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Determinants of household dietary diversity in rural Ethiopia: A household panel study

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ABSTRACT

Background: Diet diversification ensures nutritional security and hence helps in meeting nutrient requirements in humans. Despite its importance, diet diversification remains a challenge, especially in rural communities in developing countries. This study aimed to identify the determinants of DD in rural Ethiopia.

Methods: In this study, we used an agricultural and nutrition household panel data. This study collected data from 1200 households twice a year for two years in nine districts. The household dietary diversity score (HDDS) was used as the outcome measure. Several potential demographic, social, economic, and geographic determinants of HDDS were assessed. Mixed effects truncated Poisson regression was used to identify which of these determinants were associated with HDDS at household level.

Result: The HDDS value ranged from 1 to 10 with a mean of 5.52 and standard deviation (SD) of 1.54. A unit increment in the variety of crop production gave a 3.4% [95% CI: 1.9%, 4.9%,] increase in relative change (RC) of HDDS. A birr increases in income generated from livestock products resulted in a 2.6% [1.5%, 3.7%] increase in RC of HDDS. The post-harvesting season contributed to a 6.4% [3.6%, 9.3%] increase in RC of HDDS compared to the pre-harvesting. Households headed by a woman had an HDDS that was −7.9% [-12.5%, −3.3%] lower in RC of HDDS than male-lead households. An additional year of education of the household head resulted in a 1.2% [0.7%, 1.7%] increase in RC of HDDS. As the mean women's decision-making score increased by one point, the RC in HDDS increased by 3.8% [1.1%, 6.4%]. No significant association was found between the time taken to reach local markets and HDDS.

Conclusion: This study identified economic, educational, social, and seasonal factors associated with HDDS, which should be considered when planning interventions aimed at improving HDDS in rural Ethiopia or elsewhere.

1. Introduction

Dietary diversity (DD) is recognized as an important aspect of nutrition. Human nutrient requirements and nutritional security are ensured through diet diversification [1]. Insufficient DD is an immediate cause of poor nutritional status [2]. Diet diversification is vital in fighting the triple burden of malnutrition-undernourishment (lack of calories and proteins), micronutrient deficiencies, and excessive energy intake (that gets manifested as overweight and obesity) [3].

DD can be considered at an individual level or household level [4]. The individual dietary diversity score is used to assess the nutritional quality of an individual's diet whereas the Household Dietary Diversity Score (HDDS) assesses the ability of a household to access a variety of foods [5–7] and is an important indicator of food security [8]. A count of different food groups, usually from a list of between 10 and 12 food groups [9–12], is used to measure the DD of the household [7,13].

One of the targets of the United Nations' Sustainable Development Goals is to end all forms of malnutrition and provide access to safe, nutritious, and sufficient food for all people, all year round by 2030 [14,15]. However, Africa is not on track to meet this target [16]. Existing

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studies show that Household Dietary Diversity (HDD) is insufficient in several lower and middle-income countries (LMICs) which poses a challenge, especially for rural communities in developing countries as their usual diets mainly consisted of starchy staples with inadequate animal products, fresh fruits, and vegetables [9,17,18]. More studies have discovered that lack of HDD is one of the severe problems among poor populations in resource-limited countries [9,19–21]. A recent study from India also found that the majority of the households in the Uttar Pradesh State had low diet diversity scores and that foods from animal sources were rarely included in their diets [22]. HDD has similarly been found to be low in Ethiopia, especially among rural residents [12,18]. Other studies have used DD in individuals and households as a key indicator for the surveillance of actions that aimed to tackle various nutritional problems and food insecurity [23–28]. Thus, improving HDD, remains an important public health priority and there is a need to understand the determinants of HDD.

There is a large body of literature focusing on population-level determinants of DD. Studies focusing on various regions of the world have found that economic factors, educational factors, availability of agricultural technologies, and, availability of markets are associated with varying DD [5,6,25,28,29]. Studies conducted in African, Asian, and Caribbean countries have revealed that the determinants of HDDS were, among others, the diversity of on-farm production [25–28], the access to markets [26,29–31], the education level of the head of the household [17], working on homestead gardening [31], the degree of involvement of women in decision making within their household [32–34] and seasonal effects [35,36]. A recent study conducted in Bangladesh discovered that farm production diversity, total land size owned by the household, proximity to the district market, and improved irrigation processes were positively associated with HDDS [37]. Another study conducted in South Africa concluded that higher attainment of formal education by the head of the household, a higher income, a smaller household size, and a higher age of the head of household were positively associated with HDDS [38]. A recent panel study conducted by the World Bank in Ethiopia and Tanzania, reported that households closer to markets spent more money and also consumed more diverse diets than those further away from the market [39]. A further recent study in Ethiopia concluded that having a male head of household, the possession of a bank account, and livestock were positively associated with a higher HDDS, but not distance to the marketplace [40].

From studies conducted so far, one of the potential determinants of HDDS that has been less studied is women's empowerment. Women's empowerment is a complex concept for which several definitions exist. The World Bank defines empowerment as "the process of enhancing an individual's or group's capacity to make purposive choices and to transform those choices into desired actions and outcomes" [34]. One aspect of women's empowerment is their empowerment in agriculture. Decision-making in agriculture is an important component of women's empowerment in agriculture, in particular in developing countries [41], and can be measured using the Women's Empowerment in Agriculture Index (WEAI) [42]. Existing studies indicate that women's decision-making can be an important determinant for household DD in general and specifically for the DD of women and children in the household [36].

Against this background, the current study aimed to explore the determinants of DD in two large regions of Ethiopia, namely, Oromia, and the Southern Nations, Nationalities, and Peoples (SNNP). In the current study, the following potential determinants were investigated: the varieties of crops produced by the household, the income obtained from animal products, the time taken to reach the closest local markets, the season, the gender and education level of the head of the household, the family size of the household and the women's decision-making role in the agriculture of the household.

2. Materials and methods

2.1. Study design and ethical considerations

The data used for this study is from the Agriculture-Nutrition (Ag-Nutrition) household panel study which was conducted by governmental and non-governmental institutions working in Ethiopia [43,44]. The study design was based on nine districts (woredas) that were randomly selected in two large regions of Ethiopia. Two kebeles, the lowest governmental administration unit, from each district, were again selected randomly: in one kebele, the Empowering New Generation by Improving Nutrition and Economic Opportunity (ENGINE's) "nutrition-specific" intervention was implemented and in others, the "nutrition-sensitive" intervention was implemented in addition to the "nutrition-specific". Sixty households per kebele were randomly sampled. The full data set is comprised of 1200 households per round, with a total of 4800 households for the four rounds. Data collection was repeated twice a year for two years, in 2014 and 2015, twice before and twice after harvesting [43]. Three types of questionnaires were used to collect the data: the Adult Female Questionnaire was mainly concerned with food preparation; the Adult Male Questionnaire was about food production and included many other questions relating to household data; and the Mother Questionnaire focused on caregiving for children under 5 years old in the household. The data in the current study originated from the data collected by the three types of tools described above and covers all four rounds organized by Tufts University.

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the Federal Ministry of Science and Technology of Ethiopia. Written informed consent was also obtained from all subjects.

2.2. Outcome variable

Household dietary diversity score: HDDS is the count of the different food groups consumed by any of the household members during the 7 days before the survey was conducted. The food groups used in the construction of the HDDS were based on guidelines from the Food and Agriculture Organization (FAO) [5,24,45]. Ten food groups were used to calculate HDDS: foods made from grains; foods made from roots or tubers; legumes, nuts, and pulses; vegetables; fruits; meat, fish or eggs; dairy products; sugar or honey; oil, fat, or butter; and any other miscellaneous food types.

In the questionnaire, the response for each of the ten food groups was either 'yes' or 'no'. We summed up all the responses to produce the HDDS for each surveyed household on each of the four occasions, with a total of 4800 scores. One hundred and sixty out of 4800 scores were 0. A zero score is unrealistic because 7 days were used as the reference time and 7 days of starving is de facto not possible. We investigated the full data of these 160 zero-HDDS further by cross-checking whether this zero score was consistent with other relevant answers in the questionnaire. Two questions should not contradict one another and we cross-checked the responses to these questions for those households whose HDDS was '0'. The two questions were: Question 1: "In the past 7 days, did you or anyone in your household eat (food group)?", where the possible answer was yes or no; and question 2: "In the past 7 days, how many total days did you or anyone in your household consume (food group)?", with a list of the ten food groups. Among the 160 cases with HDDS = 0, there were some inconsistencies, namely, the answer to question 1 was zero while the answer to question 2 was different from zero. When we found such an inconsistency, we interpreted the lack of eating in the last 7 days as an error and we changed the response to 1 which represents a 'yes' response. After correction, 70 HDDS scores that were previously zero were changed to non-zero responses ranging between 1 and 10. The remaining 90 of the 160 households whose HDDS was zero could not be corrected as they were missing a response to the second question. These

90 measurements were considered missing and were not considered in the regression analysis.

2.3. Potential determinants

Variety of Crop Production: The unweighted count of food crop species produced by the household during the most recent seasons was used as the measure of crop production variety. The count could take values between 0 and 25.

Women's decision-making in agriculture: The women's power in decision-making in the field of agriculture was measured using 11 questions, each with a Likert scale of responses varying from 1 to 4: 1 = 'Not at all', 2 = 'Small extent', 3 = 'Medium extent' and 4 = 'To a high extent'. The questions have been validated and used before [40]. These 11 questions were not asked to women who affirmed that they were solely responsible for all decisions regarding agriculture in their household, and their answers were manually set to level "4" for all 11 questions. We did this 8165 times out of 226932. Furthermore, there were additional missing values to some of the 11 questions. Of the 4710 households included in the study, 7 households did not answer all these questions and were excluded from our analysis, leaving 4703 households to be considered. To obtain a score of women's decision-making in agriculture comparable across women, for every woman, we summed the available answers in the 11 questions and divided them by the number of questions answered, thus obtaining the average score per woman. This women's decision-making score was used as one of the potential determinants.

Income from livestock production: The total value in birr generated from livestock products in the 30 days before the survey, which took values between 0 and 6400 Birr.

Harvesting season: This indicates if the time point of the interview was before the harvesting time (taking value 0) or post-harvesting time taking the value 1.

Year of education for the head of the household: This was the total years of education for the head of the household and was between 0 and 15.

The time taken to walk to the closest local market: This took values between 0 and 55 min.

The gender of the household head (male = 0, female = 1), and the number of household members were also potential determinants included in the current study.

2.4. Data analysis

The outcome variable HDSS counts the number of different types of food groups used in the previous week by each household. From classical statistical theory, counts are conventionally modeled by a Poisson variable. Since all households ate from at least one food group, the counts are left-truncated at the value 1. Similarly, the distribution was right truncated at 10, as we only have ten groups of food [41]. The sampling scheme constitutes a clustered structure formed by households within kebeles and kebeles within districts, called woredas. Furthermore, the four repeated measurements over time represent a temporal cluster structure. These are all considered random effects, as they are not of interest by themselves but do induce correlation structures. The temporal effects are crossed with the kebeles. The association between the covariates and HDDS was hence modeled by mixed effects doubly truncated Poisson regression model that fits these assumptions appropriately. The model was estimated using the glmmTMB package [46]. For stable computation and ease of comparison in the regression, all numerical variables were standardized by subtracting their means and dividing by their standard deviations.

Omitting reference to household, kebele, woreda, and timepoint, the mean of the HDDS on the log scale, can be written as

$$\log(\mathrm{HDDS}) = \beta_0 + \beta_1 \mathrm{crp} + \beta_2 \mathrm{livestockp} + \beta_3 \mathrm{harvest} + \beta_4 \mathrm{hsex} + \beta_5 \mathrm{headeduc} + \beta_6 \mathrm{meanemp} + \beta_7 \mathrm{locnor} \quad (1)$$

where β_0 is the intercept of the model, and β_1, β_2, β_3, etc. are the coefficients for the predictors. In this formula, we abbreviated the crop production diversity as crp, the income generated from animal products as livestockp, the pre or post-harvesting seasons as harvest , the gender of the head of the household as hsex, the years of education of the head of the household as headeduc, the mean score of the women's decision-making as meanemp, and the time taken in minutes to the local market as locnor.

The relative change in HDDS in the model (1), corresponding to a change in a given covariate from its minimum x_{min} to its maximum x_{max} and keeping other variables fixed, is calculated as $\exp(\beta^*(X_{max}\text{-}X_{min}))$-1.

The goodness of fit of the model was assessed by analyzing the residuals and by studying the upper truncation above HDDS 11 in the Poisson model. see supplementary section S1.

Multicollinearity among covariates was assessed by the variance inflation factor (VIF). Multicollinearity can lead to incorrect results in regression analyses. The VIF quantifies how much the variance is inflated in regression due to collinearity among the predictors. The VIF for the estimated regression coefficient β_j, denoted by VIF_j is the factor by which the variance of β_j is inflated because of the correlation between the predictor variables in the model formally is:

$$\mathrm{VIF}_j = \frac{1}{\left(1 - R_j^2\right)} \quad (2)$$

where R_j^2 is the R^2-value obtained by regressing the jth predictor on the remaining predictors. Values above 5 indicate collinearity and the results cannot be interpreted [47]. In our model, all VIF_j values are well below 5, see Table 4 in the supplementary section S_1.

3. Results

3.1. Descriptive characteristics of the study participants

From the total of 4800 households included in the four rounds of the study conducted in two years period, 4703 households were considered for the current study. The value of the HDDS ranged from 1 to 10 with a mean of 5.52 ± SD 1.54. The median variety of crops produced by the households was 2, which ranged from the non-producers, 0, to the maximum producers of 25 crop varieties. The income generated from the livestock products in one month before the surveys was also considered and about 55% of the households included in this study did not generate income from livestock products. The maximum amount of money in birr generated from livestock products in the month before the survey was 6160. The maximum time taken to local markets was 55 min and the majority of the households accessed the local markets approximately in zero minutes. The ratio of female to male-headed households was about 1 in 12 households. The mean size of household members was 5.51 ± 2.07 SD, with a range of 1–13 members. The timing of study was done during two harvesting times and approximately an equal number of the household were covered during the pre- and post-harvesting seasons (49.70% and 50.30% respectively). More than half of the heads of the households (53.33%) did not attend formal education, 43.07% had attended elementary school, and 3.06% had education beyond elementary schooling. (Table 1). See also Fig. 1 and Table 3, both included in the supplementary section S_1.

3.2. Determinants of HDDS by mixed effects truncated Poisson regression model

The factors associated with HDDS were modeled using mixed-effects

Table 1
Descriptive statistics of variables in the agriculture nutrition household panel study in rural Ethiopia, used in this study.

Variable	Number of answers	Mean (SD)/Percentage	Median	Minimum	Maximum
Household Dietary Diversity Score (HDDS)	4703	5.52 (1.54)	6	1	10
Crop production diversity	4703	3.20 (3.11)	2.00	0	25
Income from livestock products in Birr	4703	83.56 (3.11)	0	0	6160
Time to a local market in minutes	4703	10.98 (14.82)	0	0	55
Women's decision-making score	4703	2.95 (0.59)	3.00	1	4
Education of household head in years of schooling	4703	2.17	0	0	15
Number of household members	4703	5.51 (2.07)	5	1	13
Pre-harvest interviews	2338	49.70%			
Post-harvest interviews	2365	50.30%			
Education level of the head of the household	4662				
No Education	2486	53.33%			
Elementary Education	2008	43.07%			
Above Elementary Education |	168	3.60%			
Gender of the head of the household:	4672				
Male	4159	89.02%			
Female	513	10.98%			

double truncated Poisson regression in which the household, the kebele, woreda, and years of the study were considered as random effects. The variety of crop production by the household, the income from livestock products, harvesting seasons, gender of the head of the household, years of education of the head of the household, and women's decision-making score were significantly associated with the HDDS. Time taken to reach the local markets was not statistically associated with the HDDS in this study.

The regression results show that one additional food crop variety produced by the household resulted in a 3.4% increase in relative change of HDDS (95% CI [1.9%, 4.9%]). The income generated from livestock products one month before the survey was also significantly associated with HDDS. A one birr increases in income generated from livestock products resulted in a 2.6% increase in relative change of HDDS [1.5%, 3.7%]. The relative change in HDDS due to the change in harvesting time from pre to the post-harvesting season was 6.4% [3.6%, 9.3%]. The gender of the head of the household was also significantly associated with HDDS; being in a female-headed household had a negative effect on the relative change of HDDS. The relative change in HDDS for female-headed households indicated a reduction of −7.9% compared to the HDDS of male-headed households [−12.5%, −3.3%]. Years of education of the head of the household was also; a one-year increase in years of education of the head of the household resulted in a 1.2% relative change in HDDS [0.7%, 1.7%]. The decision-making power of the women regarding agriculture was also significantly associated with HDDS. As the mean score of women's decision-making changed by one point, the relative change in HDDS increased by 3.8% [1.1%, 6.4%]. See Table 2.

3.3. Quantifying the relative contribution of the determinants varying from minimum to maximum

The relative contribution of the variables in the study to HDDS was also calculated. The variety of crops produced varied from 0 to 25 and the change from non-producer households to the highest producers increased the HDDS by 30.5% with a 95% CI of [15.9%, 50.0%]. The relative change in HDDS when the income generated from livestock products in one month before the survey changed from 0 to 6160 birr was 131.6% [62.7%, 230.0%], and the per 100-birr change was 1.4% [0.8%, 2.0%]. The relative change in HDDS when the year of education changed from 0 years to 15 years was 19.5% [11.5%, 28.0%]. The relative change in HDDS when the mean decision-making power of women changed from 1 to 4 was 11.8% [3.9%, 20.4%].

4. Discussion

This study aimed to identify the determinants of household DD using household panel data collected at four-time points in rural Ethiopia. A mixed effects and double truncated Poisson regression model was fitted to the data. The findings indicated that the variety of crops produced by the households, the income generated from animal products, the harvesting season, the years of education of the head of the household, and the women's decision-making power about agricultural issues in the household were positively associated with HDDS while being a female-headed household was negatively associated with HDDS. No association was found between the time taken to reach a market and HDDS.

Results of this study indicate that producing one additional crop variety accounts for about 3.4% of relative changes to HDDS. The positive association between HDDS and food crop production variety found in the current study is consistent with many other studies conducted in African and Asian countries [48,49]. In some other studies, the association of crop variety with HDDS varies under different conditions like harvesting seasons and the number of production diversity [30,35,50] but that was not the case in the current study. The current result is similar to a study done in India where one additional crop produced by the household contributed about 4% of the HDDS [48].

Income generated from animal products, defined as the total value in birr obtained from the selling of animal products owned by the household, was also associated with HDDS. We estimated that a one birr increase in income generated from livestock products in a month resulted

Table 2
Results of the mixed effects truncated Poisson regression analysis assessing factors associated with household dietary diversity in rural Ethiopia.

Variables	Coefficients (95% CI)	SE	RC (95% CI) in %	p-value
Crop production diversity	0.033 (0.019, 0.048)	0.007	3.4 (1.9, 4.9)	<0.001
Income from livestock products	0.026(0.015, 0.037)	0.005	2.6 (1.5, 3.7)	<0.001
Harvesting seasons (Pre = 0, Post = 1)				
Post	0.062 (0.035, 0.089)	0.014	6.4 (3.6, 9.3)	<0.001
Gender of the head of the household (Male = 0, Female = 1)				
Female	−0.082 (−0.134, −0.034)	0.024	−7.9 (−12.5, −3.3)	<0.001
Years of education of household head	0.012 (0.007, 0.016)	0.002	1.2 (0.7, 1.7)	<0.001
Women's decision-making score	0.037 (0.013, 0.062)	0.012	3.8 (1.1, 6.4)	<0.01
Time to the local market in minutes	0.002 (−0.011, 0.014)	0.006	0.2 (−1.1,18)	0.80

in a 2.6% relative change in HDDS of the household. This finding was in line with previously conducted studies, including some studies from Ethiopia, which have identified that either the availability of livestock, the number of owned livestock, or the income obtained from owned livestock was significantly associated with HDDS [9,30,35,49]. Between 2014/2015, when the present study was performed, and today, the value of the birr has approximately fallen by approximately one-third [51], a factor of 2.78 due to inflation. This means that one egg cost approximately 2.5 birrs in 2014, likely even lower in the study settings which are rural, because the chosen study area was productive and food secure rural districts. The cost of one kg of teff was 2 birr or less in 2014. This means that an additional one or two birrs could allow a household to extend its diet. Our estimates indicate that a household that had an HDDS of 5, would require approximately 7 birr to increase its HDDS by one point, while a family with HDDS 3 would need 11 birr to access a new food group. At that time, a small amount of money could be used to purchase local food in these productive districts.

Being in the post-harvesting seasons was found to be positively associated with HDDS. The relative change in HDDS due to the change in harvesting season from pre-to post-harvesting was 6.4%. This finding is in accordance with studies done in Nigeria, Ghana, and Ethiopia [35,36,52]. Additional studies have also indicated that seasonality can play an important role in factors affecting HDDS, including production and access to markets [35,37]. Contrary to our findings, HDDS was significantly higher during the lean season and the harvesting season as compared to the post-harvest season in a study conducted in Burkina Faso [50]. The differences observed between the current study and the one conducted in Burkina Faso could, at least in part, be due to the difference in the types of crops commonly produced in the two regions.

If a household has a female head, the relative change of HDDS was reduced by 7.9% compared to a household with a male head. This finding is consistent with the findings reported in another Ethiopian study [24], while it contradicts the findings of studies conducted in other three African countries including Burkina Faso, Tanzania, and Malawi [17,25,49]. The difference between the Ethiopian findings and those of the other African countries can probably be attributed to differences in gender roles in controlling the resources of the household used to improve DD.

One would expect that having a more highly educated head of household would have a positive effect on the DD of the household as education is likely to be related to a higher knowledge of the benefits of eating diverse foods. The finding of the current study is in line with this expectation, as a unit increase in years of education of the head of household had a 1.2% contribution to the relative change of HDDS. Different studies conducted in Africa and South America have found similar associations, with years of education or better schooling of the head of the household positively contributing to diversified food for the household [9,11,17,25]. Moreover, the literacy of the head of the household has an impact on having diversified food according to studies conducted in Ethiopia and India [24,48].

The other important finding was the association between HDDS and women's decision-making power in agriculture. A one-unit increase in the mean women's decision-making score in agriculture was associated with a 3.8% increase in the relative change of HDDS. Few studies have investigated the direct association between women's decision-making in agriculture and HDDS. However, studies exploring indirect, but relevant associations, mainly focusing on the association between women's decision-making and either the maternal and child DD, the women's DD, or individual DD were identified. The better the decision-making autonomy of the women in the household, the better the DD of both the women and children. Positive associations between women's decision-making and maternal and child's Dietary Diversity Score (DDS) and many of the nutritional outcome measurements like body mass index (BMI), Weight for Height Z score (WHZ), and Weight for Age Z Score (WAZ) have been observed [32,41,53]. Limited studies have assessed the direct association between women's decision-making and HDDS and reported that female participation in decision-making is associated with a higher diversity both in terms of production and consumption and concluded that intra-household decision-making is an important covariate for both production diversity and dietary quality [54]. This association could be related to the fact that as women get relatively better autonomy over household resources, especially production types and income generated from their production, they are more likely to invest in household food consumption than men.

There appears to be a contradiction between the direction of association of two covariates: the gender of the head of the household, where being female is associated with a reduction of HDDS, and the score measuring the decision-making power of the women regarding agriculture. We found that among the women who led their household only 59% had full decisional power (mean decision-making score 4) in agricultural issues. When the women were the head of the household but did not have complete authority over decision-making in agriculture, other individuals in the household or out of the household made decisions about agriculture issues.

Time taken to local markets was not found to be associated with HDDS which contradicts findings in other studies. In one of the studies exploring determinants of DD, the time taken to reach local markets or the distance to reach the nearest local markets was significantly associated with HDDS [35]. An Indian study also found access to the market to be associated with HDDS [48]. However, similar to the findings in this study, another study from Tanzania did not find this association [55]. Recently, the association was also observed in other Eastern African countries [39]. These inconsistencies in the literature could be due to differences in the season of data collection, as well as the methodological approaches used. Local markets are common in Ethiopia and are widely spread, so the distance might not make any difference.

An interesting and different way to quantify and compare the effect of the various determinants on the outcome is to estimate their effect on HDDS when they vary from their minimum to their maximum values. For example, a household producing the maximum number of different crops is expected to have a HDDS 31% higher when compared to a household that produces the minimum number of crops. A household where the mean score of women's decision-making is 4 (maximum) compared to 1 (minimum) will have an estimated 11.84% difference in HDDS. The longest education (15 years) compared to the absence of education results in an estimated difference in HDDS of 19.5%. These quantifications can be used when planning interventions, each coming with a cost and then an estimated predicted benefit for HDDS. Our quantification of the relative change in HDDS when each determinant is increased by one unit has the same scope. One can argue, for example, that working on increasing women's decision-making by one unit (3.8%) can have an effect that is comparable to the increase of one additional crop type (3.4%). Each year of education is expected to contribute to HDDS by a 1.2% relative change. We have observed this approach to interpreting the regression results has not been applied previously in the literature.

4.1. Strength of the study

The cohort has a large number of households and a good geographic spread in the two study regions. The study includes 4 consecutive interviews over two years, with a very large and well-curated set of questions. These questions allowed for the creation HDDS, crop production diversity indices, and the introduction of a women's decision-making score, which we found very useful. A further strength is our analysis, based on truncated Poisson regression, which is necessary as the HDDS is a count variable between 1 and 10. We also checked that the estimated probability that the modeled HDSS would be larger than 11, was negligibly small, thus supporting the use of this statistical model. We were able to quantify the effect of each potential determinant on the HDDS so that possible interventions can predict and compare possible effects.

4.2. Limitations of the study

Unfortunately, this study did not include the farmland size of the household which might be associated with HDDS. Another limitation was that the area of the study was limited to highlanders of Oromia and the SNNP regions, which might not be representative of other rural districts in Ethiopia; for example, these districts in Oromia and SNNP are known as food secure areas. The findings regarding the gender of the head of the household should also be interpreted with caution as only 11% of the households were led by women in the study.

5. Conclusions

The present study aimed to examine the associations between potential determinants and HDDS in the two large regions of Ethiopia using the agriculture-nutrition household panel data collected four times over two years. The study has identified several determinants using mixed effects truncated Poisson regression model.

To improve DD at the household level in rural Ethiopia (and possibly in similar places in the world), we suggest that any intervention working to improve household DD should consider the effect of seasons, focusing on the most difficult part of the year, by expanding irrigation and by utilizing modern agricultural technologies so that the households will break up the dependency on seasons. Moreover, strengthening nutritional education for the household members, especially the head of the household appears to be very important. Helping to produce different food crops and to consuming their own produce are also means of diversifying the household diet. Improving the practice of decision-making by women in the household might also be vital to improve the HDD.

Authors' contribution

TK conceived the study. TK, AF, MKG, RH and BW conceptualized the study problem. TK, AF and RH performed statistical data analyses. TK wrote the first draft of the manuscript. AF, MKG, RH and TK interpreted the results, and reviewed the manuscript critically. AF, RH and MG supervised the study. All authors have read and approved the final manuscript.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data utilized for this study can be obtained upon request from Dr. Jennifer Coates, Tufts University, Maryland, USA (Email: jennifer.coates@tufts.edu)

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List of abbreviations

DD	Dietary diversity
ENGINE	Empowering New Generation by Improving Nutrition and Economic Opportunity
FAO	Food and Agriculture Organization
HDD	Household Dietary Diversity
HDDS	Household Dietary Diversity Score
LMICs	Lower- and Middle-income Countries
RC	Relative Change
SNNP	Southern Nations, Nationalities and Peoples
WEAI	Women's Empowerment in Agriculture Index
VIF	Variance Inflation Factor

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jafr.2023.100550.

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