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Diet diversity, malnutrition and health: Evidence from Kenya

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Abstract
We investigate the effects of diet diversity on health outcomes indicated by the body-mass index (BMI) of Kenyan women in their reproductive age (15–49 years). We estimate the demand for diet diversity (which is a proxy for diet quality) and analyse its relationship with BMI by allowing the effect of diet diversity to vary along the conditional BMI distribution. Results show that diet diversity is associated with a beneficial effect on the lower and upper tails of the BMI distribution, that is, dietary diversity improves BMI for underweight individuals while, at the same time, it reduces BMI for overweight/obese individuals. Specifically, doubling the diet diversity is associated with a 14.7% increase in BMI for underweight women and a 7.0% reduction in BMI of obese women. These results support the hypothesis that diet diversity is associated with optimal BMI and, thus, better health, contributing to the policy discourse concerning the double burden of malnutrition in developing countries.

KEYWORDS
Africa, BMI, demand, diet diversity, double burden of malnutrition, food security, health, Kenya

JEL CLASSIFICATION
C21, D12, I12, Q12

1 | INTRODUCTION

Obesity has nearly tripled since 1975 globally, and has become a significant public health problem in many countries (WHO, 2021). Importantly, obesity is now emerging as a major problem in developing countries, alongside other common forms of malnutrition, giving rise to the 'double burden of malnutrition' (DBM) (Abdulai, 2010; Davis et al., 2020). Malnutrition can take several forms, including undernutrition (wasting, stunting and underweight), inadequate nutrient balance and unhealthy weight gain (overweight and obesity), often associated with the 'nutrition transition' (NT) in developing countries (Lowe et al., 2021).[1] Ultimately, malnutrition is associated with diet-related, non-communicable diseases (NCDs), such as heart disease, strokes and type 2 diabetes (WHO, 2021).

A major cause of malnutrition among poor households is the low diet diversity and the associated low intake of essential micronutrients (Bouis et al., 2011; Osendarp et al., 2020; Von Grebmer et al., 2014). Excess weight, obesity and associated NCDs are largely preventable through improvements in lifestyle choices and consumption habits (WHO, 2021). Literature on nutrition (Drescher et al., 2007; Hatløy et al., 1998; Hoddinott et al., 2015) highlights the importance of nutritious and diverse diets for better health. However, it also shows that certain foods that constitute a healthy diet are not being consumed in sufficient quantities to meet recommended intakes (WHO, 2021) or are being replaced by unhealthy (new) foods in the NT process (Davis et al., 2020; Lowe et al., 2021). This occurs particularly in poor households, where diets often consist of starchy staples and sugary beverages, which are nutrient-poor. Such diets often reflect the unavailability and unaffordability of more healthy foods (FAO, 2019).

In Kenya, the DBM—overweight and obesity existing alongside undernutrition—has been well documented (Christensen et al., 2008; Ziraba et al., 2009). Notably, there is a persistent undernutrition problem among children and a rising problem of overweight and obesity among women.[2] In Kenya, the increasing trend in obesity for women has been attributed to rapid urbanisation, and associated factors such as: (i) change in consumption patterns brought about by nutritional transition and growth of supermarkets and fast food outlets (Rischke et al., 2015); (ii) changes in lifestyles such as physical inactivity and unhealthy eating habits (Popkin, 2002); and (iii) the use of hormonal contraception such as pills, intrauterine devices, injections and implants (Mkuu et al., 2018).

Nonetheless, there are some misconceptions of obesity, often due to social and cultural perceptions and attitudes. For example, Renzaho's (2004) study of obesity in sub-Saharan Africa shows that being obese or overweight is seen as a symbol of wealth, autonomy, attractiveness, happiness, beauty and success within the community. Lowe et al. (2021) report similar findings for Indonesia. In addition, some attribute underweight or 'thinness' to underlying health problems such as HIV (Human Immunodeficiency Virus) and AIDS (Acquired Immune Deficiency Syndrome). These misconceptions could result in a shift in dietary intake to high-fat and highly processed foods and beverages which, in turn, may constitute an unhealthy diet (Davis et al., 2020; Popkin, 2002).

An accelerator of the nutritional transition is rising incomes that have led to a greater demand for and consumption of nutrient-rich foods such as fruit, vegetables, wholegrains and seafood (Kearney, 2010). People tend to diversify their diet as their income increases, largely because of affordability. Therefore, a lack of affordability (i.e., being poor or unable to access desired foods) often causes insufficient consumption of diversified diets, characterised as healthy and nutritionally adequate (Braha et al., 2017; Ruel, 2003). Diet diversity is critically important for nutrition (Hatløy et al., 1998), but diet diversity resulting from a shift towards more processed energy-dense foods is not what improved nutrition calls for (Osendarp et al., 2020; Pinstrup-Andersen, 2012).

Thus, assessing household dietary diversity—even though it is an imperfect measure of nutritional quality—is vital because it reflects household's economic ability to access a variety of food nutrients (Ruel, 2003). Further, the focus of this study is the relationship between a diverse (quality) diet and good health, which creates a specific context for the importance of optimal diet evaluation. Given limited knowledge on the link between dietary quality and health in developing countries (Lowe et al., 2021) our study should be useful for academics and policy-makers.[3]

[1]Nutritional transition (NT) involves an increase in the consumption of highly processed foods and beverages, which are often high in fat, sugars, salt and processed meat (Popkin, 2002). These foods are often cheap, satisfying, convenient and heavily promoted, thus influencing consumers' buying behaviour (Kearney, 2010). The resulting diet changes often worsen the diet nutritional quality (Drewnowski & Popkin, 1997; Popkin, 2002).

[2]Increased incidences of overweight and obesity have been attributed to multiple genetic, environmental and behavioural factors (Hurt et al., 2011).

[3]Relevant studies from the transition country context are Huffman and Rizov (2010) and Braha et al. (2017).

We develop a theoretically founded, two-stage analytical framework. First, we investigate the dietary situation of Kenyan households in terms of access to a good quality diet and the various constraints of accessing such a diet. We estimate the optimal demand for diet diversity following Jackson (1984) and Herzfeld et al. (2014), and borrowing ideas from Lee and Brown (1989) and Leschewski et al. (2017). Our subsequent analysis investigates the impact of diet diversity on individual body mass index (BMI) while controlling for a range of individual/household and environmental factors, following Huffman and Rizov (2010) and Braha et al. (2017). To deal with simultaneity issues, the predicted value of demand for diet diversity is used as a regressor, together with exogenous factors, to estimate the BMI supply function, defined in our theory section.

The following propositions, motivated by theory and empirical evidence, guide our analysis:

i. Household socioeconomic status affects diet diversity, and a more diverse diet indicates better food utilisation and, hence, improved food security status;
ii. A diverse diet is associated with optimal individual BMI, which, in turn, is associated with better health-related outcomes.

Next, Section 2 introduces the data, discusses the underlying theory and our empirical methods. The findings are presented and discussed in Section 3, followed by conclusions and recommendations for further research.

2 | MATERIALS AND METHODS

2.1 | Data

We use data from the 2014 Kenya Demographic and Health Survey (KDHS), which is a national representative cross-sectional household survey, commissioned by the World Bank. The 2014 KDHS used a household questionnaire for women aged 15–49 and men aged 15–54, which we use to analyse the (household) demand for diet diversity. A dedicated women's questionnaire was also administered, and the associated data were used in subsequent analysis of the relationship between diet diversity and health. This questionnaire recorded a variety of individual information, including the height and weight measurements of surveyed women. Both questionnaires were administered to all households. One of the main purposes of the household questionnaire was to identify women who were eligible for the individual interview. A total of 15,317 women were identified as eligible for the full women's questionnaire, of whom 14,741 were successfully interviewed—a response rate of 96%.

The sample for the 2014 KDHS was drawn from a master sampling frame that the Kenya National Bureau of Statistics (KNBS) operated then to conduct household-based surveys throughout the country. Kenya is divided into 47 counties, which serve as devolved units of administration, and each county is stratified into urban and rural strata; because the counties of Nairobi and Mombasa have only urban areas, the resulting total was 92 sampling strata. The 2014 KDHS was designed to produce representative estimates at a national level for most of the survey data, for urban and rural areas separately at a regional level, and for selected indicators only at a county level. Therefore, data were appropriately weighted to ensure its representativeness at national, regional and county levels accounting for the non-proportional allocation of the sampling strata and the fixed sample size per cluster.

We restricted our analysis to data containing complete individual anthropometric and household information. In the first stage—analysis of household demand for diet diversity—we use data from 36,430 households. In the second stage, we used individual anthropometric data for 13,048 women in their reproductive age (between 15–49 years). Household respondents in the 2014 KDHS were asked how many days during the 7 days preceding the survey members of their household had consumed items from various food groups (staples, pulses, vegetables, fruit, meat, dairy, oil and condiments). They were also asked if there were any days in the 7-day recall period in which their household did not have food or enough money to buy food. Key socioeconomic variables were also used for the analysis such as age, gender and education level of the household head; at household level main variables were family size, location and household wealth indicator. Additionally, some basic information was collected on the characteristics of each household member, including age, gender, education and relationship to the household head.

2.2 | Measurement and demand for diet diversity

Diet diversity is measured by a function of the number of individual food items or food groups consumed over a given period of time (Ruel, 2003). The type and number of food groups may vary, depending on the intended purpose and level of measurement. Most often, it is measured by simply counting the number of food groups or food items consumed. More elaborate diet diversity indices are also considered. At a household level, such indices can be interpreted as access to diverse foods (e.g., the household's ability to access food items or food groups), whereas at an individual level, they reflect dietary quality, mainly in terms of the micronutrient adequacy of the individual's diet (Kennedy et al., 2011).

We use five distributional indices as measures of diet diversity: (i) Count Measure (CM), which counts the number of food products consumed by a household or individual (Ruel, 2003); (ii) Entropy Index (EI), which reflects how many different types of food items are consumed and how evenly these different items are distributed (Theil & Finke, 1983); (iii) Simpson Index (SI) also known as the Berry Index, which is used to evaluate dietary diversity in terms of number as well as distribution and quantity of different food items consumed (Berry, 1971; Greene, 2003); (iv) Dietary Diversity Score (DDS), which is a qualitative measure of food consumption that reflects a household's access to a variety of foods, as a proxy for nutrient adequacy of the diet (Kant, 1996; Kant et al., 1995); and (v) Healthy Food Diversity (HFD) index, which captures three important aspects of a varied diet simultaneously: number, distribution, and health value of consumed foods (Drescher et al., 2007). We calculate these measures from information on the quantity and frequency of consumption of 16 food groups within a 7-day recall period. Appendix A, online, gives more details on the definition and calculation of each of the five diet diversity measures.

2.3 | Diet diversity and health (BMI)

Following Huffman and Rizov (2010), we use an empirical framework, based on a theoretical model of household production of health (Grossman, 2000; Rosenzweig & Schultz, 1982), through which we analyse the relationship between diet diversity and health measured by BMI. [4] The framework leads to an individual BMI production function:

$$BMI = f(D, L, O, \varepsilon), \tag{1}$$

where *BMI* is a function of consumption of food, *D* (capturing diet diversity); leisure, *L*; fixed individual characteristics, such as age, gender, education, socioeconomic background, *O*; and unobservable/unobserved individual characteristics such as genetic factors that affect an individual's BMI, ε. We note that in large meta-population samples, ε tends to be randomly distributed, with a zero mean, influencing the different population cohorts in a similar manner (Malis et al., 2005).

[4]BMI as an indicator of health status has its limitations. Nuttall (2015) shows that BMI's use to estimate percentage of body fat and ultimately predict health-related outcomes is a rather crude approach. Even when some comorbidities are considered, the correlation of mortality rates with BMI should also take into consideration such factors as individual age, lifestyle and occupation, family history of diabetes, hypertension, and coronary heart disease, familial longevity, and so on.

Food consumption affects utility directly and indirectly through BMI production by providing energy, vitamins and minerals. In maximising their utility, subject to a budget constraint, individuals choose optimal levels of D and L (and consumption of other goods, C).

$$\Phi^* = f_\Phi\left(P_D, P_C, W, N, O, \varepsilon_\Phi\right), \Phi = D, L \quad (2)$$

where the demand for inputs Φ into the BMI production function depends on the prices of all purchased inputs, P_D and P_C, the wage rate, W, non-labour income, N, fixed (individual) factors, O and unobserved factors, ε_Φ, which are assumed to have a zero expected mean.

Substituting the demand functions D and L into the BMI production function (Equation 1) leads to the individual BMI supply function.[5]

$$BMI^* = f_S\left(P_D, P_C, W, N, O, \varepsilon_\Phi\right). \quad (3)$$

Equation (3) represents the solution to the first order (Kuhn-Tucker) conditions for the structural endogenous variables (D, L) in terms of exogenous factors, which include wages, prices and characteristics of BMI production (and utility) function. The BMI supply function (Equation 3) is a reduced-form, behavioural relationship based on the individual's optimal decisions, whereas the individual's BMI production function (Equation 1) is a technological relationship. This is the most common method to make a transition to an empirical framework (Huffman & Rizov, 2010).

An alternative 'structural' approach to the transition to an empirical framework can be implemented in two stages: first, estimating the demand functions for inputs (D^*, L^*) and, secondly, substituting the predicted values in the technology (Equation 1). Given our goal of analysing the factors associated with the double burden of malnutrition in Kenya, we adopt a modified structural approach in this paper. [6] Thus, in the empirical analysis, we first estimate the optimal demand for diet diversity. In the second stage, the predicted value of a measure of diet diversity is used as a regressor, together with the exogenous (predetermined), individual characteristics, listed in vector O, to estimate the BMI supply function:

$$BMI^* = f_s^*\left(D^*, L', O, \varepsilon'_B\right) \quad (4)$$

Equation (4) is the focus of our empirical analysis of the link between health, BMI and diet diversity. An advantage of the two-stage procedure is that it deals with the possible endogeneity of the main explanatory variable of interest—diet diversity—used in the BMI supply equation. Specifically, we use a predicted value from the first stage in the second stage Furthermore, it is reasonable to assume that factors affecting current BMI are predetermined, since BMI results from lagged decisions and choices.

2.4 | Empirical implementation

Following the formulation of the two-stage (structural) approach above, we first estimate the endogenous diet diversity variables affecting BMI production and supply. We then use the predicted values, one by one, in the second stage for the BMI supply function (Equation 4). The diet diversity specification used in this study is based on the demand for diet diversity and extensions by Jackson (1984) and Herzfeld et al. (2014). We implement empirically the household diet diversity demand function following Herzfeld et al. (2014) and Cupák et al. (2016) by specifying and estimating an equation in which household diet diversity is explained by a set of household income quartile dummies (Poorest, Poorer, Richer and Richest), regional dummy variables capturing price variations, household

[5] This is analogous to the derivation of the supply function for farm output in an agricultural household model (Huffman, 1991).

[6] We call our empirical approach 'modified' because we use a predicted value from the first stage only for the diet diversity measure. The demand for leisure, L' is proxied by the individual (predetermined) characteristics and additional location controls, capturing variation in wages.

characteristics (highest education level in the household, gender of household head, age of household head, household size), food insecurity status and ratio of auto-consumption (consumption from own production). The diet diversity demand function is estimated by OLS regression.

In the second stage, we use the predicted diet diversity values from the first stage to estimate the individual (women's) BMI supply function (Equation 4) by GLS and quantile regression. We also include as explanatory variables: individual characteristics, specified in vector O (women's age and education); a set of dummy variables controlling for regional (including rural/urban and capital city) differences; a wealth index controlling for reservation wage. To address concerns about endogeneity with some of the explanatory variables, we introduce the explanatory variables stepwise to check for stability of coefficients to changes in the specification where stability of coefficients suggests no severe endogeneity.

3 | RESULTS AND DISCUSSION

3.1 | Demand for diet diversity

The summary statistics for the variables used in the OLS regressions of demand for diet diversity are shown in Table 1. Of particular interest are the diet diversity measures, alongside socioeconomic factors, demographic characteristics, ratio of auto-consumption, and food insecurity dummies. Dietary behaviours among adults are influenced by such factors as health status, individual characteristics (gender and education), socioeconomic status, lifestyle practices, early dietary influences, knowledge, psychological attributes and culture (Davis et al., 2020; Huffman & Rizov, 2010). Diet is a known risk factor for chronic diseases. For instance, the research of Conklin et al. (2016) in the UK provides evidence that individuals who reported consuming all five major food groups had a 30% reduced incidence of type 2 diabetes, but the cost of such a diet was 18% higher than a diet comprising of three or fewer food groups. Several studies have shown that HFD and DDS are better measures of diet diversity and are therefore good proxies for diet quality (e.g., Berry, 1971; Braha et al., 2017; Drescher et al., 2007). Furthermore, recently, the HFD index has been frequently used, and it seems to be the most preferred measure of 'healthy' dietary diversity, being both positively related to measures of dietary adequacy and inversely related to excess nutrients (Drescher et al., 2007; Verger et al., 2021). The correlation matrix of the five diet diversity measures is available in Online Appendix A, Table A1. Most consistent correlation coefficients, always above 0.5, are exhibited by the HFD measure.

The mean representation of the data further reveals some interesting facts. Looking at the wealth index, which is scored into five quintiles based on a set of household characteristics, 17% of the population are placed in the poorest category and 24% are the richest households, with the reference category being the middle-income group. In the sample, most individuals have completed primary education (46%), with equal percentages of those who have no education or higher education (both 14%); the reference category is primary education group representing 26%. The household size has a mean of 4 people, and the age of the household head is around 43 years, with most of the households headed by males (68%). Further, 58% of the sample are from the rural regions, while 10%, 2%, 14%, 10%, 14%, 11%, 25%, 13%, and 12% are from the Coast, North-eastern, Western, Eastern, Central, Rift valley, Nyanza, and Nairobi provinces, respectively. Finally, 31% of the population is food insecure.

The household demand for diet diversity estimation results are presented in Table 2 as separate specifications are estimated, with each diversity measure discussed as the dependent variable. Reported standard errors are robust, and the hypothesis that all explanatory variables are jointly equal to zero is rejected in all regressions, with coefficients varying in magnitude and direction.[7]

[7]Diagnostic tests were performed to test the appropriateness of using the OLS model such as the Ramsey test for omitted variables, test for the exogeneity of each endogenous variable, test for normality in residuals, including Shapiro–Wilk test for normality. The tests were satisfied; the detailed results are available from the authors.

TABLE 1 Summary statistics

Variable	Mean	Min	Max	Std. dev.
BMI	23.70	12.57	58.61	4.59
CM	10.36	1	16	2.56
EI	2.28	0.69	2.80	0.23
SI	0.87	0	0.93	0.04
TSI	1.94	−1.27	2.65	0.31
DDS	1.23	0	2	0.19
HFD	0.41	0	0.59	0.05
Household (HH) size	3.99	1	23	2.43
Rural dummy	0.58	0	1	0.49
Coast dummy	0.10	0	1	0.30
North-eastern dummy	0.02	0	1	0.14
Eastern dummy	0.14	0	1	0.35
Western dummy	0.10	0	1	0.30
Central dummy	0.14	0	1	0.34
Rift-valley dummy	0.25	0	1	0.44
Nyanza dummy	0.13	0	1	0.33
Nairobi dummy	0.12	0	1	0.33
Poorest HH	0.17	0	1	0.37
Poorer HH	0.18	0	1	0.38
Middle HH	0.19	0	1	0.39
Richer HH	0.23	0	1	0.42
Richest HH	0.24	0	1	0.42
No education (in HH)	0.14	0	1	0.34
Primary education (in HH)	0.46	0	1	0.50
Secondary education (in HH)	0.26	0	1	0.44
Higher education (in HH)	0.14	0	1	0.34
Male headed HH	0.68	0	1	0.47
Age (HH head)	42.93	14	95	15.74
Food insecure	0.31	0	1	0.46
Ratio of 'auto consumption'	0.15	0	1	0.18
Age (women)	28.26	15	49	9.27
No-education (women)	0.07	0	1	0.25
Primary education (women)	0.48	0	1	0.50
Secondary education (women)	0.34	0	1	0.47
Higher education (women)	0.11	0	1	0.31
Rural dummy (women)	0.60	0	1	0.49
Capital dummy (women)	0.12	0	1	0.29
Wealth index (women)	3.27	1	5	1.41

Note: HH denotes household. Number of observations is 17,343 for HH regression variables and 14,927 for women regression variables respectively.

TABLE 2 OLS estimates of demand for diet diversity

Variables	CM	TSI	EI	HFD	DDS
Household size	0.040***	0.006***	0.004***	0.001***	−0.003***
	(0.009)	(0.001)	(0.001)	(0.000)	(0.001)
Rural dummy	−0.256***	−0.026***	−0.022***	−0.006***	−0.035***
	(0.053)	(0.006)	(0.005)	(0.001)	(0.004)
Coast dummy	−0.161	0.017	0.002	0.013***	0.037***
	(0.091)	(0.011)	(0.008)	(0.002)	(0.007)
North-eastern dummy	−0.507***	−0.003	−0.017	−0.023***	0.052***
	(0.123)	(0.017)	(0.012)	(0.003)	(0.013)
Eastern dummy	−0.045	0.031**	0.012	0.025***	0.019**
	(0.081)	(0.010)	(0.007)	(0.002)	(0.006)
Central dummy	0.014	0.036***	0.015	0.015***	0.069***
	(0.089)	(0.011)	(0.008)	(0.002)	(0.007)
Rift-valley dummy	−0.322***	−0.012	−0.019**	0.007***	0.000
	(0.077)	(0.010)	(0.007)	(0.002)	(0.006)
Nyanza dummy	0.104	0.000	0.003	0.009***	0.021***
	(0.083)	(0.010)	(0.007)	(0.002)	(0.006)
Nairobi dummy	−0.048	0.006	−0.003	0.018***	0.020*
	(0.122)	(0.014)	(0.010)	(0.002)	(0.009)
Poorest HH	−1.414***	−0.181***	−0.137***	−0.015***	−0.030***
	(0.069)	(0.009)	(0.006)	(0.002)	(0.006)
Poorer HH	−0.635***	−0.072***	−0.058***	−0.005***	−0.008
	(0.067)	(0.008)	(0.006)	(0.001)	(0.005)
Richer HH	0.414***	0.040***	0.032***	0.003*	0.022***
	(0.066)	(0.007)	(0.006)	(0.001)	(0.005)
Richest HH	1.256***	0.126***	0.102***	0.011***	0.072***
	(0.082)	(0.009)	(0.007)	(0.002)	(0.006)
No education (in HH)	−0.441***	−0.064***	−0.047***	−0.012***	−0.020**
	(0.069)	(0.009)	(0.007)	(0.002)	(0.006)
Secondary education (in HH)	0.335***	0.033***	0.027***	0.004***	0.009*
	(0.058)	(0.006)	(0.005)	(0.001)	(0.004)
Higher education (in HH)	0.687***	0.075***	0.059***	0.008***	0.032***
	(0.082)	(0.009)	(0.007)	(0.002)	(0.006)
Male headed HH	0.209***	0.028***	0.020***	0.002	0.013***
	(0.047)	(0.006)	(0.004)	(0.001)	(0.004)
Age (HH head)	−0.009***	−0.001***	−0.001***	0.000*	0.000
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Food insecure HH	−1.013***	−0.138***	−0.098***	−0.011***	−0.039***
	(0.052)	(0.006)	(0.005)	(0.001)	(0.004)
Ratio of 'auto consumption'	0.594***	0.111***	0.076***	0.031***	0.223***
	(0.127)	(0.017)	(0.012)	(0.003)	(0.011)
Constant	10.779***	1.960***	2.306***	0.395***	1.191***
	(0.118)	(0.014)	(0.010)	(0.002)	(0.009)

TABLE 2 (Continued)

Variables	CM	TSI	EI	HFD	DDS
R-squared	0.322	0.299	0.315	0.144	0.142
No. of observations	17,343	17,337	17,343	17,343	17,343

Note: HH denotes household. Reference category for the level of income is middle-income group; reference category for level of education is primary education group; reference category for location is Western (dummy) region.

* $p<0.05$, ** $p<0.01$, *** $p<0.001$.

According to the empirical results, household size has a positive, significant impact on demand for diverse diets in all specifications, except for the DDS measure, which gives higher weight to healthy food items. This suggests that the larger the household, the less access it has to healthy food—'more mouths to feed'. Although this can be true for poor households, they can actually access more food items, as indicated by the positive relationship with the rest of the measures (CM, TSI, EI and HFD). Lee and Brown (1989) find similar results showing that a diverse diet is positively related to the number of household members in different ages and gender groups. However, Lee (1987) suggests that an increase in female members has a greater impact on the number of different foods consumed than the addition of male members. The age of the household head has a negative impact on diet diversity, except in terms of the DDS measure. These results correspond to findings by Lee (1987) and Thiele and Weiss (2003), suggesting that there is a non-linear relationship between diet diversity demand and age. However, Drescher and Goddard (2008) found contrasting results of a positive association between age and diet diversity in Canadian data.

Male-headed households (except for the HFD measure) have a positive effect on the demand for diet diversity. This could imply that men as a source of income and stability for the household can secure better diets. However, Akerele and Odeniyi's (2015) study in Nigeria finds a positive relationship between women household heads and the consumption of diverse diets. This is because women traditionally have a nurturing role and they often control the food budget within the household. As such, they can enhance the quality of the food consumed by their households if empowered and given more resources. Households with no education have a lower diet diversity, whereas households with some education (except for DDS in secondary education) show a better diet diversity. Education is likely to impact upon dietary practices and nutrition through improvements in health knowledge, literacy, wealth and prenatal care utilisation. Makate and Makate (2018) further suggest that promoting schooling access of girls in resource-poor nations might have far-reaching implications on feeding practices and, consequently, child nutrition.

The ratio of auto-consumption has a positive effect on the demand for diverse diet. The finding resonates with the theory of household production which posits that a household consumes commodities that it produces as the production of each commodity requires an input of human time of one or more household members and inputs/goods purchased in the market (Becker, 1965; Michael & Becker, 1973). The auto-consumption ratio represents subsistence consumption, which is usually high in smallholder households (Fredriksson et al., 2021). This highlights the importance of focusing on smallholder subsistence farmers, as they tend to be the majority in developing countries. Sibhatu et al. (2015) provide evidence to suggest that increasing on-farm diversity could be an effective way of improving diet diversity in smallholder households, while Hoddinott et al. (2015) and Kanter et al. (2015) discuss how important agriculture and food system policies are to nutritional outcomes and public health.

Rural location has a negative impact on diet diversity, perhaps because a larger proportion of rural households are subsistence farmers. This suggests investment in rural household production capacity could result in reducing poverty, increasing food security, improving nutrition, and strengthening resilience (Korir et al., 2021). Turning to regional effects on diet diversity demand, the Coast, North-eastern, Eastern, Rift-valley and Nairobi provinces have a negative effect on diet diversity. Nyanza shows a significant positive effect on diet diversity in the CM, HFD and DDS specifications.

Central province locations also show a significant positive effect on household diet diversity in most specifications reflecting the variety of crops grown in the province. This suggests that the geopolitical zones in which households belong (also associated with cultural differences) significantly influence consumption behaviour (Akerele & Odeniyi, 2015). Furthermore, the increasing growth of towns and cities has offered, alongside the accelerated NT, stable and consistent access to a wide range of foods with different dietary qualities (Lowe et al., 2021; Rischke et al., 2015).

Richer and richest households show a positive association with diet diversity in all specifications, whereas poorer households have less diverse diets. Lee and Brown (1989) and Stewart and Harris (2005) report a positive relationship between income and demand for variety, and Temple (2006) finds similar results by using ownership of a dwelling to represent wealth. However, Akerele and Odeniyi (2015) find that demand rises at a declining rate as household income grows. The positive relationship is also consistent with the theory of household production, which implies that an individual's opportunity cost of time determines their demand for variety. We also find that diet diversity increases with education across all diversity measures, perhaps in contrast to Makate and Makate (2018), who find that education increases the likelihood of buying ready-meals. However, it may be the case that education increases awareness of the importance of consuming a healthy diet (Huffman & Rizov, 2010).

3.2 | Diet diversity and BMI

In this section, we report the main (second stage) estimation results from the GLS and conditional Quantile Regression (QR) estimators for each of the five (predicted) diet diversity measures (CM, TSI, EI, DDS and HFD) as main explanatory variables. BMI is our dependent variable linked with the consumption of diverse diets. Our data show that the women in the sample have a mean BMI of 23.7; thus, most of them are within the optimal BMI range from 18.5 to 25 according to WHO (2021); a BMI above 30 indicates obesity. The distribution of BMI in our sample shows 11.6% are undernourished individuals, 59.2% have optimal BMI, 20.3% are overweight and 8.9% are obese.

Our estimation results are shown in Tables 3 and 4, and Figure 1. We focus on five quantiles of the BMI distribution ($Q = 0.05$, $Q = 0.20$, $Q = 0.50$, $Q = 0.80$, and $Q = 0.95$) which capture the three main categories of individual weight (and health) status—underweight, normal weight, and overweight/obese. Table 3 shows a summary set of results from the QR specification with the HFD index, which is, as discussed, the most preferred measure of diet quality. Detailed estimation results, with other diversity measures, which are similar to the HFD results reported here are available from the authors. The first column represents the GLS estimation coefficients, followed by the results for the quantile regression results. Fitted values of HFD index in Table 3 show that diet diversity is positively associated with BMI for the lower quantiles (q05, q20, and q50) and negatively for the higher quantiles (q80 and q95). At the 95th quantile, which represents the most obese individuals of the population, HFD shows a significant, negative association with BMI, suggesting that a diverse diet may reduce the BMI of obese individuals. This result, taken together with the finding that HFD is significantly and positively associated with BMI at the 5th and 20th quantiles, provides evidence of an inverted-U-shape relationship between diet diversity and BMI. Thus, our results imply that a diverse diet is associated with (if not causal to) a reduced double burden of malnutrition.

The results further show that age exerts a significant positive influence on BMI. The quadratic term of age is also statistically significant but with a negative sign, which is suggestive of a non-linear relationship between age and BMI. This shows that, although an increase in age will positively affect BMI, the effect would rise at a declining rate as individual age increases. Women's education has a negative impact on BMI, which may reflect better social status and lifestyle as they are associated with a lower BMI. Furthermore, there is evidence that women who receive even a minimal education may be more aware than those who have no education about their own nutritional status and that of their families. Makate and Makate (2018) have noted that highly educated mothers are more likely

TABLE 3 GLS and QR estimates: Dependent variable is women's BMI

Variables	GLS	Q05	Q20	Q50	Q80	Q95
Diet diversity (fitted values)	0.348**	0.815***	0.652***	0.362*	−0.061	−0.550*
	(0.130)	(0.203)	(0.149)	(0.151)	(0.189)	(0.261)
Age	0.019***	0.019***	0.016***	0.018***	0.022***	0.023***
	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.003)
$Age^2 \times 10^2$	−0.020***	−0.020***	−0.019***	−0.023***	−0.026***	−0.023***
	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)	(0.004)
No education	−0.051***	−0.043***	−0.057***	−0.065***	−0.044***	−0.052***
	(0.007)	(0.007)	(0.007)	(0.008)	(0.01)	(0.013)
Secondary education	0.009*	0.014*	0.010*	0.009	0.014*	0.001
	(0.004)	(0.007)	(0.005)	(0.005)	(0.006)	(0.009)
Higher education	0.002	−0.022	−0.008	0.014	0.011	0.004
	(0.008)	(0.012)	(0.010)	(0.009)	(0.009)	(0.014)
Rural dummy	−0.010*	0.004	0.001	−0.009	−0.020***	−0.025**
	(0.004)	(0.007)	(0.005)	(0.005)	(0.006)	(0.008)
Capital dummy	0.006	0.025*	0.013	0.004	0.009	0.004
	(0.009)	(0.011)	(0.009)	(0.012)	(0.018)	(0.021)
Wealth index	0.034***	0.020***	0.025***	0.033***	0.040***	0.048***
	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)	(0.004)
Constant	2.552***	2.189***	2.384***	2.547***	2.758***	3.056***
	(0.054)	(0.085)	(0.062)	(0.061)	(0.078)	(0.108)
R-squared	0.222					
Pseudo R^2	-	0.093	0.110	0.133	0.161	0.156
No. of observations	14,927	14,927	14,927	14,927	14,927	14,927

Note: The dependent variable, BMI is in log. Diet diversity is measured by the HFD fitted values. Reference category for level of education is primary education group.
$*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

TABLE 4 Summary of BMI diet diversity elasticities

	CM	TSI	EI	HFD	DDS
Q05	0.093***	0.053***	0.086***	0.147***	0.104***
	(0.018)	(0.014)	(0.016)	(0.036)	(0.021)
Q20	0.074***	0.045***	0.071***	0.104***	0.093***
	(0.007)	(0.005)	(0.008)	(0.016)	(0.013)
Q50	0.054***	0.033***	0.056***	0.059***	0.071***
	(0.008)	(0.006)	(0.006)	(0.013)	(0.011)
Q80	0.024**	0.013	0.029**	−0.011	0.036*
	(0.008)	(0.008)	(0.009)	(0.016)	(0.014)
Q95	−0.006	−0.006	−0.002	−0.070**	−0.027
	(0.019)	(0.012)	(0.019)	(0.023)	(0.022)

Note: $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

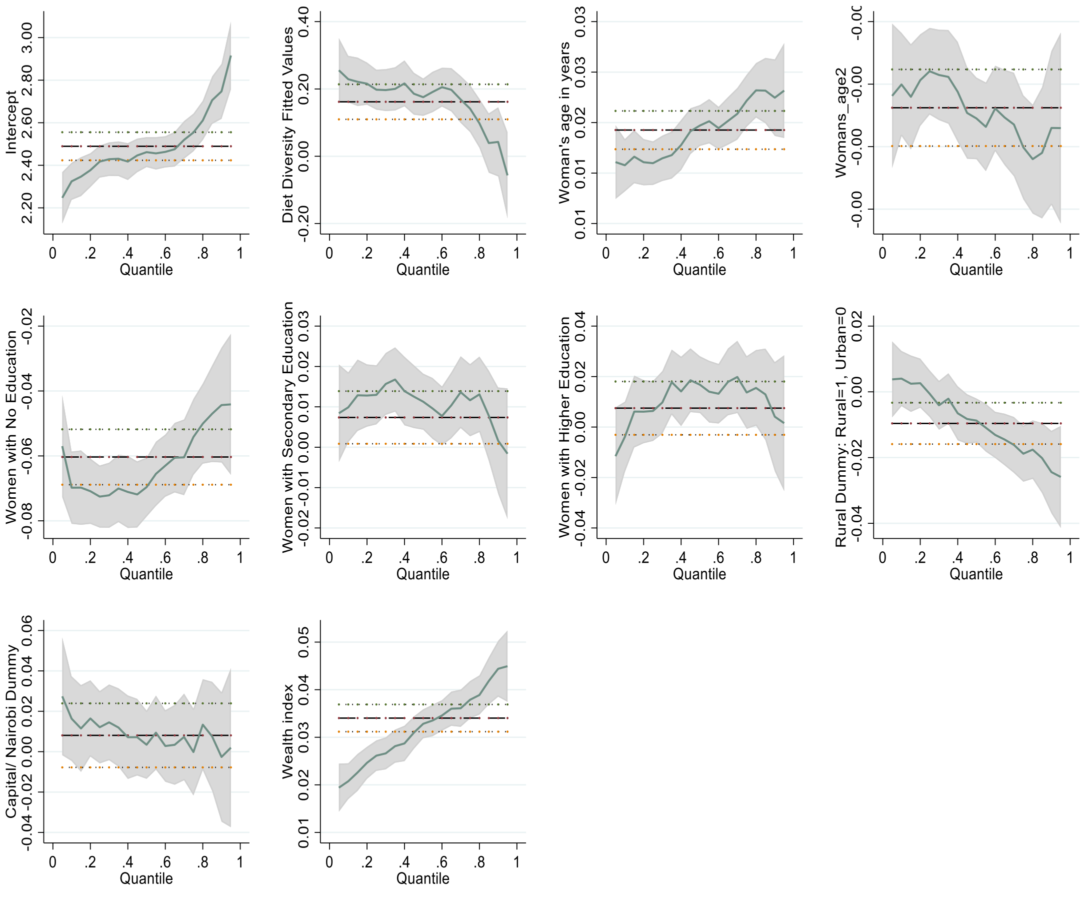

FIGURE 1 Plot of coefficients for each regressor by quantile; diet diversity measure—HFD.

to engage in health-seeking behaviours, such as prenatal care and maintaining health cards for their children. Education may also empower women to make independent decisions for other household members and to have greater access to household resources that are important to nutritional and health status (Osendarp et al., 2020).

Household economic status is another key determinant of the quality of lifestyle and nutrition of women. Evidence shows that, compared with women residing in households of a medium/higher economic status, women in very poor or poor households have a significantly higher risk of being malnourished (Abdulai, 2010; Davis et al., 2020). Poverty amplifies the risks of and from malnutrition, which are associated with sub-optimal BMI. Wealth Index as a proxy for income has a significantly positive impact on BMI, throughout the quantiles of our QR estimation. This suggests that, in our context, higher income may also contribute to the double burden of malnutrition by increasing BMI in the higher quantiles of the distribution (Davis et al., 2020; Osendarp et al., 2020).[8]

Table 4 reports elasticities of diet diversity computed from the QR regressions with different diet diversity measures. The elasticity results show that there is a 14.7% increase in BMI for doubling the diet diversity (HFD), holding other factors constant, for the undernourished at q05. Similarly, a 7% decrease in BMI for doubling the diet diversity as measured by HFD, holding other factors constant, can be observed for the obese individual at q95.

[8]Makate and Makate (2018) in their study find that the mean BMI of women decreases with increasing household income, above a certain level.

Overall, the QR results in Table 4 show that doubling diet diversity is predicted to increase BMI by 9.3%, 5.3%, 8.6%, 14.7% and 10.4%, respectively, for the CM, TSI, EI, HFD and DDS diet diversity measures, for the undernourished fraction of the distribution. HFD and DDS have the highest incremental percentage impacts on BMI of 14.7% and 10.4%, respectively, where both measures place relatively high weightings on the consumption of healthy food items. For the obese individuals, generally, the effects are not statistically significant, except for HFD, even though they consistently show negative associations of diet diversity and BMI, with the proportional effects of diet diversity on BMI consistently falling across the BMI distribution for all our measures of diversity.

The graphs in Figure 1 present coefficient plots for each regressor by quantiles for the HFD specification. They show how the effects of individual regressors on BMI vary over the quantiles, and how the magnitude of the effects at various quantiles differ considerably from the GLS coefficients (GLS estimates are presented in dashed lines), and in terms of the confidence intervals around each coefficient (Rodriguez-Caro et al., 2016). It is interesting to observe the inverse relationship between the fitted values of the diet diversity measure and BMI. At lower quantiles (q05 for example), diet diversity is associated with a higher impact on BMI up until about q50; from that point, diet diversity reduces the BMI.

3.3 | Robustness analysis

We also further explored the possible endogeneity issues, briefly discussed above. As an alternative to our two-stage estimation framework, we employ a simultaneous system approach where the diet diversity (HFD) and BMI equations are simultaneously estimated. The two simultaneously estimated equations are specified as before, with the only changes: the addition of BMI as explanatory variable in the diet diversity equation and the use of the original (not the fitted) values of HFD in the BMI equation. The system is estimated using a three-stage least squares (3SLS) estimator where both dependent variables are allowed to be endogenous to the system and are treated as correlated with the disturbances in the system's equations. The 3SLS is superior to the two-stage instrumental variables estimator (2SLS) as it is a combination of 2SLS and the seemingly unrelated regression estimator (SURE) and is consistent and more efficient than the 2SLS (Kennedy, 2009).

The results of the 3SLS estimation are presented in Online Appendix B, Table B1. The main finding is that the coefficients estimated are very similar to the GLS coefficients presented in Table 3. Further, we run the Breusch-Pagan Lagrange Multiplier (LM) diagonal covariance matrix test of 3SLS validity; the LM test statistic is 418.23 ($\chi^2(2)$) with a p-value of 0.001. Therefore, we reject the null hypothesis of diagonal disturbance covariance matrix (associated with independent equations)—a result in support of the 3SLS estimator. This result suggests that indeed diet diversity (not its fitted values) and BMI simultaneously affect each other. This is also confirmed by the fact that both coefficients of BMI and HFD are statistically significant. However, we must note the large difference in the marginal effects of BMI and HFD, which is almost eight times in favour of diet diversity (HFD). [9]

Considering the findings in this section, we argue that even though diet diversity and BMI are indeed endogenous to each other, the magnitudes (and the lags, as argued earlier) of the effects are very different. In practical terms, the diet diversity effect on BMI is way more important. Furthermore, since the estimated coefficients both by GLS and 3SLS are very similar, we argue that the theoretically founded two-stage framework we have used in previous sections appears to be a feasible alternative to the system of simultaneous equations tested in this section. Nevertheless, the estimates from both approaches should be interpreted with caution for any causal implications.

[9] Considering that the diet diversity (HFD) equation represents a level-log regression, doubling BMI would lead to an increase in HFD by 3.2% at the sample mean. The BMI equation represents a log-level regression and therefore doubling HFD at the sample mean would lead to an increase in BMI by 24.9%, which is almost eight times higher than the increase in HFD above.

4 | CONCLUSIONS AND RECOMMENDATIONS

We focus on the link between diet diversity and health, as measured by BMI. We devise a theoretically founded estimation framework where in a first stage we estimate demand for diet diversity, and in a second stage analyse the diet diversity and BMI relationship. Our first-stage findings draw attention to a variety of factors influencing diet diversity of Kenyan households. Based on five measures of diet diversity, we conclude that Kenyans are significantly exposed to food security risks, associated with the double burden of malnutrition, caused mainly by low incomes and low education levels, as the risks are highest in rural areas.

Our findings are in line with previous studies on Africa and Kenya in particular. Christensen et al. (2008) and Ziraba et al. (2009) find that despite the lower obesity rates in Africa, obesity exists alongside undernutrition and that individuals suffering from undernutrition are mostly found in rural areas, while those who are overweight or suffering from obesity are found in urban areas. This phenomenon is also observed in other regions in the world (Davis et al., 2020; Lowe et al., 2021).

The presence of a double burden of malnutrition is also confirmed by our second-stage analysis which focuses on women. We find a clear link between BMI and diet diversity, which has a potentially important role in tackling underweight and obesity problems, both associated with food and nutritional insecurity. Given that underweight and obesity problems signal health hazards, policies facilitating more diverse, better-quality diets and healthy lifestyles would positively impact public health in Kenya.

Furthermore, our findings suggest that women's power and status constitute a particularly important driver of (and solution to) the double burden of malnutrition. In line with this point, an IFPRI (2016) report shows that mothers aged 18 or under are more likely to have stunted children and children are less likely to be stunted if their mothers have secondary education. Considering that women often control household budgets and play an important role in diet choices (Makate & Makate, 2018), empowering women could be crucial in ensuring the health of the rest of the family members (Osendarp et al., 2020).

More generally, the quality of food that people access is also important, particularly for the poorest and for people with a limited understanding of nutrition. When food prices rise, or the incomes of poor people fall for other reasons, there is a risk of undernourishment as consumers switch to lower-priced foods that fail to adequately meet their nutritional needs. As Osendarp et al. (2020) argue, to ensure adequate micronutrient intakes by the poor, it is important to increase access to diverse nutritious foods. This would require educational campaigns to guide demand and increases in government spending to improve research and development in the agricultural sector to enhance food security in all of its dimensions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.