluded from models that also included crop and livestock species richness); whether the household had a non-agricultural source of income; whether the household cultivated a garden during the preceding agricultural season; and study region. Models with MDD-W and MPA >60% as the dependent variables were fit with logistic regressions and adjusted for the same covariates as the Poisson models. Finally, ordinary least squares (OLS) regressions were fit to models using MPA as the dependent variable and adjusted for the same set of covariates. The sampling approach using landscapes was not intended to produce region-specific estimates from stratified analyses, nor to derive representative region-specific estimates. Rather, the sampling approach was intended to ensure representative variation in the principal independent variables. Therefore, all analyses were conducted on the full sample of available households, and we did not calculate sampling weights. For all models, variance estimates were obtained using the robust estimator of variance (32), adjusting SE and variance-covariance matrices of the estimators for within-study region correlations.

We conducted a path analysis to examine potential mediation of the association of agricultural biodiversity with diet outcomes by the proportion of agricultural production sold or earnings from sold agricultural production. Standardized path coefficients (i.e., regression coefficients converted to standardized Z-scores) were calculated using maximum-likelihood estimation of direct, indirect, and total effects of agricultural biodiversity on each of the five diet outcomes described above (in separate models) with potential mediation by the proportion of agricultural production sold, and earnings from sold agricultural production, respectively. We used the Huber-White sandwich estimator to calculate robust standard errors for each model.

In sub-analyses, we also examined moderation of the association of agricultural biodiversity with diet outcomes by farm market orientation. We used the multiple regression models described above, but, in separate models, included additional model terms for the interaction of proportion of household production sold and earnings from sold agricultural production, respectively, with crop species richness and crop and livestock species richness. Because not all sample households grew field crops during the 2016-2017 agricultural season, we examined these dynamics in separate models from the main analyses, which retained the full sample and did not include an interaction term.

Associations were considered to be consistent with random variability at *P*>0.1.

Ethical approval

The study protocol was approved by the University of Michigan Health Sciences and Behavioral Sciences Institutional Review Board and from the Research Ethics Committee of the Instituto de Investigación Nutricional (IIN) in Lima, Peru. Comprehensive informed consent was obtained from all study participants.

RESULTS

Descriptive characteristics of sample

Data for diet diversity and quality and agricultural biodiversity were available for 600 women from 48 communities. Approximately five different food groups were consumed by women on the day prior to the survey (DDS: mean ± SD: 4.6 ± 1.6), encompassing 12 distinct species (DSR: 12.1 ± 3.8) (**Table 1**). Slightly more than half of women (55.2%) met the threshold for a minimally diverse diet, and 9.3% of women achieved a MPA > 60%. Among households that grew field crops during the 2016-2017 agricultural season (64 of 600 households did not), 2.5 ± 1.4 different species of crops were cultivated (Table 1). This value, calculated from household survey data, was lower than, but positively correlated with the value calculated from plot-level sampling of cultivated fields (3.5 ± 3.1; r = 0.29, *P*<0.01). Slightly more than two-fifths of the amount of field crops harvested (42.2%) were sold. Nearly all households raised livestock

(97.8%) (**Supplemental Table 1**), and the total number of different species of livestock and field crops raised, in aggregate, was 5.8 ± 1.5.

Associations of agricultural biodiversity with diet diversity and quality

In adjusted analyses, farm-level crop species richness of field crops was associated with a higher DDS (IRR: 1.03; $P<0.05$), and MPA (OLS β coefficient: 0.65; $P<0.1$), as well as higher odds of achieving a minimally diverse diet (MDD-W: OR (95% CI): 1.17 (1.11, 1.23)), and a diet that met a minimum threshold for micronutrient adequacy (MPA >60%: 1.21 (1.10, 1.35)) (**Table 2**). Species richness of both field crops and livestock was similarly associated with higher odds of meeting the MDD-W indicator (1.08 (1.05, 1.12)) and the minimum MPA threshold (MPA >60%: 1.16 (1.06, 1.27)) (Table 2). We observed no consistent evidence of a statistical interaction between indicators of the market orientation of farms and measures of agricultural biodiversity on associations with indicators of diet diversity and quality (**Supplemental Table 2**). In the few models where a statistically significant interaction was observed, the magnitude of the interaction was small. Similarly, we did not observe consistent evidence of mediation of the association of agricultural biodiversity with diet diversity and quality by these indicators of farm market orientation (**Supplemental Table 3**). In path analyses examining the proportion of agricultural production sold as a potential mediator of the association between crop species richness and diversity and quality, the indirect effect of proportion of agricultural production sold was negative and statistically significant in three of five models tested (i.e., models using DDS, MDD-W, and MPA as outcome variables). However, the magnitudes of the effects were modest and these same trends were not observed for other models.

Among all crop categories, cultivation of pulses and vegetables demonstrated the strongest associations with diet outcomes (**Table 3**). The rearing of specific livestock species was not consistently associated with diet diversity or quality; however, home production of animal-source foods, especially eggs, demonstrated strong associations with diet outcomes (Table 3).

Agricultural and sociodemographic differences across households with varying levels of agricultural biodiversity

Households in the lowest tercile of crop species richness (i.e., those households growing only one field crop) cultivated less agricultural land, were less likely to cultivate pulses, other vitamin A-rich fruits and vegetables, and other fruits, and sold a higher proportion of their produced field crops as compared to households in the highest tercile of crop species richness (lowest vs. highest terciles of crop species richness: 60.3% ± 38.3% vs. 31.8% ± 30.0%) (**Table 4**). Households growing only one field crop, however, had lower total production of field crops as compared to households with more diverse production (lowest vs. highest terciles of crop species richness: 3.8 ± 5.4 metric tons vs. 4.4 ± 5.1 metric tons), though had higher yields, and similar earnings from sold agricultural production (Table 4). More than three-quarters (78%) of households cultivating only a single crop grew either maize or potato. Those growing pulses, other vitamin A-rich fruits and vegetables, or other fruits sold a larger share of their production of these crops as compared to households in the highest tercile of crop species richness (Table 4). No consistent differences were observed across terciles of crop species richness in the educational level of the index woman, the wealth status of the household, ownership of livestock, household food security status, or whether the household had a non-agricultural source of income.

DISCUSSION

We examined the relationship between farm-level agricultural biodiversity and indicators of women's diet diversity and quality in diverse communities of the Peruvian central highlands. Consistent positive associations between the crop species richness of farms and both the diversity and quality of women's diets were observed. Similar to previous studies that have examined the association of agricultural biodiversity with diet diversity (7), the magnitudes of these associations using a food group diversity score and a continuous measure of the micronutrient adequacy of diets as dependent variables, respectively, were modest (i.e., a one-unit increase in crop species richness was associated with a 3% increase in DDS, and an additional 0.65 percentage points of MPA, respectively). However, the magnitudes of associations of agricultural biodiversity with dichotomous variables of women's diet diversity and quality—indicating whether diets met a minimum level of micronutrient adequacy—were stronger (i.e., a one-unit increase in crop species richness was associated with 17% higher odds of achieving the MDD-W indicator and 21% higher odds of achieving a MPA >60%). Therefore, while more diverse agricultural production was only moderately associated with more diverse and higher quality diets in absolute terms, it may have been important for achieving more adequate diets at the margin among women with less adequate diets. These findings are aligned with previous experimental research demonstrating that both direct dietary interventions as well as indirect, nutrition-sensitive interventions are more likely to yield dietary improvements among households and individuals with less adequate diets (33, 34).

We hypothesized that the magnitude of the association between agricultural biodiversity and women's diet outcomes would be diminished among households with a greater market orientation of agricultural production. Such an interaction has been observed in previous research using aggregate data from Indonesia, Kenya, Ethiopia, and Malawi (8), though not in other studies from Malawi, Benin and Ghana (10, 35, 36). Two findings from our study suggested that we might have observed such an interaction. First, the association between agricultural biodiversity and diet outcomes in this study likely operated through subsistence production (therefore selling larger shares of agricultural production would diminish the potential for diversified agriculture to directly influence diets). The lack of evidence of mediation of this association by earnings from sold production, and the modest mediating effect of proportion of agricultural production sold observed in some, but not all models, supported this assertion. In addition, cultivation of pulses was strongly positively associated with both MDD-W and MPA. Pulse production, therefore, was likely a principal driver of the overall positive association observed between farm-level agricultural biodiversity and diet outcomes. This finding lends further support to the subsistence mechanism given that among households with high crop species richness, a low proportion of pulses were sold. Second, there were important differences in the market orientation of households with differing levels of agricultural biodiversity. Households in the lowest tercile of crop species richness sold nearly double the proportion of their production vis-à-vis households in the highest tercile (60.3% vs. 31.8%).

Despite these findings, however, we did not observe a consistent interaction between farm market orientation and agricultural biodiversity on associations with women's diet diversity and quality. One possible explanation for this finding is that farm market orientation, independent of other covariates, was not strongly or consistently associated with diet outcomes. Yet, another likely reason for this finding is that households with higher levels of agricultural biodiversity earned nearly as much from sold agricultural production as households in the lowest tercile of crop species richness, in part because these households had greater overall agricultural production, especially of high-value horticultural crops. This is consistent with evidence from previous studies that farm diversification is associated with high agricultural revenues, even compared to less diversified farms (37, 38). Thus, in this context, larger shares of sold agricultural production did not necessitate a meaningful trade-off between production destined for markets and production intended for subsistence consumption. Greater overall production among diversified farms meant that non-trivial quantities of crops were able to be both kept for own consumption and sold to market. Similarly, households with lower agricultural biodiversity, while both selling a larger share of their production and earning more from crop sales as compared to households with higher agricultural biodiversity, still retained a substantial proportion of their agricultural production for own consumption (~40%).

Households in the highest tercile of crop species richness had approximately 0.5 and 1 hectares more agricultural land than households in the lowest and middle terciles of crop species richness, respectively. These households with more land were not wealthier or more highly educated in our sample, but appeared to utilize the greater land available to diversify production. Similar dynamics have been observed in some settings (10, 39), but not others (40, 41), wherein access to more land can facilitate agricultural diversification. While the socioeconomic profiles of households and individuals were not associated with farm-level agricultural biodiversity, the magnitudes of the associations of household wealth and education status of index women with diet outcomes were larger than the associations of crop species richness with these outcomes.

These findings corroborate previous evidence demonstrating the considerable independent influence of socioeconomic status on diet outcomes (14, 42-45). Similarly, the magnitudes of the associations of home production of animal-source foods, especially eggs, with women's diet outcomes were also larger than the associations of crop species richness with these outcomes. This finding is consistent with evidence that these animal-source foods provide a rich source of bioavailable micronutrients that contributes strongly to nutrient adequacy (46, 47).

This study had several limitations. First, because the data were collected using an observational design, our ability to draw a causal inference from the observed associations is limited. Second, the recall period for our outcome variables (i.e., the previous 24-hours) and that of our exposure variable (i.e., the previous agricultural season) did not fully align. This could have led to underestimates of the association between agricultural biodiversity and diet outcomes. We purposefully planned data collection to coincide with the peak of the harvest season in the study region to ensure that agricultural production was available to households both for direct consumption, and as a source of income that might indirectly influence diets through food purchases. However, not all crops were harvested simultaneously, and given that the survey implementation spanned eight weeks, the timing of data collection varied modestly across households within the sample. For garden crops in particular, which may be harvested multiple times throughout the year, such misalignment of recall period may have attenuated estimates of association. Finally, we were able to carry out repeat 24-hour recalls among only a subset of women (n=100), which may have limited our ability to accurately calculate intra-individual variance of nutrient intakes. Nonetheless, the approach we adopted for modeling probability of adequacy of intakes has been shown to be valid for assessing the relationship between diet diversity and the micronutrient adequacy of diets (26). Furthermore, the diet outcomes described pertain only to adult women, thus limiting the comparability of these results to previous studies that have examined household-level diet outcomes (7).

In conclusion, consistent with previous research from sub-Saharan Africa, we found that farm-level agricultural biodiversity was associated with moderately more diverse and more micronutrient-adequate diets among women in the Peruvian Andes. This association was not strongly mediated by earnings from agricultural production, thus indicating that in this context, agricultural biodiversity likely contributes to women's diets through consumption of home-produced food crops. Nonetheless, our findings support previous evidence suggesting that agricultural diversification is consistent with market-oriented production (7). Households in our study with highly diverse farms were considerably market oriented and farm market orientation did not consistently moderate the association of agricultural biodiversity with diet outcomes. In practice, risk-averse smallholder farmers often diversify into commercial crops with the aim of diffusing risk, while maintaining subsistence production of key safety net food crops (48). Indeed, diversification may offer new opportunities for market engagement (14), and the decision to diversify production may be directly in response not only to production risks such as climate change (49), but also to market signals (35). Longitudinal research is needed that prospectively models the extent and pathways through which changes in farm crop portfolios influence diets at individual- and regional-levels. Insights from such studies are needed to inform policies that strengthen the ability of smallholder farmers to align their production with market demand, while providing incentives for diverse regional food systems that allow vulnerable households to meet their needs for diverse and healthy diets.

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ADJ, HCK, KSZ and SdH conceived and designed the study. GCG and MC further contributed to the study design. HCK coordinated the overall implementation of the research. ADJ, HCK, KSZ and SdH designed the analysis plan for the study. MC, KM, FPA, MM, and LG facilitated implementation of the data collection, and contributed to data quality assurance, cleaning and analyses. MT supervised agricultural data collection, coordinated efforts across data collection teams, and carried out data quality assurance. ADJ led the statistical analysis and wrote the first draft of the manuscript. All authors contributed to the writing and revision of the manuscript, and read and approved the final manuscript. The authors have no conflicts of interest to declare.

Table 1. Dietary, agricultural, and sociodemographic characteristics of the household survey sample.

	Entire sample	
	n	mean ± SDs (ranges) or percentages
Dietary characteristics		
Dietary Diversity Score (DDS)	600	4.6 ± 1.6 (1-9)
Minimum Dietary Diversity for Women (MDD-W), %		
Yes	331	55.2
No	269	44.8
Dietary Species Richness (DSR)	600	12.1 ± 3.8 (3-27)
Mean Probability of Adequacy (MPA)	600	37.2 ± 16.2 (0.01-91.1)
Mean Probability of Adequacy > 60%, %		
Yes	56	9.3
No	544	90.7
Agricultural biodiversity and production characteristics		
Crop species richness (field crops)	536	2.5 ± 1.4 (1-10)
Crop species richness (garden crops)	503	7.2 ± 4.6 (1-26)
Crop and livestock species richness (field crops)	536	6.1 ± 2.2 (1-16)
Crop and livestock species richness (garden crops)	503	10.8 ± 5.0 (2-29)
Household agricultural land area, hectares	536	1.7 ± 3.8 (0.01-48)
Agricultural production (field crops), metric tons	533	3.9 ± 5.3 (0-46.5)
Agricultural yields (field crops), metric tons per hectare	533	4.2 ± 5.7 (0-62.3)
Proportion of agricultural production sold (field crops)	536	42.2 ± 36.0 (0-100)
Earnings from sold agricultural production (field crops), hundreds of $US	533	6.1 ± 10.2 (0-76)
Sociodemographic characteristics		
Household size	600	4.9 ± 1.8 (1-14)
Highest attained education level of index woman, %		
No education	81	13.5
Incomplete primary	246	41.0
Complete primary	103	17.2
Incomplete secondary	76	12.7
Complete secondary or post-secondary	94	15.7
Household wealth quintiles, %		
Lowest	111	18.6
Low	128	21.4

Middle	114	19.1
High	125	20.9
Highest	120	20.1
Non-agricultural source of household income, %		
Yes	236	39.3
No	364	60.7
Household food security status, %		
Food secure	84	14.1
Mildly food insecure	384	64.2
Moderately food insecure	110	18.4
Severely food insecure	20	3.3

[1]Values are means ± SDs (ranges) or percentages; [2]The sample is equally distributed across the three study regions (n = 200 per region): 1) Huánuco-Quisqui (altitude in meters above sea level (masl): mean (range): 2,637 (1,840-3,885); 2) Amarilis (2,524 (1,852-3,373); and 3) Molino-Umari (2,790 (2,371-3,475). Sample sizes for crop species richness are shown only for those households that cultivated field crops and garden crops, respectively, in the 2016-2017 agricultural season. Sample size for household agricultural land area is shown only for those households that cultivated field crops in the 2016-2017 agricultural season. In total, 64 and 97 households did not cultivate field and garden crops, respectively, in the 2016-2017 agricultural season. [3]Minimum Dietary Diversity for Women was achieved if the respondent consumed foods from 5 or more of the following food groups in the day preceding the interview: 1) grains, white roots and tubers, and plantains; 2) pulses (beans, peas and lentils); 3) nuts and seeds; 4) dairy; 5) meat, poultry and fish; 6) eggs; 7) dark green leafy vegetables; 8) other vitamin A-rich fruits and vegetables; 9) other vegetables; and 10) other fruits. Diet Diversity Score is a simple count of these different food groups consumed. Dietary Species Richness is a count of the number of different plant and animal species consumed (considering only foods from those 10 food groups used to define the Minimum Dietary Diversity for Women indicator). Mean Probability of Adequacy is the mean of the probabilities of adequacy of nine micronutrients including thiamin, riboflavin, niacin, folate, vitamin C, vitamin A, calcium, iron, and zinc. Probabilities of adequacy were calculated from the best linear unbiased predictor of each respondent's usual intake of the nutrient.

Table 2. Results of multiple regression analyses of the associations of measures of agricultural biodiversity with indicators of diet diversity and quality (n=595).

	Dietary Diversity Score		Minimum Dietary Diversity for Women		Dietary Species Richness		Mean Probability of Adequacy		Mean Probability of Adequacy >60%	
	IRR		OR		IRR		Coefficient		OR	
Model	1	2	1	2	1	2	1	2	1	2
Crop species richness	1.03**	.	1.17***	-	1.02	-	0.65*	-	1.21***	-
Crop and livestock species richness	-	1.01*	-	1.08***	-	1.01	-	0.54*	-	1.16***
Household size	1.00	0.99	0.99	0.99	1.01	1.01	-0.20	-0.21	0.93	0.92
Sex of head of household										
Male (reference)	-	-	-	-	-	-	-	-	-	-
Female	1.04	1.04	1.29	1.32	1.03	1.04	2.43**	2.45**	0.96	1.00
Age of woman, y	0.99***	0.99***	0.97***	0.97***	0.99	0.99	-0.12	-0.11	0.97*	0.98*
Pregnancy status of woman										
No (reference)	-	-	-	-	-	-	-	-	-	-
Yes	0.95	0.95	0.72	0.73	1.01	1.01	6.04	6.20	2.45	2.54
Marital status of woman										
Single (reference)	-	-	-	-	-	-	-	-	-	-
Married	1.07	1.07	1.18	1.23	1.03	1.04	2.22	2.16	1.61	1.66
Unmarried, cohabiting	1.09*	1.10	1.32	1.39	1.05	1.06	1.53	1.49	0.96	0.99
Separated, divorced or widowed	1.10***	1.11***	1.60	1.65	1.00	1.01	1.52	1.31	0.22*	0.21*
Education level of woman										
No education (reference)	-	-	-	-	-	-	-	-	-	-
Incomplete primary	1.07**	1.07**	1.28	1.28	1.05**	1.05**	2.09	2.12	1.71	1.75
Complete primary	1.12**	1.13**	1.61	1.64	1.07	1.07*	3.43**	3.43***	2.31	2.43
Incomplete secondary	1.13***	1.13***	1.60	1.61*	1.04	1.04	4.44**	4.47**	3.91***	4.05***
Complete secondary or post-secondary	1.10*	1.10**	1.15	1.17	1.06	1.06	0.60	0.66	1.34	1.41
Household wealth quintiles, %										
Lowest (reference)	-	-	-	-	-	-	-	-	-	-
Low	1.04	1.04	1.36	1.36	1.02***	1.02***	0.31	0.43	0.46***	0.47***
Middle	1.09***	1.09***	1.92***	1.90***	1.05*	1.04	1.06	1.15	0.91	0.93
High	1.13***	1.14***	2.05***	2.07***	1.10***	1.11***	1.35	1.50	0.65	0.67
Highest	1.17*	1.17*	3.43***	3.38***	1.15***	1.15***	4.54**	4.78**	1.36	1.38
Household food security status										
Food secure (reference)	-	-	-	-	-	-	-	-	-	-
Mildly food insecure	1.01	1.01	0.88	0.88	0.99	0.99	-1.30	-1.26	1.18	1.17

Moderately food insecure	0.97	0.97*	0.76	0.76	0.93**	0.93***	-5.09***	-5.03***	0.76	0.75
Severely food insecure	0.94***	0.93***	0.69*	0.69*	0.91	0.91	-6.57	-6.71	0.68	0.66
Agricultural land area, ha	0.99**	0.99**	0.94	0.94	0.99	0.99	0.00	0.03	0.96	0.96
Livestock units	1.00	-	0.99	-	0.99*	-	0.53	-	1.08***	-
Non-agricultural source of household income										
No (reference)	-	-	-	-	-	-	-	-	-	-
Yes	1.04	1.04	1.09	1.11	0.99	0.99	0.35	0.35	0.70	0.71
Cultivation of garden										
No (reference)	-	-	-	-	-	-	-	-	-	-
Yes	1.02	1.01	1.29	1.21	1.09***	1.08***	0.48	0.26	1.19	1.08
Study region										
Huánuco-Quisqui (reference)	-	-	-	-	-	-	-	-	-	-
Amarilis	0.84***	0.84***	0.31***	0.31***	0.89***	0.89***	-6.63***	-6.57***	0.79***	0.78***
Molino-Umari	0.90***	0.91***	0.51***	0.53***	0.88***	0.89***	2.22**	2.22**	1.04	1.05

[1]Values for models with Dietary Diversity Score and Dietary Species Richness as dependent variables are incidence-rate ratios (IRR) from Poisson regressions adjusting for the covariates shown in the table; values for models with Minimum Dietary Diversity for Women and Mean Probability of Adequacy >60% as the dependent variables are odds ratios (OR) from multiple logistic regression models adjusting for the covariates shown in the table; values for models with Mean Probability of Adequacy as the dependent variable are from ordinary least squares regression models adjusting for the covariates shown in the table; variance estimates for all models were obtained using the robust estimator of variance, adjusting SE and variance-covariance matrices of the estimators for within-study region correlations; [2]Model “1” for each dependent variable includes “crop species richness” as the primary independent variable. Model “2” for each dependent variable includes “crop and livestock species richness” as the primary independent variable; [3]Two households were missing data for household food security, two households were missing data for the wealth index, and one household was missing data for the pregnancy status of the index woman; [4]*P*-values indicate the statistical significance of the point estimates shown; $^{*}P<0.1$, $^{**}P<0.05$, $^{***}P<0.01$.

Table 3. Results of multiple regression analyses of the associations of production of specific groupings of crops and livestock with indicators of diet diversity and quality (n=595).

	Dietary Diversity Score	Minimum Dietary Diversity for Women	Dietary Species Richness	Mean Probability of Adequacy	Mean Probability of Adequacy >60%
	IRR (95% CI)	OR (95% CI)	IRR (95% CI)	Coefficient (95% CI)	OR (95% CI)
Any household production of…					
Grains, white roots and tubers, and plantains	0.96 (0.88, 1.06)	0.89 (0.39, 2.02)	1.00 (0.93, 1.08)	-0.23 (-11.8, 11.3)	0.75 (0.33, 1.75)
Pulses (beans, peas and lentils)	1.04 (0.97, 1.11)	1.17** (1.03, 1.33)	1.03 (0.95, 1.13)	1.08** (0.24, 1.92)	1.10 (0.83, 1.45)
Dark green leafy vegetables	1.14*** (1.05, 1.23)	1.97 (0.41, 9.36)	1.28*** (1.12, 1.46)	9.8*** (6.9, 12.8)	-
Other vitamin A-rich fruits and vegetables	0.99 (0.96, 1.03)	1.09 (0.92, 1.28)	0.97 (0.88, 1.06)	2.09 (-1.05, 5.24)	1.66*** (1.17, 2.36)
Other vegetables	1.11*** (1.03, 1.19)	1.35*** (1.25, 1.45)	1.09*** (1.06, 1.12)	-1.19 (-7.40, 5.01)	1.33 (0.77, 2.31)
Other fruits	1.01 (0.93, 1.10)	1.22 (0.69, 2.16)	1.03 (0.94, 1.14)	0.89 (-7.97, 9.74)	0.75 (0.37, 1.51)
Any household rearing of…					
Cattle	0.98 (0.90, 1.06)	0.99 (0.62, 1.57)	0.97 (0.93, 1.01)	1.10 (-6.82, 9.01)	1.45 (0.70, 3.00)
Goats	1.06 (0.99, 1.13)	1.50 (0.67, 3.37)	1.04*** (1.02, 1.07)	-0.46 (-20.1, 19.2)	0.86 (0.18, 4.07)
Sheep	1.01 (0.93, 1.09)	0.95 (0.79, 1.14)	1.04 (0.98, 1.11)	0.25 (-5.44, 5.94)	0.81 (0.62, 1.07)
Poultry	0.97* (0.94, 1.00)	0.94 (0.62, 1.42)	1.00 (0.98, 1.02)	1.06 (-14.5, 16.6)	2.96 (0.25, 35.2)
Any household production of…					
Milk	1.08* (1.05, 1.10)	1.96** (1.15, 3.33)	1.06** (1.01, 1.10)	1.88 (-3.59, 7.35)	1.39 (0.55, 3.50)
Cheese	1.05 (0.91, 1.21)	2.10 (0.74, 5.97)	1.03 (0.91, 1.18)	5.15** (1.47, 8.83)	2.88*** (1.72, 4.83)
Eggs	1.21*** (1.14, 1.28)	2.90*** (1.97, 4.25)	1.07*** (1.02, 1.12)	3.41*** (2.57, 4.26)	1.52*** (1.30, 1.77)

[1]Values for models with Dietary Diversity Score and Dietary Species Richness as dependent variables are incidence-rate ratios (IRR) from Poisson regressions adjusting for the covariates shown in Table 2; values for models with Minimum Dietary Diversity for Women and Mean Probability of Adequacy >60% as the dependent variables are odds ratios

(OR) from multiple logistic regression models adjusting for the covariates shown in Table 2; values for models with Mean Probability of Adequacy as the dependent variable are from ordinary least squares regression models adjusting for the covariates shown in Table 2; variance estimates for all models were obtained using the robust estimator of variance, adjusting SE and variance-covariance matrices of the estimators for within-study region correlations; independent variables are dichotomous variables indicating whether or not one or more field crops from the crop category was cultivated by the household in the agricultural season preceding the survey, and whether or not the category of livestock was currently reared by the household, respectively; crop categories are based on the food group definitions of the Minimum Dietary Diversity for Women indicator; [2]Given the small number of households that cultivated dark green leafy vegetables as field crops (n=4), this variable was perfectly associated with achievement of the >60% Mean Probability of Adequacy threshold; therefore, no ORs were calculated for these models; [3]Two households were missing data for household food security, two households were missing data for the wealth index, and one household was missing data for the pregnancy status of the index woman; [4]P-values indicate the statistical significance of the point estimates shown; *$P<0.1$, **$P<0.05$, ***$P<0.01$.

Table 4. Comparisons of sociodemographic, agricultural, and agricultural biodiversity characteristics of households, by terciles of crop species richness.

	Terciles of crop species richness			
	1	2	3	
	% or mean ± SD	% or mean ± SD	% or mean ± SD	F or X^2 value
Sample size (n)	159	130	247	
Sociodemographic characteristics				
Household size	4.8 ± 1.8	4.9 ± 1.7	5.0 ± 1.9	0.91
Female head of household, %	15.1	12.3	17.8	2.0
Highest attained education level of index woman, %				9.5
No education	8.8	14.6	16.6	
Incomplete primary	45.9	38.5	42.1	
Complete primary	17.6	16.9	19.0	
Incomplete secondary	14.5	12.3	11.7	
Complete secondary or post-secondary	13.2	17.7	10.5	
Household wealth quintiles, %				15.4*
Lowest	19.8	15.4	20.2	
Low	23.6	20.8	22.3	
Middle	21.7	22.3	16.6	
High	14.0	21.5	27.5	
Highest	21.0	20.0	13.4	
Household food security status, %				8.5
Food secure	10.1	17.7	13.5	
Mildly food insecure	62.9	63.9	64.9	
Moderately food insecure	24.5	13.9	18.4	
Severely food insecure	2.5	4.6	3.3	
Study region, %				13.8***
Huánuco-Quisqui	37.1	26.2	29.6	
Amarilis	27.0	46.2	32.4	
Molino-Umari	35.9	27.7	38.1	
Agricultural and agricultural biodiversity characteristics				
Crop Species Richness (field crops)	1 ± 0	2 ± 0	3.7 ± 1.1	711***
Crop Species Richness (garden crops)	4.9 ± 4.5	5.6 ± 4.8	6.4 ± 5.3	4.4**
Crop and Livestock Species Richness (field crops)	4.4 ± 1.5	5.5 ± 1.4	7.6 ± 1.9	185***
Crop and Livestock Species Richness (garden crops)	8.3 ± 5.0	9.1 ± 5.2	10.2 ± 5.8	6.7***
Household agricultural land area, hectares	1.7 ± 4.3	1.1 ± 1.1	2.1 ± 4.4	3.3**
Any household production of…, %				

Grains, white roots and tubers, and plantains	76.7	86.2	89.9	13.3***
Pulses (beans, peas and lentils)	6.9	40.8	71.7	165***
Dark green leafy vegetables	0	0.77	1.2	1.9
Other vitamin A-rich fruits and vegetables	3.1	18.5	64.0	178***
Other vegetables	10.7	12.3	18.2	5.1*
Other fruits	2.5	5.4	12.2	13.9***
Livestock units	1.3 ± 1.3	1.4 ± 1.3	1.7 ± 1.7	3.7**
Any household rearing of…, %				
Cattle	25.2	31.5	31.6	2.2
Goats	3.1	3.1	5.7	2.1
Sheep	47.2	50.0	57.9	5.0*
Poultry	84.3	90.0	90.3	3.8
Any household production of…, %				
Milk	13.2	12.3	18.2	3.1
Cheese	6.3	9.2	13.0	4.9*
Eggs	35.9	28.5	41.3	6.1**
Agricultural production (field crops), metric tons	3.8 ± 5.4	3.1 ± 5.6	4.4 ± 5.1	2.7*
Agricultural yields (field crops), metric tons per hectare	5.2 ± 7.8	3.5 ± 5.1	3.9 ± 4.2	4.1**
Proportion of agricultural production sold (field crops)	60.3 ± 38.3	39.6 ± 35.0	31.8 ± 30.0	34.6***
Earnings from sold agricultural production (field crops), hundreds of $US	6.9 ± 10.9	4.4 ± 7.9	6.5 ± 10.8	2.4*
Harvested production of… (field crops), metric tons				
Grains, white roots and tubers, and plantains	3.3 ± 5.4	2.4 ± 5.4	2.8 ± 4.7	1.2
Pulses (beans, peas and lentils)	0.11 ± 0.74	0.12 ± 0.32	0.23 ± 0.44	3.0**
Dark green leafy vegetables	0	0.002 ± 0.03	0.02 ± 0.15	1.4
Other vitamin A-rich fruits and vegetables	0.17 ± 1.4	0.21 ± 0.73	0.71 ± 1.4	11.0***
Other vegetables	0.15 ± 0.84	0.24 ± 1.5	0.48 ± 1.7	2.6*
Other fruits	0.02 ± 0.19	0.02 ± 0.14	0.09 ± 0.49	2.2
Proportion of production of…sold (field crops), %				
Grains, white roots and tubers, and plantains	53.8	25.2	20.4	49.0***
Pulses (beans, peas and lentils)	67.2	36.6	19.5	13.3***
Dark green leafy vegetables	0	100	66.7	0.25
Other vitamin A-rich fruits and vegetables	74.8	55	27.3	7.8***
Other vegetables	88.7	96.6	83.8	1.2
Other fruits	100	55	42.3	3.4**
Earning from sold production of… (field crops), %				
Grains, white roots and tubers, and plantains	5.1 ± 9.9	2.7 ± 6.3	3.3 ± 8.0	3.5**
Pulses (beans, peas and lentils)	0.51 ± 4.0	0.51 ± 2.0	0.73 ± 4.2	0.23
Dark green leafy vegetables	0 ±	0.003 ± 0.03	0.04 ± 0.51	0.83
Other vitamin A-rich fruits and vegetables	0.37 ± 2.8	0.73 ± 3.4	0.95 ± 4.2	1.2
Other vegetables	0.60 ± 3.5	0.34 ± 1.8	1.0 ± 3.7	1.9

Other fruits	0.29 ± 2.5	0.07 ± 0.68	0.36 ± 2.5	0.78
Non-agricultural source of household income, %	32.7	40.0	35.2	1.7

[1]Values are proportions or means ± SD of each characteristic among households within the given tercile of crop species richness; terciles of crop species richness are based on diversity of field crops only; [2]Households that cultivated no field crops in the agricultural season preceding the survey were excluded; sample size varies for the variables under the heading "Proportion of…production sold (field crops), %" as not all households cultivated the crop categories shown; [3]*P*-values indicate the statistical significance of F-statistics testing differences in means across terciles of crop species richness or of Pearson's chi-squared test statistic testing differences in proportions across terciles of crop species richness; *$P<0.1$, **$P<0.05$, ***$P<0.01$.