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Can household dietary diversity inform about nutrient adequacy? Lessons from a food systems analysis in Ethiopia

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Abstract

This study examined the use of the household dietary diversity score (HDDS) to assess household nutrient adequacy in Ethiopia. It also examined the correlates of HDDS following the food systems framework. Results show that the average nutrient consumption in Ethiopia varies by place of residence and by income profile, where households in urban areas and those in the higher income quintiles rank favorably. Among 13 nutrients under study, we found nutrient inadequacy for fat, calcium, zinc, riboflavin, niacin, folate, vitamin C and vitamin A ranging between 46% and 89%, and the prevalence of inadequacy for vitamin B12 to be up to 100%. Econometric results showed that HDDS is a strong predictor of a household's mean probability of nutrient adequacy (MPA), and that an HDDS of 10 is the minimum threshold at which HDDS can improve household MPA. We found suggestive evidence within the food systems that improving household-incomes, access to health and transport services are beneficial to improve HDDS and nutrient consumption in Ethiopia.

Keywords Nutrient adequacy · Household dietary diversity · Food systems · Ethiopia

1 Introduction

Low dietary diversity and nutritional inadequacy are widely prevalent in Ethiopia with significant variations between urban and rural areas, across regions and other socio-economic characteristics (e.g., Abegaz et al. 2018; Berhane et al. 2011; D'Souza and Jolliffe 2016; EPHI 2013, 2016; Herrador et al. 2015), and between agricultural seasons (Hirvonen et al. 2016; Roba et al. 2019). According to the 2016 Demographic and Health Survey (DHS), for example, the proportion of children aged 6–23 months who received the minimum acceptable diet[1] was very low: 19% in urban areas in contrast to 6% in rural areas; and, 27% in Addis Ababa in contrast to 2–3% in Afar, Somali, and Amhara regions (CSA and ICF 2016). However, emerging evidence shows food consumption and diets are gradually changing in Ethiopia.

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[1] The report used the WHO 2008 definition of minimum acceptable diet for children which combines the minimum dietary diversity (MDD) and minimum meal frequency that ensures appropriate growth and development. The minimum acceptable diet for children recommends consumption of food from at least four food groups. This increases the likelihood of consuming at least one animal source of food and at least one fruit or vegetable in addition to a staple food (grains, roots, or tubers).

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In 2011, the average daily calorie consumption per adult equivalent was 800 kcal more than in 1995[2]; and, the budget shares of high value products including animal products, fruits and vegetables have increased by more than 2% each, on average (Worku et al. 2017). Staples contributed to 75% of total caloric intake with little change between 1995 and 2014 (Worku et al. 2017; D'Souza and Jolliffe 2016).

Evidence from the national consumption survey of 2011 shows that the prevalence of inadequate intakes of iron, zinc and vitamin A in women aged 19 to 45 years was 12.9%, 50.4%, and 81.9%, respectively (EPHI 2013). According to the national micronutrient survey of 2015, iron, zinc and vitamin A deficiencies were mild-to-moderate public health problems in the country (EPHI 2016). Other studies assessing diets and the nutritional situation in Ethiopia examined energy intakes with little attention to diet quality and adequacy in nutrients. For example, Hirvonen et al. (2017) used the household dietary diversity score (HDDS) as proxy for access to nutrients without necessarily measuring nutrient adequacy. This may be due to lack of data on food consumption at the level of the individual, especially from nationally representative samples. Nonetheless, recent studies show that household level data may provide a useful alternative to draw policy relevant information on nutrient adequacies (e.g. Sununtnasuk and Fiedler 2017; Coates et al. 2017).

To better understand problems of diets and nutrition and identify potential interventions, the emerging approach is to understand food as a "system", taking into account food supply chains, food environments[3] and consumer behavior (HLPE 2017). This is because food systems affect human and planetary health, influence producers' decisions and consumers' food choices, and vice versa. A meta-analysis of studies from low-and middle-income countries shows that increasing production diversity is not a universally-applicable tool to improve diets and nutrition (Sibhatu and Qaim 2018). For example, based on survey data from rural households in East Hararghe zone in Ethiopia, Aweke et al. (2020) find that households heavily depend on the market to supplement their own food production, and that size of landholding and farm income are strongly associated with food consumption. This implies that improving diets and nutrition status in the population partly relies on other components of the food systems. Hence, the food systems approach may help identify the problem areas in the context of nutrient acquisition as well as enabling innovations, interactions and dynamics among the different components of the food systems including production, processing, distribution, trade, food environments and consumer behavior in Ethiopia (Gebru et al. 2018).

The link between components of the food systems and consumption of nutritious food has been illustrated in earlier studies. Worku et al. (2017) show that household income is one of the key determinants of access to food in Ethiopia. With economic growth, household incomes may rise, and this may lead to improved access to nutritious food. The real GDP growth in Ethiopia between 2004 and 2014 was 10.9% per year on average (World Bank 2015) and a significant part of this growth was from agriculture (Bachewe et al. 2015). Given that the majority of Ethiopians rely on agriculture and related sectors for their livelihood, household incomes may have increased and this may partly explain the improvements in calorie consumption in recent years.

Despite improvements in calorie consumption, evidence shows little shift in consumption of diverse nutrient dense foods in Ethiopia. By examining the monthly price patterns of different food groups for a period of 10 years (2007–2016), Bachewe et al. (2017) explained this development by much faster rising prices of more nutritious foods compared to starchy staples and other food items. Nonetheless, the effect of rising prices on consumption is not the same across the population, because diets differ across income and location of residence. For example, over the period of 2006 to 2011 the price increases of animal source foods (ASF) was relatively high. Yet, the share of ASF expenditures on total food for people in the richest quintile was three times higher than for those in the poorest quintile and residents in urban areas spent twice as much on ASF per capita than their rural counterparts (Abegaz et al. 2018).

Access to markets, market information, and proximity of roads reduce transaction costs and facilitate innovations in the food supply chains which may contribute to consumption of more nutritious diets. Coverage of road and telephone infrastructure in Ethiopia has increased over the last two decades, leading to better connectivity. For example, the share of people that reside more than 10 h of travel time away from a city of 50,000 people in 1994 has dropped from about 29% to about 5% in 2015; and, the number of phone subscribers per 100 inhabitants, increased from 7% in 2008/09 to 63% in 2016/17 (Minten et al. 2018). While there could be a time lag before economic benefits associated with the expansion of these infrastructures are fully realized, recent studies in Ethiopia found impacts of road infrastructure and market connectivity on location choice and entry of manufacturing firms (Shiferaw et al. 2015), intensification decisions of farmers (Vandercasteelen et al. 2018), and of access to roads on reduction of poverty and increasing consumption growth (Dercon et al. 2009) and income growth (Wondemu and

[2] Note that even though the average calorie consumption was well above the minimum requirement of 2100 kcal per adult, this does not necessarily mean that all people had access to sufficient calories since the energy requirements vary by age, sex, body size, physical activity level, etc. However, the referred study did not provide such information nor the percentage of people meeting this threshold.

[3] The food environment is defined as the physical, economic, political and socio-cultural context in which consumers engage with the food system to make their decisions about acquiring, preparing and consuming food (HLPE 2017, p.28).

Weiss 2012). Further, evidence suggests that access to market and roads joint with nutrition knowledge of the consumer improves consumption of more diverse diets in Ethiopia (Stifel and Minten 2017; Hirvonen et al. 2017; Hirvonen 2016).

A major limitation of the above referred studies in Ethiopia, with a few exceptions including EPHI (2013, 2016), is that they are based mainly on samples which are not nationally representative. In addition, none of these studies fully examined nutrient and dietary gaps by food system components. Hence, the main objective of this research was to examine how the various components of food systems might explain HDDS and nutrient adequacies in Ethiopia. It also examines the associations between HDDS and the mean nutrient adequacy. The novelty of this research is the analysis of household nutrient adequacy by components of food systems. Furthermore, we explore a potential threshold at which HDDS may affect household nutrient adequacy.

2 Methods

This study employed both bivariate and multivariate data analysis. We used descriptive statistics to examine HDDS and household nutrient gap by components of food systems in Ethiopia. Examining nutrient adequacy involves calculating total food consumption in relation to the required level of energy and nutrients. To achieve this, we first converted consumed foods to nutrients using the Ethiopian food composition table (Ågren et al. 1968), and other sources including the USDA (2016), Langenhoven et al. (1991), West et al. (1989), where nutrient information was missing. We applied waste and retention factors (USDA 2016) to raw foods to account for nutrient losses during preparation. For foods whose waste factors were not available, we made imputations using similar foods.

To proxy the intra-household distribution of food, we allocated a consumer unit proportion to each individual household member. We defined one consumer unit as the energy requirements of an adult non-pregnant, non-lactating woman, 20–30 years, referred to as an adult female equivalent (1 AFE). Each individual is allocated a proportion of the AFE based on the proportion of their energy requirements (specific to the age and sex of each individual in the household, assuming moderate activity level) to that of an adult non-pregnant, non-lactating woman. The total household AFE was calculated as the sum of the AFEs for each individual household member.

We calculated daily consumption per AFE as the daily household consumption (calculated as total observed consumption divided by 7 to correct for the 7-day recall) divided by the total household AFE. We conducted nutrient consumption gap analysis using the Estimated Average Requirements (EARs) cut-point approach (IOM, 2006; Murphy and Vorster, 2007) using the European Food Safety Authority (EFSA) intake recommendations for non-pregnant, non-lactating women (EFSA, 2017). The prevalence of inadequacy was estimated as the proportion of households with daily consumption per AFE below the EAR for energy, and nutrients including protein, fat, calcium, zinc, thiamin, riboflavin, niacin, vitamin B_6, folate, vitamin B_{12}, vitamin C, and vitamin A. As the requirements for iron are known to be skewed for non-pregnant, non-lactating women (see IOM 2006 pp.43–44), the cut-point approach is not applicable; and, we calculated the prevalence of inadequacy for iron per adult women using the probability of adequacy table (see Wiesmann et al. 2009, p.206, adapted from IOM 2006) assuming a bioavailability of 5%.

The prevalence of nutrient inadequacy calculated using the cut-point approach does not differentiate between households that fall just below the EAR and of those very far below the EAR, however. Errors potentially arising from aggregation may lead to inaccurate conclusions especially if the average nutrient adequacy is analyzed against potential drivers. For this reason, we estimated the mean probability of adequacy (MPA) for micronutrients. The probability approach is considered to be robust to misspecification of variance so long as the distribution of requirements is symmetric (Wiesmann et al. 2009). Assuming normal distribution of nutrient requirements of adult women, we calculated the probability of adequacy for each micronutrient (excluding iron, whose probability of adequacy is calculated as described earlier) by solving for the standardized score (z-score):

$$z\text{-score}_i = \frac{usual\ intake_i - EAR_i}{SD_i}, \qquad SD = CV \times EAR \tag{1}$$

where SD and CV respectively represent the standard deviation and coefficient of variation for nutrient i. We replaced usual intake by observed daily nutrient consumption per AFE described earlier. We used the EAR and SD values from WHO/FAO (2004) for an adult female (19–65 years). Using the standardized z-scores and the property of standard normal distribution, we computed the probability of adequacy for each nutrient. Finally, we calculated the MPA by averaging the probability of adequacy of 11 micronutrients including iron, calcium, zinc, thiamin, riboflavin, niacin, vitamin B_6, folate, vitamin B_{12}, vitamin C, and vitamin A.

In this paper we assessed the household dietary diversity using the Household Dietary Diversity Score (HDDS), a composite measure and proxy for a household's average food access (Swindale and Bilinsky 2006). The HDDS is calculated based on whether anyone in the household consumed any food from the 12 food groups during the recall period. These food groups include: cereals; white roots and tubers; vegetables; fruits; meat, poultry; eggs; fish and other sea food; pulses, nuts and seeds; milk and milk products; oils and fats; sweets; spices, condiments and beverages.

Finally, we investigated the associations between MPA, HDDS and their drivers including indicators of components of food systems. The econometric specifications are described in Section 4.

2.1 Data

We used the 2015/2016 Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA) from Ethiopia (CSA and World Bank 2017). The survey consists of 4954 households drawn from 11 regions (9 regional states and 2 administrative cities). The sample is nationally representative. But at sub-national level, it is representative only for the four most populous regions (i.e. Amhara, Oromia, SNNP and Tigray) and Addis Ababa (CSA and World Bank 2017), which together comprise over 75% of the total sample. Population weights are available in the database and are used in the analysis (after making adjustments for the observations excluded from the analysis) to ensure representativeness of the data. Due to errors in food consumption data, we excluded about 17% of the observations from the analysis, following several stages of data cleaning including checking on: measurement units, consumption expenditure and food prices per unit, and amounts of consumption per AFE. We checked whether the quantity of total consumption for each food item is equal to the sum of quantities consumed from own stock, from purchases and gifts; and, whether the reported consumption expenditure is consistent with prices per unit of the food item. The amounts of food purchases are considered outliers if the corresponding unit prices are three times the interquartile range below or above the median prices (Filzmoser et al. 2016) for the same *kebele*.[4] In such cases, we recalculated the amount of food purchases based on the total spending on a given food item and the median price reported by other households in the same *kebele*. We also checked whether the daily total food consumption per AFE is feasible based on criteria from a human nutrition perspective; excluding households whose estimated energy consumption per AFE is below 500 kcal per day and those above 5000 kcal per day (Voortman et al. 2017). Hence, this study was based on 4101 households.

[4] *Kebele* is the smallest administrative unit in Ethiopia.

2.2 Descriptive statistics

2.2.1 Descriptive statistics of household demographic and socio-economic characteristics

Table 1 presents a general overview of the socio-economic and demographic characteristics of sample households. From Table 1, about 74% of households are male headed. The average age and schooling attainment of a household head was about 46 years (s.d. 15) and 3.37 years (s.d. 4.58), respectively. The average family size in adult equivalent was about 4 (s.d. 1.9) people with the number of children under 15 and the number of adults above 64 in the household being 2.12 (s.d. 1.74) and 0.17 (s.d. 0.42), respectively. About 71% of households are from rural areas. Households were located at a radius of around 56 km (s.d. 47.1) from the nearest weekly market and at a radius of around 32 km (s.d. 29.6) from the nearest population center with 20,000+ people. Vehicles pass on the main road throughout the year in about 76% of the communities.

2.2.2 Nutrient gap and adequacy

Table 2 presents the prevalence of inadequacy for energy and select nutrients disaggregated by region and some indicators of food systems. The prevalence of inadequacy for calcium, vitamin A, fat, vitamin C, and vitamin B_{12} was above 79% with highest prevalence for vitamin B_{12} (100%, not reported in Table 2).[5] In contrast, the prevalence of nutrient inadequacy is relatively low for thiamin (5%), iron (14%), vitamin B_6 (17%), and protein (23%). The shares of households consuming below the EAR for niacin, riboflavin, folate, and zinc were between 46% and 60%. Nutrient inadequacies across regions closely follow the patterns observed at country level with the exception of a few nutrients. For example, the prevalence of inadequacy for iron in Somali region is 56% while the corresponding figure for other regions is between 3 and 28%. Similarly, the shares of households in Dire Dawa consuming below the EAR for niacin and riboflavin is 25% each while corresponding figures for other regions are between 31 and 76% for riboflavin and 36 and 60% for niacin.

Across indicators of the food system components, the data show that the share of households consuming below the EAR were slightly higher in communities where health posts are available (for energy and all nutrients except for zinc,

[5] Based on serum vitamin B_{12} concentrations, the National MNS report (2016) shows that the prevalence of vitamin B_{12} deficiency among non-pregnant women aged 15–49 years was 15.1%. However, this method of estimation/measurement is different from ours and hence the estimates cannot be compared. On the other hand, vitamin B_{12} is only available in animal-sourced foods (asf) (and in seaweed but this is not consumed in Ethiopia). Vitamin B_{12} intake is directly related to intake of animal-sourced food and intake of asf in Ethiopia is low (see the National food consumption survey, EPHI 2013).

Table 1 Demographic and socio-economic characteristics of households in Ethiopia

	Mean	s.d.	Min	Max
Male household head (1/0)[1]	0.7	0.4	0	1
Age of household in years	46.3	15.1	13	99
Years of education of household head	3.4	4.6	0	18
Household size in adult equivalent	4.0	1.9	0.7	13.1
Number of children under 15	2.1	1.7	0	9
Number of adults above 64	0.2	0.4	0	2
Household expenditure quintile	3.1	1.4	1	5
Rural (1/0)	0.7	0.5	0	1
Household distance in km to nearest market	56.3	47.1	0	283
Household distance in km to nearest population center with more than 20,000 inhabitants	32.2	29.6	0	214
Vehicles pass throughout the year in the community (1/0)	0.8	0.4	0	1
Availability of health post in the community (1/0)	0.7	0.5	0	1
Availability of hospital/health center in the community (1/0)	0.4	0.5	0	1
Percent of agriculture within approximately 1 km buffer	28.7	19.6	0	97
Elevation (m)	2013	520	203	3357

[1] (1/0) denotes dummy variable and s.d. denotes standard deviation

Table 2). In contrast, the corresponding figures were slightly lower in communities where a hospital or a health center is available. Note that health posts are available mainly in places where a hospital or health center is not close by. Similarly, the share of households consuming below the EAR are slightly lower in communities where vehicles pass on the main road in the community throughout the year (for energy and other nutrients with the exception of protein, zinc, vitamin B_6 and vitamin A).

To facilitate description of the prevalence of nutrient inadequacy by indicators of the food system components with continuous variables (including distance to market, distance to nearest town with 20,000+ people, the percentage of land under agriculture within approximately 1 km of residence, and elevation), we convert the continuous variables into terciles. As Table 2 shows, there does not seem to be a clear trend in the prevalence of nutrient inadequacy by proximity to large weekly markets. For example, households that are more remotely located (tercile 3) from a large weekly market in the community seem to have a slightly higher share of households with nutrient inadequacy than those close by (tercile 1) for five nutrients including protein, fat, iron, vitamin B_6 and folate. In contrast, those in closer proximity to a weekly market (tercile 1) have a slightly higher share of households with nutrient inadequacy than those in tercile 3 for four nutrients including calcium, zinc, riboflavin, niacin, and vitamin C. On the other hand, there seems to be a negative relationship between proximity to the nearest population center and the share of households with inadequate consumption. For example, across terciles of distance to the nearest population center, those in closer proximity (i.e. tercile 1) have a slightly smaller share of households with nutrient inadequacy than those in terciles 2 and 3 for energy and nutrients excluding zinc. Further, there seems to be negative relationship between the fraction of agriculture within approximately 1 km and the share of households with inadequate consumption. Across elevation terciles, Table 2 shows that households that are at a lower elevation (tercile 1) seem to have a slightly lower share of households with nutrient inadequacy than those on higher ground (i.e. terciles 2 and 3) for protein, fat, niacin, and vitamin C.

Disaggregating the data by location of residence reveals that the share of households with nutrient consumption below the EAR is significantly higher for rural people compared to their urban counterparts for all nutrients except for zinc, vitamin B_6, and energy (Fig. 1). Across income quintiles,[6] the share of households consuming below the EAR declines with rising income profiles for energy and all nutrients with the exception of vitamin B_{12}, vitamin A and vitamin C (Fig. 2). The share of households in the bottom expenditure quintile consuming below the EAR is statistically significantly smaller than that of each of the remaining quintiles for vitamin A; and that of vitamin C for the 2nd income quintile and top income quintile. Consumption of vitamin B_{12} is below the EAR regardless of income profile (see Fig. 2).

Note: * denotes proportions differ statistically significantly at $p < 0.05$.

Note: Q1, Q2, Q3, Q4, and Q5 respectively represent the bottom (1st), 2nd, 3rd, 4th and top (5th) expenditure quintile.

[6] Households were grouped into quintiles based on real per adult equivalent monthly consumption (food and nonfood) expenditure. In this paper, we interchangeably refer to them as income or expenditure quintiles.

Table 2 Percentage of households with energy and nutrient consumption (per adult female equivalent (AFE)/day) below the estimated average requirement (EAR), by some indicators of food systems[1]

	Energy	Protein	Fat	Calcium	Iron[2]	Zinc	Thiamin	Riboflavin	Niacin	VitB6	Folate	VitC	VitA
EAR	2078	38.6	69.3	750.0	25.2	10.2	0.6	1.3	11.3	1.3	250.0	80.0	490.0
unit	kcal	g	g	mg	mg	mg	mg	mg	mg	mg	ug	mg	ug
% consuming below EAR													
Country	38	23	89	79	14	60	5	51	46	17	51	89	83
Indicators of food system components													
Health post in this community: Yes[a]	39	25*	91*	82*	17*	58*	6*	55*	47*	18	57*	92*	86*
No[a]	38	18	82	71	8	66	2	41	42	16	34	80	78
Hospital/health center in this comm.: Yes[b]	39	21*	85*	77*	12*	61	3*	49*	44*	19*	47*	87*	82*
No[b]	38	24	91	81	16	60	6	53	47	16	53	90	84
Vehicles pass throμghout the year: Yes[c]	38	23	88*	79	13*	61	4*	50*	45	18*	50*	88*	84*
No[c]	39	23	92	81	18	58	7	56	47	15	54	91	81
Distance to market: tercile 1	40	22	85	82	9	66	6	51	48	16	48	88	84
tercile 2	36	20	91*	76*	16*	57*	4	53	45	17	52	92*	87
tercile 3	40	27*	89*	81	17*	60*	6	49	44	19	50	87	79*
Distance to pop center: tercile 1	36	19	85	74	7	65	3	45	42	14	38	80	75
tercile 2	40	26*	93*	81*	18*	56*	6*	56*	50*	19*	58*	94*	87*
tercile 3	38	22	87	82*	16*	61	5	51*	44	19*	53*	91*	87*
Fraction of agriculture: tercile 1	43	24	86	78	16	64	5	51	48	24	48	88	85
tercile 2	37*	20	90*	79	11*	58*	3	54	45	15*	53*	90	84
tercile 3	35*	25	89*	80	17	59*	8*	48	45	15*	50	89	81*
Elevation: tercile 1 (below 1708 m a.s.l.)[3]	38	22	83	82	20	61	5	53	44	18	56	85	85
tercile 2 (1708 m – 2079 m a.s.l.)	37	23	91*	75*	15*	59	6*	56	48	16	52*	87	77*
tercile 3 (above 2079 m a.s.l.)	40	23	90*	81	21*	61	4	47*	46	19	46*	92*	88

Note: [1] Percent consuming below EAR is 100% for vitamin B_{12}, hence excluded from this table

[2] The prevalence of inadequacy for iron is calculated based on the probability approach (for method, see Wiesmann et al. 2009, p.206)

[3] a.s.l. denotes above sea level

[*] Proportions differ statistically significantly at $p < 0.05$. a, b, and c denote that comparison is made within same group. For indicators with tercile groups, comparison is made between tercile 2 against tercile 1 and tercile 3 against tercile 1

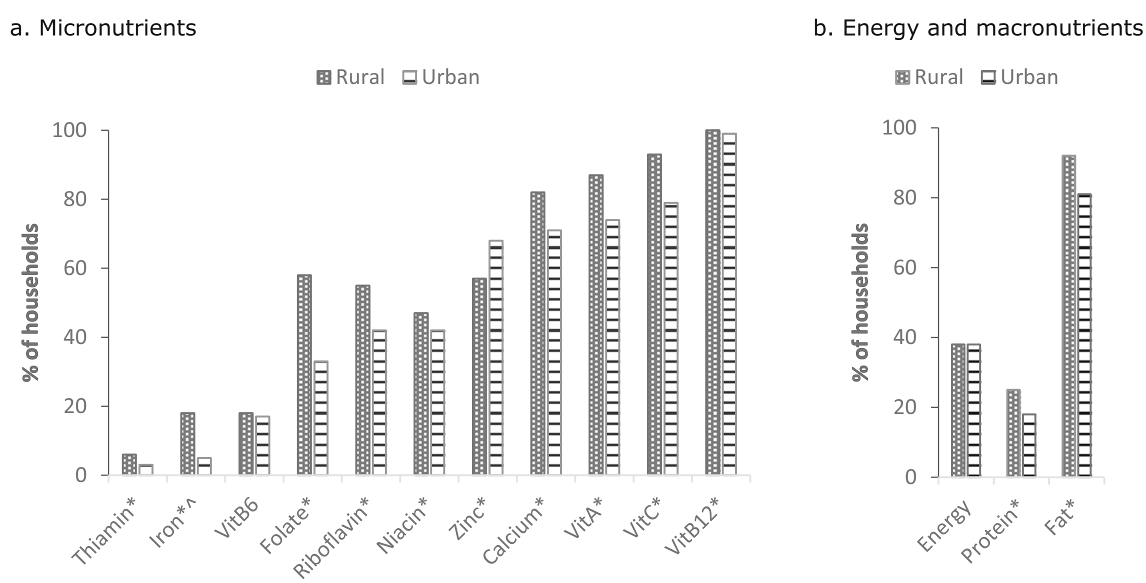

Fig. 1 Percent of households consuming below the estimated average requirement (EAR) by location of residence (rural/urban)

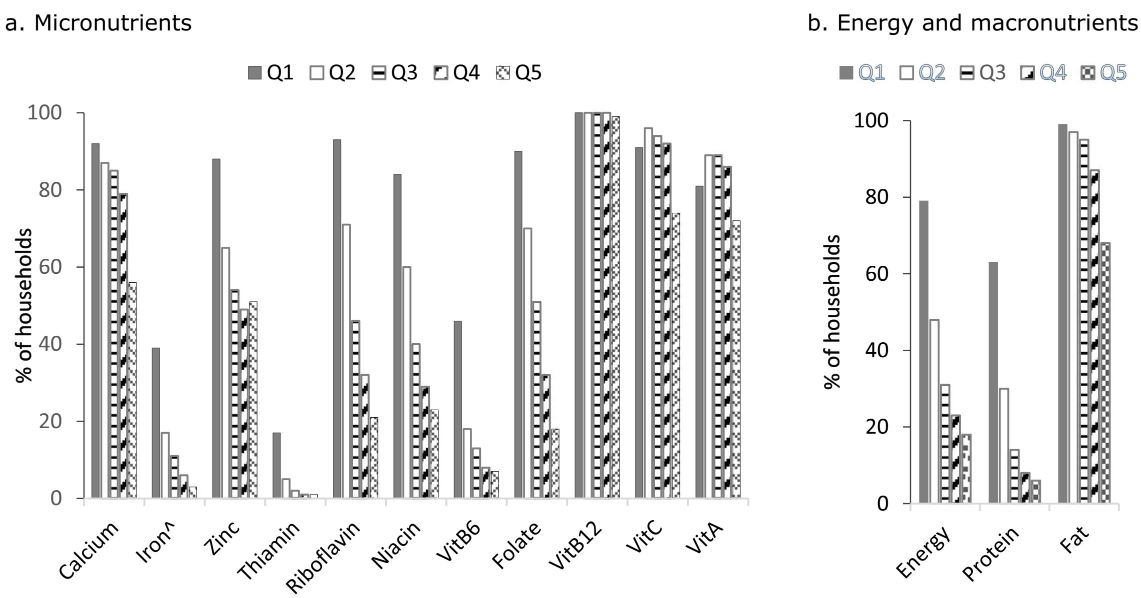

Fig. 2 Percent of households consuming below the estimated average requirement (EAR) by expenditure quintile

The prevalence of consumption below the EAR for nutrients described so far does not reflect the total number of nutrient inadequacies (or the 'intensity' of nutrient inadequacies) that households may experience. As shown in Table 3, the average number of nutrients with consumption below the EAR was 6.9 (s.d. 2.7) out of 12, and this number is smaller for urban compared to rural areas, and declines with rising income profile. The inequality across households in terms of multiple nutrient inadequacies is more pronounced when comparison was made between households in the top and bottom expenditure quintiles. As shown in Table 3, the average number of nutrients with consumption below the EAR was about 9.4 (s.d. 2.1) for households in the bottom expenditure quintile while the corresponding figure was 5 (s.d. 2.4) for households in the top expenditure quintile. Similar disparity was also observed across regions.

Figure 3 presents the MPA by place of residence (rural and urban), expenditure quintiles and region. Results show that the mean MPA for 11 nutrients was 0.51 (s.d. 0.22) and urban households had a significantly larger MPA ($p < 0.01$) than their rural counterparts, and the probability of overall nutritional adequacy increases with household income profile. Somali region followed by Benishangul Gumuz and Harari showed the lowest MPA while, by contrast, Dire Dawa and Afar the highest.

Note: The mean probability of adequacy (MPA) was calculated for 11 micronutrients including calcium, iron, zinc, thiamin, riboflavin, niacin, vitamin B_6, folate, vitamin B_{12},

Table 3 Distribution of the average number of nutrients with inadequate consumption[1]

	Mean (s.d.)[2]	Share of households (%) with inadequate consumption by number of nutrients				Mean (s.d.)[2]	Share of households (%) with inadequate consumption by number of nutrients		
		1 to 4	5 to 8	9 to 12			1 to 4	5 to 8	9 to 12
Total	6.9 (2.7)	19.1	49.2	31.7	Tigray	6.6 (2.6)	20.1	55.2	24.7
					Afar	5.8 (2.9)	32.2	46.7	21.1
Rural	7.2 (2.5)	14.0	52.2	33.8	Amhara	7.3 (2.6)	12.8	50.9	36.3
Urban	6.3 (3.0)	31.7	41.9	26.5	Oromia	6.5 (2.5)	20.6	55.1	24.3
					Somali	8.2 (2.3)	6.1	44	50
Q1:bottom	9.4 (2.1)	3.9	22.6	73.6	B. Gumuz	7.5 (3.0)	20.3	34.7	45
Q2	7.9 (2.2)	5.6	50.2	44.2	SNNP	7.0 (3.1)	25.2	36.2	38.6
Q3	6.8 (2.2)	11.7	63.1	25.2	Gambella	7.3 (2.7)	16.1	49.4	34.5
Q4	6.0 (2.1)	22.0	63.7	14.2	Harari	7.5 (2.7)	16.2	51.1	32.7
Q5:top	5.0 (2.4)	48.9	42.0	9.1	Addis Ababa	7.0 (3.0)	24.5	42.7	32.8
					Dire Dawa	5.9 (2.7)	27.3	54.9	17.8

Note: [1] Energy and iron were not included; [2] s.d. denotes standard deviation presented in brackets

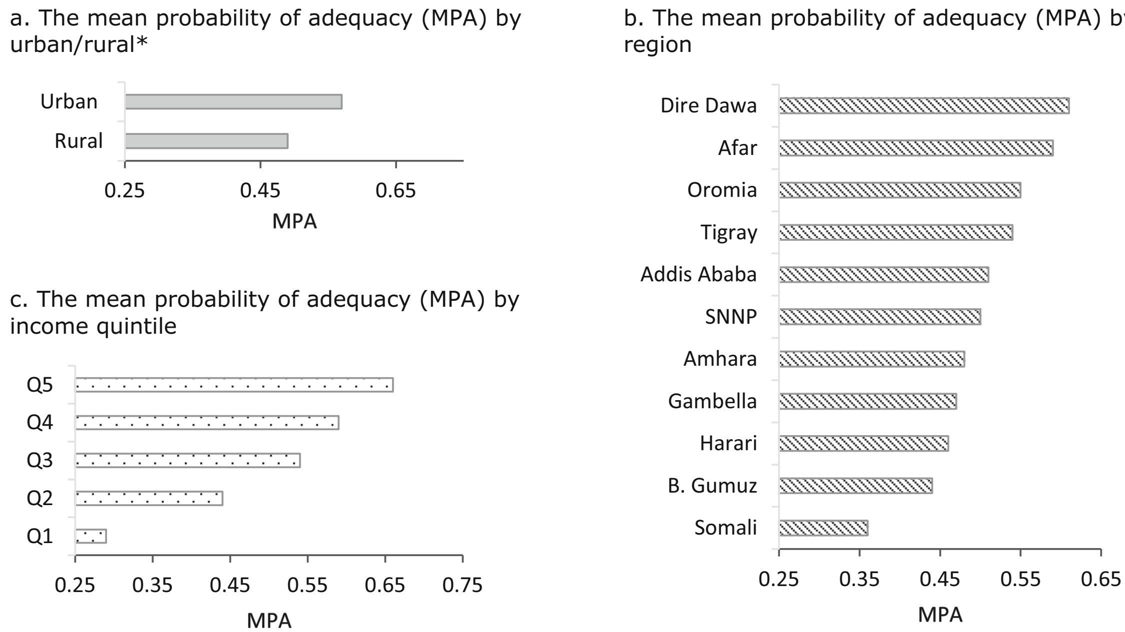

Fig. 3 MPA by rural-urban gradient, income quintiles and regions of Ethiopia

vitamin C, and vitamin A. The mean and standard deviation of MPA were 0.51 and 0.22, respectively.

* Denotes mean differences are statistically significant at $p < 0.05$. Q1, Q2, Q3, Q4, and Q5 respectively represent the bottom, 2nd, 3rd, 4th and top expenditure quintile.

2.2.3 Household dietary diversity score and household nutrient consumption

From seven days consumption of up to 12 food groups, the average HDDS in the country was 6.7 (s.d. 1.8), and the corresponding value for urban and rural households was 7.9 (s.d. 1.7) and 6.2 (s.d. 1.7), respectively (Table 4). From 11 regions, Amhara scored the lowest with the average HDDS of 6.0 (s.d. 1.8) while Harari, Addis Ababa and Dire Dawa scored the highest average HDDS in the country, with a mean of 7.6 (s.d. 1.6), 8.2 (s.d. 1.6), and 7.6 (s.d. 1.9), respectively. Table 4 also shows that households with access to a health post, hospital or health center in the community, and availability of car transport in the community throμghout the year have a significantly higher HDDS ($p < 0.01$) than their counterparts with no or limited access to such services.

Figure 4 plots the relationship between the household MPA and HDDS using non-parametric (kernel) regression. Figure 4 sμggests that the overall household nutrient adequacy (or MPA) increases with HDDS. In Section 3, we test if this relationship between household MPA and HDDS holds in a multivariate context since dietary consumption is conditioned by the food environment (Herforth and Ahmed 2015).

3 Econometric approach

We examined the correlates of household nutrient adequacy and HDDS in two parts. First, we analyzed how HDDS may affect the MPA, given other factors. As noted before, food consumption is conditioned by the food environment including access to markets, health services, transport services, and other socio-economic characteristics. These represent different components of food systems, including production, processing, distribution, trade; and also consumer behavior. In the second part we examined the relationship between HDDS and access to market and other components of food systems.

3.1 Household dietary diversity score and nutrient adequacy

We analyzed the relationship between household MPA_i and $HDDS_i$ by estimating:

$$MPA_{ij} = \alpha HDDS_{ij} + \boldsymbol{x_{ij}\beta} + \boldsymbol{\delta}_j + e_{ij} \tag{2}$$

where $\boldsymbol{x}_{ij}$ denotes a vector of household i's observable characteristics including age, gender, religion, and level of education of the household head, the household size and composition, income status, place of residence, and indicators of components of food systems described at the beginning of this section; $\boldsymbol{\delta}_j$ denotes location fixed effects and controls for unobservable characteristics including institutional and cultural factors that do not vary in a region of residence j but may influence nutrient consumption; and e_{ij} is an error term. α, $\boldsymbol{\beta}$ and δ are coefficients to be estimated. Our main interest is the estimate of α. We estimated three versions of eq. 2, starting

Table 4 Average household dietary diversity score for Ethiopia based on 12 food groups

	Mean	s.d.	Min	Max		Mean	s.d.	Min	Max
Country	6.7	1.8	1	12	Region				
Rural[a]	6.2	1.7	1	11	Tigray	6.6	2	2	12
Urban[a]	7.9	1.7	1	12	Afar	7.1	1.6	2	10
Q1: Bottom	5.6	1.6	1	11	Amhara	6.0	1.8	1	11
Q2	5.9	1.5	1	10	Oromia	7.0	1.7	2	12
Q3	6.5	1.6	2	12	Somalie	6.7	1.6	2	11
Q4	7.1	1.5	3	12	B. Gumuz	6.9	1.7	3	11
Q5: Top	8.3	1.7	2	12	SNNP	6.8	1.9	1	12
Health post in this community (Yes)[b]	7.6	1.9	2	12	Gambelia	7.3	1.7	4	11
Health post in this community (No)[b]	6.4	1.7	1	11	Harari	7.6	1.6	3	11
Hospital/health center in this community (Yes)[c]	7.2	1.9	1	12	Addis Ababa	8.2	1.6	2	11
Hospital/health center in this community (No)[c]	6.4	1.7	1	12	Dire Dawa	7.6	1.9	3	12
Vehicles pass throughout the year (Yes)[d]	6.9	1.8	1	12					
Vehicles pass throughout the year (No)[d]	6.1	1.8	1	12					

Note: [a,b,c,d] mean difference between groups, for same indicator, is statistically significant at $p < 0.05$

with a basic specification where only *HDDS* and region dummies are explanatory factors. To better isolate the effect of HDDS on MPA we further included other controls in the second specification. In both cases, HDDS enters regressions as a continuous variable. While the coefficient estimate of α, $\alpha \neq 0$, in these specifications, may show the importance of HDDS, it does not inform the minimum threshold at which HDDS may influence household MPA. Hence, we tested for potential threshold effects with a third specification by replacing the HDDS with 11 dummies generated for the number of food groups consumed by the household, leaving out the HDDS of 1 as the base category. In each of the regressions, we cluster standard errors at the district level since the error variances may be correlated within a district.

Table 5 presents summary results of an ordinary least squares (OLS) estimation of the three specifications described above. After controlling for region dummies, we found that HDDS is indeed positively and strongly associated with household MPA, as implied in the bivariate analysis (Fig. 4). For example, as shown in Column 1, one standard deviation[7] increase in HDDS is associated with a 0.23 point increase in household MPA. This is about a 46% increase over the MPA. The relationship between MPA and HDDS remains positive and statistically significant after controlling for other explanatory factors (Column 2). Yet, the magnitude of the coefficient estimate of HDDS is reduced by about two-thirds. While these results strongly sμggest improvements in the MPA with increasing HDDS, identifying the minimum number of food groups that may affect MPA is also important. Hence, as can be seen in Column 3, the HDDS of 10 (out of 12 food groups consumed over seven days) is the minimum threshold that is significantly associated with an increase in household MPA. Among controls, results suggest that household size and the share of expenditure (per AFE) on meal away from home (MAFH) over food at home are negatively, and income profile positively, associated with household MPA (Columns 2 and 3). In contrast, the number of children under 15 years of age is positively and strongly associated with the household MPA. Years of education attained, gender and religion of household head, location of residence, and number of adults above 64 years of age did not seem to be strong predictors of the household MPA.

[7] The mean HDDS and MPA are 6.7 (s.d. 1.8) and 0.51 (s.d. 0.22), respectively.

3.2 Correlates of household dietary diversity

We examined the correlates of household dietary diversity score ($HDDS_i$) by estimating:

$$HDDS_{ij} = \boldsymbol{FS_{ij}}\boldsymbol{\lambda} + \boldsymbol{x_{ij}}\boldsymbol{\beta} + \boldsymbol{\delta}_j + u_{ij} \quad (3)$$

where $\boldsymbol{x}_{ij}$ and $\boldsymbol{\delta}_j$ are as defined in Eq. 2, denoting demographic and other household characteristics and region dummies, respectively, $\boldsymbol{FS_{ij}}$ denotes a vector of indicators of the food systems, and elevation of place of residence to control for differences in agro ecologies; and u_{ij} denotes the error term. These components of food systems are hypothesized to affect people's food choices, and the indicators were selected based on previous literature and their availability in the data. Since the rural and urban food systems may have distinct characteristics, we interacted the food systems indicators with a dummy variable indicating whether or not the household is from a

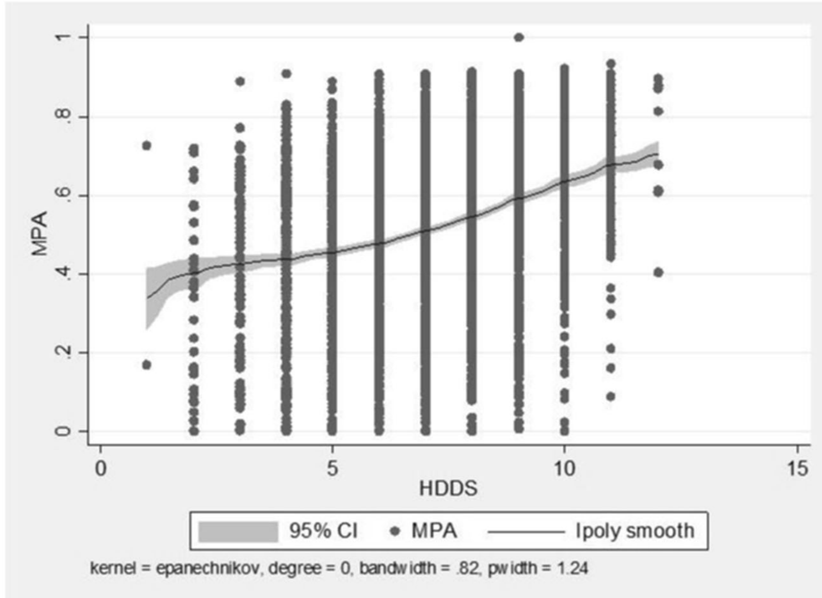

Fig. 4 The relationship between the mean probability of adequacy (MPA) and household dietary diversity score (HDDS) using kernel (local constant) regression

rural area. Hence, we also estimated a variant of Eq. 3 that includes these interaction terms.

In this study, HDDS is a measure of the number of food groups consumed over the period of seven days. Hence, the dependent variable HDDS in Eq. 3 takes a non-negative integer, which gives rise to Poisson estimation technique that can accommodate the properties of count data (Cameroon and Trivedi 2010). The Poisson model assumes the equality of (conditional) mean and variance, also called equidispersion. However, this assumption is often violated; in many cases, there is overdispersion i.e. the variance is larger than the mean, and in some cases underdispersion (Cameroon and Trivedi 2010). In our data, we found evidence of underdispersion in HDDS with a mean and standard deviation of 6.7 and 1.8, respectively (Table 4), and the corresponding variance of 3.2 which is smaller than the mean. We conducted formal tests using auxiliary regressions for two specifications used in this study. In both cases, the test results strongly rejected the null hypothesis of equidispersion and show evidence of underdispersion.[8] For underdispersed count data, Harris et al. (2012) showed that generalized Poisson regression models are suitable, and hence employed in this study. For ease of interpretation, we report the incidence-rate ratio (IRR) instead of the coefficient estimates. IRR may represent the change in HDDS in terms of a percentage increase or decrease, with the precise percentage determined by the amount the IRR is either above or below 1. Further, for the purpose of comparison, we also estimated Eq. 2 with OLS, corresponding to the general Poisson specifications. Summary results are presented in Table 6.

In general, the coefficient estimates from both OLS and general Poisson were qualitatively similar (Table 6). Notice that the IRR values are always reported with positive sign. IRR values greater than 1 indicate the corresponding coefficient estimates are positive; and conversely, IRR values less than 1 mean the estimated coefficients are negative. We interpret results from the general Poisson models, our preferred approach. Among the food system components, results of Column 3 suggest that HDDS was positively associated with proximity to the nearest population center of at least 20,000 people (IRR = 0.99 ($p < 0.05$)), but negatively associated with high elevation (IRR = 0.99 ($p < 0.05$)). When interaction terms are included, we find that availability of transport throughout the year appears to increase HDDS 1.05 times at the rate of those with no transport available throughout the year ($p < 0.05$). Further, results also suggested that rural people from areas of high elevation are less likely to diversify their diets at the rate of urban people in high elevation areas do (IRR = 0.99 ($p < 0.05$)). Surprisingly, proximity to local market does not appear to be an important correlate of HDDS. On the other hand, the interaction term of the rural dummy and distance to the nearest population center implies that rural people who are located remotely from population centers are less likely to diversify their diets at the rate of those who are close by (IRR = 0.99 ($p < 0.05$)). This along with the coefficient estimate on availability of transport services may also be signaling the effect of rural-urban linkages on HDDS. Lastly, we did not find a statistically strong relationship between HDDS and the percent of land under agriculture within approximately 1 km of the household. Further, according to Table 6, Column 3, years of education of the household head and family size of the household are all positively and statistically significantly associated with HDDS with

[8] The estimated coefficients (standard errors) for two specifications are −0.1 (0.001) and − 0.1 (0.001) with corresponding p-values of 0.000 each, respectively.

Table 5 Correlates of the mean probability of nutrient adequacy (MPA)

	(1)	(2)	(3)
HDDS	0.035**	0.010**	
	(0.004)	(0.003)	
HDDS = 2 (1/0)			0.062
			(0.050)
HDDS = 3 (1/0)			0.039
			(0.043)
HDDS = 4 (1/0)			−0.005
			(0.035)
HDDS = 5 (1/0)			−0.021
			(0.036)
HDDS = 6 (1/0)			0.012
			(0.035)
HDDS = 7 (1/0)			0.001
			(0.036)
HDDS = 8 (1/0)			0.034
			(0.031)
HDDS = 9 (1/0)			0.031
			(0.033)
HDDS = 10 (1/0)			0.079*
			(0.033)
HDDS = 11 (1/0)			0.109**
			(0.035)
HDDS = 12 (1/0)			0.082
			(0.046)
Household size in adult equivalent		−0.030**	−0.030**
		(0.003)	(0.003)
Number of children under 15		0.021**	0.021**
		(0.003)	(0.003)
Expenditure (per AFE) on MAFH over food at home		−0.079**	−0.081**
		(0.017)	(0.017)
Income quintile2 (1/0)		0.140**	0.144**
		(0.012)	(0.012)
Income quintile3 (1/0)		0.242**	0.245**
		(0.013)	(0.013)
Income quintile4 (1/0)		0.299**	0.303**
		(0.013)	(0.013)
Income quintile5 (1/0)		0.372**	0.370**
		(0.019)	(0.020)
Other controls[a]	No	Yes	Yes
Constant	0.314**	0.275**	0.303**
	(0.031)	(0.067)	(0.076)
Observations	4101	4081	4081
r2	0.110	0.419	0.427

[a] Other controls include age, gender, and religion of the household head, the number of adults above 64 years of age, rural dummy, region dummies, some indicators of food systems (i.e. distance to market, distance to nearest town with 20,000+ inhabitants, dummy for availability of health center/hospital in the community, dummy for availability of health post in the community, dummy for availability of transport throughout the year, the percent of agriculture within approximately 1 km buffer), and interaction of rural dummy and indicators of food systems

Standard errors clustered at district-level and presented in brackets.

** $p < 0.01$, * $p < 0.05$

Table 6 Correlates of household dietary diversity

	OLS		General Poisson	
	(1)	(2)	(3)	(4)
Household distance in km to nearest population center with +20,000	−0.003	−0.002	0.999*	0.999
	(0.002)	(0.002)	(0.000)	(0.000)
Vehicles pass throughout the year (1/0)	0.288	0.395*	1.031	1.047*
	(0.170)	(0.183)	(0.024)	(0.026)
Health post in this community (1/0)	0.421*	0.712*	1.064	1.117*
	(0.165)	(0.281)	(0.032)	(0.056)
Elevation (m)	−0.000*	0.000	0.999*	1.000
	(0.000)	(0.000)	(0.000)	(0.000)
Rural (1/0)	−1.91**	−1.708**	0.846**	0.832**
	(0.176)	(0.514)	(0.022)	(0.05)
Rural x Household distance to nearest pop. Center		−0.001		0.999**
		(0.002)		(0.000)
Rural x Elevation		−0.000*		0.999*
		(0.000)		(0.000)
Male household head (1/0)	0.165	0.152	1.024	1.022
	(0.091)	(0.088)	(0.014)	(0.012)
Years of education	0.045**	0.042**	1.005**	1.005**
	(0.008)	(0.008)	(0.008)	(0.001)
Household size in adult equivalent	0.235**	0.239**	1.037**	1.037**
	(0.025)	(0.024)	(0.004)	(0.004)
Expenditure (per AFE) on MAFH over food at home	−0.271*	−0.277**	0.959*	0.958*
	(0.100)	(0.097)	(0.019)	(0.019)
Income quintile2 (1/0)	0.542**	0.550**	1.082**	1.081**
	(0.152)	(0.156)	(0.026)	(0.026)
Income quintile3 (1/0)	1.094**	1.095**	1.182**	1.181**
	(0.148)	(0.150)	(0.028)	(0.028)
Income quintile4 (1/0)	1.543**	1.559**	1.241**	1.244**
	(0.169)	(0.168)	(0.031)	(0.031)
Income quintile5 (1/0)	2.394**	2.389**	1.408**	1.405**
	(0.191)	(0.187)	(0.038)	(0.036)
Other interaction terms[a]	No	Yes	No	Yes
Other controls[b]	Yes	Yes	Yes	Yes
Constant	4.848**	5.099**	5.043**	5.007**
	(0.322)	(0.597)	(0.293)	(0.458)
Observations	4080	4080	4080	4080
r2	0.442	0.453		
atanhdelta			−1.240	−1.292
			(0.170)	(0.183)
delta			−0.837	−0.859
			(0.048)	(0.048)

[a] These include: interaction of rural dummy and: distance to market, dummy for availability of health center/hospital in the community, dummy for availability of health post in the community, dummy for availability of transport throughout the year, the percent of agriculture within approximately 1 km,

[b] Other controls include age and dummies for religion of the household head, the number of children below 15 years of age, and the number of adults above 64 years of age, region dummies, dummies for month of interview, distance to nearest market, dummy for availability of health center/hospital in the community, and the percent of agriculture within approximately a 1-km buffer. Standard errors clustered at district level and presented in brackets

** $p < 0.01$, * $p < 0.05$

corresponding IRR values of 1.01 ($p < 0.01$) and 1.04 ($p < 0.01$), respectively. Results also suggest that HDDS increases with income profile of the household. As can be seen in Column 3, for example, households in the second income quintile are likely to increase their dietary diversity 1.08 times at the rate of those in the 1st (or lower) income quintile ($p < 0.01$). The corresponding IRR for the 3rd, 4th and 5th (upper) income quintiles are 1.18 ($p < 0.01$), 1.24 ($p < 0.01$), and 1.41 ($p < 0.01$), respectively. Results also suggest that the share of expenditure (per AFE) on MAFH over food at home and being from a rural area are negatively associated with HDDS, with a IRR of 0.96 ($p < 0.01$) and IRR of 0.86 ($p < 0.01$), respectively.

4 Discussion and conclusions

This study examined the state of nutrient adequacy for 13 nutrients and calorie consumption in rural and urban households in Ethiopia. Descriptive statistics showed that the average nutrient consumption varies by place of residence and income profile, with households located in urban areas and from higher income quintiles ranking favorably. The data analysis suggests that the prevalence of nutrient inadequacy for fat, calcium, zinc, riboflavin, niacin, folate, vitamin C and vitamin A ranging between 46% and 89%, and that of vitamin B_{12} up to 100%. Some of these findings are in line with a previous national food consumption survey in Ethiopia (i.e. EPHI 2013). For example, our estimates suggest that the prevalence of inadequacy of iron, zinc and vitamin A is 14%, 60%, 83%, respectively. These estimates are comparable to that of EPHI's (2013), which reported the prevalence of inadequate intakes of iron, zinc and vitamin A in non-pregnant women aged 19 to 45 years to be 13%, 50%, and 82%, respectively. Some of the discrepancies may have come about due to differences in the year of survey, recall period, methods of estimation, and measurement error. For example, unlike EPHI (2013) which used individual food intakes based on 24-h recall for non-pregnant women aged 19 to 45 years, our estimates were based on 7-day recall of a household's consumption converted to adult female equivalent, and do not take into account out-of-home consumption. Nonetheless, given such limitations, the comparability of our results to those of national consumption surveys adds evidence on the potential of household expenditure and consumption surveys to help draw policy relevant information in the absence of national food consumption surveys which are more costly and hence not routinely collected. Coates et al. (2017) also show similar evidence based on data from Oromia and SNNPR regions of Ethiopia and the 2011–2012 Bangladesh Integrated Household Survey (BHIS). Sununtnasuk and Fiedler (2017) also provide similar evidence using the 2011–2012 BHIS. These two studies slightly differ from ours since their data have information on the dietary intake of every individual in the household as well as the aggregate household-level consumption for the previous 24 h. This allowed them to make a comparison of individual intakes with household level consumption using the adult male equivalent (AME) approach. By contrast, our data were based on 7-day recall for household level consumption and using the adult female equivalent.

Dietary diversity is one of the proxies for diet quality, and previous studies have shown that individual (in some studies household) dietary diversity is associated with nutrient adequacy (see Ruel 2003, 2019; Ruel et al. 2018). Nonetheless, attaining household nutrient adequacy may require consumption of a broad number of food groups. Hence, this study also tested for potential threshold effects of household dietary diversity score in Ethiopia. First, regression results showed that HDDS is indeed strongly associated with a household's mean probability of nutrient adequacy (MPA). After controlling for covariates, we found that a standard deviation increase in HDDS is associated with about 15% increase over the MPA. Second, based on a household's food consumption over the previous seven days, results showed that an HDDS of 10 is the minimum threshold at which HDDS may improve household MPA.

The novelty of our research also lies in the use of the food systems perspective, an emerging approach which understands food as a "system", taking into account food supply chains, food environments and consumer behavior (HLPE 2017). Accordingly, across indicators of food system components, the descriptive statistics show that households with access to a health post, hospital or health center in the community, and to vehicle transport throughout the year reach higher HDDS than their counterparts with no or limited access to such services. These results hold in a multivariate context, when HDDS is analyzed against potential drivers with specific focus on indicators of food system components. Results suggest that HDDS is positively and strongly associated with availability of a health post in the community, proximity to the nearest large population center, and availability of transport throughout the year, but negatively associated with elevation. Surprisingly, proximity to local market does not appear to be an important correlate of HDDS. This is possibly because households rely more on larger markets in larger population centers where opportunities for access to modern production inputs, new information and exchanging own produce for more diversified foods are greater than they are in local markets. For example, Minten et al. (2016) found farmers located closer to the large market of Addis Ababa adopting modern inputs more frequently. Access to such markets may result in improved marketing of agricultural surplus and purchased consumption goods (Stifel and Minten 2017). This may be facilitated by availability of transport throughout the year, potentially signaling the important role of rural-urban linkages for improved HDDS. On the other hand, rural people who are located remotely from larger population centers are less likely to diversify their diets at the rate of those who are close by. These results are in line with previous studies which find that market access (e.g. proxied by transport cost) improves consumption of diverse diets in Ethiopia (e.g. Stifel and Minten 2017; Hirvonen et al. 2017; Hirvonen 2016). Additionally, there seemed to be no strong relationship between HDDS and the percentage of land under agriculture within approximately 1 km of a household's location. This is surprising given that availability or production of fresh and diversified foods (and hence consumption) are likely to be higher with the increase in the share of agriculture near population centers (e.g. Tasciotti and Wagner 2014). Strong associations between local production and local consumption patterns are expected partly because perishable foods are produced near population centers and not traded long distances, given poor infrastructure in low-income countries (Heady and Masters 2019). In fact, the tendency of producing perishable foods near population centers and hence consumption have long been theorized by von Thünen (1826), although the underlying assumptions might seem "simplistic" in a contemporary context.

Results of this study, however, need to be interpreted with care for the following reasons. First, in observational studies, the preferred method of data collection on food intakes is based on quantitative 24-h recalls (IOM 2006). The dietary consumption data for this study came from a household consumption survey and are not based on individual dietary intake. Second, the amounts of food consumed during the recall period were estimated by the respondent, possibly introducing recall bias. Also, there was a fixed list of food items to recall from and the information on the out-of-home consumption was limited and hence not included in the calculations. In fact, the negative relationship between the share of expenditure (per AFE) on meal away from home (MAFH) over food at home with the MPA, and with that of the HDDS, suggest that our estimates of nutrient adequacy and HDDS are biased downwards. Third, even though nutrient consumptions in this study were assessed under the assumption that nutrients are acquired by household members according to energy requirements specific to the individual's age, sex, physical activity level, and so-on, this may not be necessarily the case (e.g. Coates et al. 2018; Wibowo et al. 2015). This is because intra-household food allocation is determined by relative differences in household members' income, bargaining power, food behaviors, social status, tastes and preferences, and interpersonal relationships (Harris-Fry et al. 2017), among others. Fourth, the correlates of nutrient consumption may vary by individual nutrients and their food sources. Hence the correlates of household MPA assessed in this study may not fully take these heterogeneities into account. This warrants further research on individual nutrient consumption and factors that may influence dietary choices such as cultural norms and beliefs, such as social desirability or a person's relative position in the society.

In sum, given the caveats, results of this study provide suggestive evidence that policies and interventions targeting HDDS may improve household nutrient adequacy. A systems approach that improves household incomes, together with improvement of access to health and transport services may be beneficial.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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