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Application of the Nutrition Functional Diversity indicator to assess food system contributions to dietary diversity and sustainable diets of Malawian households

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Abstract

Objective: Dietary diversity is associated with nutrient adequacy and positive health outcomes but indicators to measure diversity have focused primarily on consumption, rather than sustainable provisioning of food. The Nutritional Functional Diversity score was developed by ecologists to describe the contribution of biodiversity to sustainable diets. We have employed this tool to estimate the relative contribution of home production and market purchases in providing nutritional diversity to agricultural households in Malawi and examine how food system provisioning varies by time, space and socio-economic conditions.

Design: A secondary analysis of nationally representative household consumption data to test the applicability of the Nutritional Functional Diversity score.

Setting: The data were collected between 2010 and 2011 across the country of Malawi.

Subjects: Households (n 11 814) from predominantly rural areas of Malawi.

Results: Nutritional Functional Diversity varied demographically, geographically and temporally. Nationally, purchased foods contributed more to household nutritional diversity than home produced foods (mean score = 17·5 and 7·8, respectively). Households further from roads and population centres had lower overall diversity ($P < 0·01$) and accessed relatively more of their diversity from home production than households closer to market centres ($P < 0·01$). Nutritional diversity was lowest during the growing season when farmers plant and tend crops ($P < 0·01$).

Conclusions: The present analysis demonstrates that the Nutritional Functional Diversity score is an effective indicator for identifying populations with low nutritional diversity and the relative roles that markets, agricultural extension and home production play in achieving nutritional diversity. This information may be used by policy makers to plan agricultural and market-based interventions that support sustainable diets and local food systems.

Keywords
Nutritional functional diversity
Malawi
Dietary diversity
Sustainability
Indicator

Sustainable diets are emerging as a core concept of global development dialogues and have become a cornerstone of achieving food security in an environmentally sustainable way[(1)]. Dietary diversity is a key measure of sustainable diets and is currently being considered as one of the principal indicators in the post-2015 Sustainable Development Goals (SDG)[(2)]. A recent working paper on nutrition and environmental sustainability by the UN System Standing Committee on Nutrition[(3)] provides ten principles to integrate nutrition and environment in food systems. The third principle proffered is to 'maximize biological diversity at different levels of the food system, in the landscape, the markets, and diets'. The rationale behind this is diversity's central role in ecological sustainability[(4)], ecosystem resilience[(5)] and human nutrition[(6,7)]. UN Secretary General Ban Ki-Moon launched the 'Zero Hunger Challenge,' calling

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on all nations to work towards a future where everyone enjoys their right to food and all food systems are resilient. Since a nutritionally adequate diet is central to this right, a better understanding of the role of diversity in diets is a key to addressing this challenge.

Indicators for measuring dietary diversity[8,9] have contributed to our understanding of how food variety is associated with nutrient adequacy[10–12] and health[13,14], but the focus of these indicators has been on consumption rather than food provisioning. Diets are determined in large part by food availability and accessibility – factors which are influenced by geography, demography, economics and commerce[15]. While the role of complex food systems has been recognized in determining consumer choices and diets[16,17], little is known about food diversity at different stages of these systems or how it is transmitted to dietary diversity at the household level.

These issues become critical for developing countries as policy makers navigate the dietary transition from smallholder farming-based food systems to industrialized agriculture and integration into global food trade. Urbanization, rising incomes, globalization, agricultural intensification and lifestyle changes affect food production and consumption with consequences for the healthfulness of diets[17]. The dietary transition results in the gradual replacement of diets high in localized and biodiverse varieties of legumes, fruits, nuts and wild caught animals and fish with simplified diets high in global commodities and processed foods[18], with important implications for both human health and environmental sustainability[19]. Policy makers need metrics to understand the impact of agricultural programmes, trade policies, transportation infrastructure and market regulations on dietary diversity and which demographic groups are being impacted.

For food systems to be sustainable, the rate of utilization of natural resources employed in producing and distributing food cannot exceed the capacity of ecosystems to replenish those resources. Food security, of which nutrient adequacy is an essential condition, is the ultimate objective of a sustainable food system[18], but only recently have conservation policies begun to incorporate food security objectives[20]. Developing effective policies to support sustainable food systems is hindered by a lack of metrics that are useful in understanding how diets can improve population health while conserving environmental resources[21].

Previous research has demonstrated how the Functional Diversity indicator[22], developed by ecologists to evaluate the impact of biodiversity in natural and managed systems[23] and to test the resilience of those systems[24], can be adapted to describe the diversity of nutrients in cropping systems. In so doing, DeClerck[25] and Remans[26] and co-workers provided evidence supportive of the proposition that agrobiodiversity can affect human nutrition, since the addition of key species belonging to distinct nutritionally functional groups on a farm increases the availability of nutrients. Their adapted indicator, called the Nutritional Functional Diversity (NFD) score, has advantages in linking agrobiodiversity to diets: (i) it can be applied at any scale to describe diversity in available nutrients from farm fields to markets to diets; and (ii) it reflects large nutritional differences in groups of foods that are not captured by a food variety score (a count of different foods consumed) while providing a continuous measure of nutritional variations in foods that are not captured by categorical measures such as a dietary diversity score (a count of the number of food groups consumed). A third advantage is that using a trait-based approach permits a methodological link between environmental and nutritional objectives, so that either agro-ecological traits, such as biodiversity of cropping systems, or nutritional traits, such as nutrient content of crops, could be studied using an analogous functional diversity metric in the same farm/household system.

While DeClerck *et al.*[25] and Remans *et al.*[26] showed how NFD can be applied to measure the nutritional diversity of different cropping systems, these studies were limited in scope to thirty farms in Kenya and 170 farming households in three East African countries, respectively. Neither study applied the NFD score to foods consumed or examined the role of geography and markets in providing nutritional diversity.

To enable a better understanding of how diversity transmits through food systems, the present study expands the use of the NFD to a nationwide sample and evaluates it at different levels of the household food system. The specific objectives of the study are to: (i) estimate the relative contribution of home production and market purchases in providing nutritional diversity to agricultural households in Malawi; and (ii) examine how this food system provisioning varies by time, space and socio-economic conditions. By developing a methodology that uses the NFD with a commonly available data set, this research allows for subsequent policy making in a wide variety of countries that focuses on enhancing sustainable diets by linking household dietary diversity to agricultural and market sources.

Methods

Study population

The present study is based on data from the 2010–2011 Malawi Third Integrated Household Survey (IHS3), which was conducted by the National Statistics Office of Malawi with support from the World Bank and other donors. The survey was conducted nationwide between March 2010 and March 2011 with surveys conducted in every district throughout the year. The IHS3 used a stratified two-stage cluster sampling design with a total of 768 census enumeration areas, as the first-stage clusters, and 12 271 households in the overall sample. Because the aim of the present analysis is to understand the relative importance of market purchases and home produced foods in providing for dietary diversity, enumeration areas in which none of the households had any agricultural land were eliminated from the analysis. This reduced the total number of clusters in the final analytic sample to 741 and the final sample size to 11 814 households.

Food consumption module

The IHS3 follows the format of many of the World Bank's Living Standards Measurement Study (LSMS) surveys and contains extensive demographic, agriculture, health, geographic and consumption data. The household food consumption module is an important module for the LSMS, both because it is essential for determining poverty thresholds and because it is the largest source of expenditure for many low-income households; thus, great care is taken in recording an exhaustive list of foods consumed. Enumerators recorded information on foods consumed in the previous week. This included cereals, tubers, plantains, nuts, legumes, vegetables, animal products, prepared foods from vendors, milk and dairy products, sugars and fats. Open-ended questions prompted respondents to specify any additional foods they may have consumed such as wild or traditional food sources not specifically mentioned. For each food consumed, respondents were asked whether the food was purchased, home produced or received as a gift. Foods received as a gift are included in the total NFD score, but are otherwise not examined here due their relatively low contribution to dietary diversity and lack of relevance to market and agricultural policy.

Nutritional Functional Diversity (NFD) score

The Functional Diversity metric was developed by Petchey and Gaston[22] to better evaluate the impact of biodiversity on the provisioning of ecosystem services. The metric uses a trait-based approach to quantify biodiversity in a way that does not give equal weight to species that fulfil a redundant function in the ecosystem (e.g. some bees, birds and moths all function as pollinators, even though they are different species). Their approach starts with a matrix of species' traits that reflects the ecological contribution of each species to specific functions as a basis for measuring breadth of diversity within an ecological community or ecosystem. Ecological communities with a large number of species but a high degree of similarity in traits receive a relatively lower FD score, whereas communities with greater differentiation in traits receive relatively higher scores. For example, a system that produces rice, wheat and maize would have a lower FD score than one that produces maize, beans and squash, since the latter system maximizes trait differences for growth and resource use efficiency. DeClerck *et al.*[25] employed the Functional Diversity metric as specified by Petchey and Gaston[22], but substituted nutrient content of foods for the species' traits more typically used by ecologists and termed it Nutritional Functional Diversity. We calculated NFD as specified by DeClerck *et al.*[25]. Our methodological contribution is to apply this indicator at the household level to different levels of the household food system: home production, market purchases and overall consumption.

NFD is the extent of functional differences among foods available on a farm, in a market or consumed in one's diet. These functional differences are based on the nutrient profiles of each food, i.e. the amounts of energy and seventeen different nutrients in a standard amount of each food. The NFD score is a relative measure, with higher scores indicating a more diverse diet. There are four main steps to calculating the NFD indicator as described below.

First, a food–nutrient matrix is created

In this matrix, each row is one of the foods in the IHS3 food consumption module and each of the columns is a nutrient, such that each cell of the matrix gives the nutrient content of each of the foods. After excluding processed foods (alcoholic beverages, soft drinks, meals eaten in restaurants) and those with negligible nutritional value (e.g. bottled water, salt and spices), eighty-seven foods were retained. The food–nutrient matrix was composed of energy and seventeen nutrients: protein, fat, carbohydrate, fibre, β-carotene, vitamin D, vitamin E, vitamin C, thiamin, riboflavin, niacin, folate, vitamin B_{12}, Ca, K, Fe and Zn. A food composition table for Malawi was not available so the nutritional values used came from composition tables for Tanzanian foods, which listed quantities of nutrients per 100 g of food products[27]. Nutrient contents for four foods not found in the Tanzanian food composition table were obtained from NutriBase (CyberSoft, Inc., Phoenix, AZ, USA). The nutrient values in the food matrix were then standardized in two ways: (i) they were divided by the RDA for an adult male[28]; and (ii) these were then standardized to have mean = 0 and SD = 1.

Second, the food–nutrient matrix is converted into a food–food distance matrix

In this distance matrix, each of the rows and columns represents one of the eighty-seven foods, and each of the cells represents the 'distance' between a given food i and another food j. Distance is a measure of the difference between two foods, based on their nutrient composition. It is simply calculated as Euclidean distance is calculated in geometry. Specifically:

$$D_{ij} = \sqrt{(i_1 - j_1)^2 + (i_2 - j_2)^2 + \cdots + (i_{18} - j_{18})^2},$$

where $D_{i,j}$ is the distance between food i and food j, i_1 is the amount of standardized nutrient 1 in food i and j_1 is the amount of standardized nutrient 1 in food j. There are eighteen terms in the formula representing energy and the seventeen nutrients.

Third, the distance matrix is used to produce a cluster diagram, called a dendrogram

A cluster analysis was performed on the distance matrix to group the foods by nutrient similarities into clusters and to assess the distance between each cluster, as well as the distance between foods within a cluster. The group average method (also called the unweighted pair-group method using arithmetic averages, or UPGMA) was employed to do this[29]. The food clustering and distance information was used to create the dendogram that graphically represents this information and can be used for calculating the NFD score.

Fourth, the dendogram is used to calculate the NFD score

Figure 1 illustrates how the NFD score is calculated from a dendrogram with a simplified example. In Fig. 1, there are five foods that have been clustered into groups. The horizontal lines are called branches and the vertical lines are called nodes. The longer the branches, the greater the functional diversity. Foods C and D are more similar to each other in their nutritional content than foods A and B are to each other, as can be seen by the longer branch lengths that connect A and B to their nodes. Therefore, foods C and D would represent more nutritional redundancy when both are included in a diet than foods A and B.

The potential NFD is calculated by summing the branch lengths, but not the nodes, of all foods with each branch only included once. In the example shown in Fig. 1, the total branch length is 14. A hypothetical household, Household X, only consumed four of the possible five foods (A, B, C and E) for a total branch length of 13. The total NFD score for Household X is 13/14 × 100 = 92·9. Household X purchased foods A, B and C with a total branch length of 10 for a market NFD score of 71·4 (10/14 × 100). Household X produced foods B and E for a home production NFD score of 57·1 (8/14 × 100).

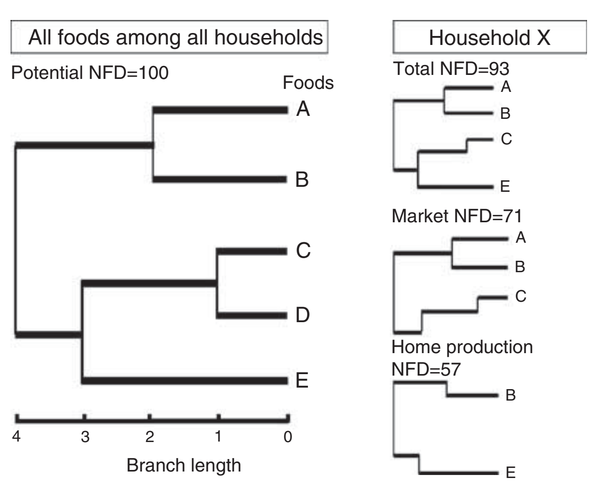

Fig. 1 A simplified illustration showing how the length of branches (horizontal lines shown in bold) from a dendrogram are summed and then divided by the potential NFD and multiplied by 100 to generate the NFD score (NFD, Nutritional Functional Diversity)

Statistical methods

Mean NFD scores were calculated by geographic and temporal categories for total NFD, market NFD and home production NFD. One-way ANOVA tests were performed to test for differences among categories followed by *t* tests using the Sidak correction for multiple comparisons to test for differences between categorical levels. Sample characteristics were analysed by inclusion in the top four quintiles of total NFD and the bottom quintile. The Rao–Scott χ^2 test was used to compare distributions of categorical variables by the two quintile groups and *t* tests were used to compare differences in means by the two groups.

A logistic regression model was conducted to provide odds ratios for the likelihood that a household's total NFD score fell into the lowest quintile of national total NFD scores. The model included variables for demographic characteristics, region, access to markets, agricultural seasons, agricultural landholdings and access to agricultural extension services.

All data operations and statistical analyses were done using the statistical software package SAS version 9·3. Functional Diversity was calculated using PROC DISTANCE, PROC CLUSTER and PROC TREE. All data analyses were done using PROC SURVEYFREQ, PROC SURVEYMEANS, PROC SURVEYREG and PROC SURVEYLOGISTIC. All analyses were weighted using the IHS3 national sample weights and account for the clustered survey sample design in the calculation of standard errors.

Results

Table 1 shows that households in the bottom quintile of total NFD scores had a mean score for total NFD that is half of that of households in the top four quintiles (13·2 and 26·4, respectively). The difference was greater for NFD coming from market purchases, with the lowest quintile having a mean NFD score that is only 42 % of the mean for the top quintiles. NFD scores for home production did not show as much difference, but were still lower for the bottom quintile than the top four quintiles (6·4 and 8·2, respectively).

Table 1 also presents mean NFD scores by geographic and temporal factors. The contributions of markets and home production to total NFD varied across agro-ecological zones, with households in the tropical highlands showing the greatest diversity from home production and the lowest diversity from markets, and households in the sub-humid zones having the least diversity from home production and the most from

Table 1 Mean Nutritional Functional Diversity (NFD) scores for total consumption, market purchases and home produced foods by spatial and temporal factors; 2010–2011 Malawi Third Integrated Household Survey (IHS3)†

			NFD score					
			All sources		Market		Home production	
	n	%	Mean	SE	Mean	SE	Mean	SE
Quintile								
Top four quintiles	9451	79·4	26·4[a]	0·1	19·9[a]	0·2	8·2[a]	0·2
Bottom quintile	2363	20·6	13·2[b]	0·1	8·4[b]	0·1	6·4[b]	0·1
National	11 814	100·0	23·7[c]	0·2	17·5[c]	0·2	7·8[c]	0·2
Agro-ecological zone								
Semi-arid	5466	49·9	23·3[a]	0·3	17·3[a]	0·2	7·8[a]	0·2
Sub-humid	4212	32·5	24·3[b]	0·3	18·8[b]	0·4	6·9[b]	0·3
Tropical highlands	2136	17·6	23·7[a,b]	0·4	15·7[c]	0·4	9·5[c]	0·4
Region								
Northern	1582	10·1	24·0[a]	0·4	16·1[a]	0·5	8·5[a]	0·5
Central	4413	42·7	24·1[a]	0·3	17·5[a,b]	0·4	8·6[b]	0·2
Southern	5819	47·2	23·2[a]	0·3	17·9[b]	0·3	6·9[b]	0·2
Distance to road								
<1 km	2572	18·2	25·9[a]	0·4	20·9[a]	0·5	6·4[a]	0·4
1 to <10 km	5642	47·6	24·1[b]	0·2	18·0[b]	0·3	7·6[b]	0·3
≥10 km	3600	34·2	21·9[c]	0·3	15·0[c]	0·3	8·8[c]	0·2
Distance to population centre (with >20 000 residents)								
<10 km	1984	14·6	26·9[a]	0·4	23·5[a]	0·6	4·5[a]	0·4
10 to <50 km	6576	64·3	23·5[b]	0·2	16·8[b]	0·3	8·6[b]	0·2
≥50 km	3254	21·2	21·8[c]	0·3	15·6[c]	0·3	7·5[c]	0·3
Distance to daily market								
<5 km	6321	52·5	24·5[a]	0·3	19·3[a]	0·4	6·8[a]	0·2
5 to <10 km	2583	22·6	23·0[b]	0·3	15·8[b]	0·3	8·9[b]	0·3
≥10 km	2910	24·9	22·4[b]	0·3	15·3[b]	0·3	8·8[b]	0·3
Agricultural season								
Growing (Dec–Mar)	4126	33·6	21·9[a]	0·3	15·9[a]	0·4	7·9[a]	0·2
Harvest (Apr–Jun)	2346	21·0	25·0[b]	0·4	16·9[a]	0·6	9·7[b]	0·5
Post-harvest (Jul–Nov)	5342	45·4	24·4[b]	0·2	19·0[b]	0·3	6·8[c]	0·2

[a,b,c]Mean values within a column with unlike superscript letters were significantly different ($P=0{\cdot}05$) using *t* test adjusted for multiple comparisons.
†All frequencies, means and *t* tests incorporated sampling weights and design characteristics in the calculation to provide nationally representative estimates.

markets. Households in the southern region accessed the lowest diversity from home production.

As the distance from households to primary and secondary roads increased, households accessed less of their diversity from markets and more from home production for a lower mean total NFD. A similar association was found as the distance increased from households to population centres of greater than 20 000 residents. Those households closest to a population centre had the highest mean total NFD with decreasing mean total NFD as the distance increased. As the distance from a household to a population centre increased, households accessed less diversity from markets and more from home production, although with a decrease in mean home production NFD seen for households the furthest from a population centre.

Households located in villages within 5 km of a daily market had higher market NFD as well as total NFD scores than households in villages located further from daily markets. Households in villages within 5 km of a daily market had lower home production NFD than households in villages further from daily markets.

NFD varied across agricultural seasons. The growing season (coinciding with the rainy season), when farms are planted and tended, had the lowest mean total NFD score. The harvest season, characterized by cool weather and low rainfall, had the highest mean home production NFD score. The post-harvest season (coinciding with the dry season) showed the highest mean NFD score from market purchases and the lowest mean NFD score from home production.

Tables 2 and 3 demonstrate how households with low NFD scores, defined here as the lowest quintile of households based on their total NFD score, differ from households with higher NFD scores.

The frequencies show that there were greater percentages of households in the bottom quintile of NFD scores with a head of household who was older, female, less educated, and separated or divorced. These frequencies show that a greater percentage of households in the bottom quintile contained fewer persons than households in the top four quintiles. A greater percentage of households in the bottom quintile were located in villages without an agricultural extension office. There was no statistically significant difference in the distribution of households in the bottom quintile by either agro-ecological zone or region.

The mean total real annual expenditure per household as measured in Malawi Kwachas for households in the lowest quintile was less than half of that for households in the top four quintiles. Households in the lowest quintile

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Table 2 Demographic, geographic and economic characteristics of households included in the study; 2010–2011 Malawi Third Integrated Household Survey (IHS3)

Frequencies	Top four quintiles *n*	Top four quintiles %	Bottom quintile *n*	Bottom quintile %
Age of household head†				
<30 years	2434	26·2	460	19·4
30 to <50 years	4540	47·1	953	41·1
≥50 years	2477	26·7	950	39·5
Gender of household head†				
Male	7417	78·5	1537	65·7
Female	2034	21·5	826	34·3
Education of household head†				
Primary completed	1053	10·4	153	5·8
Secondary completed	2043	18·8	112	3·9
Marital status of household head†				
Married/cohabitating	8154	86·6	1820	78·4
Separated/divorced	1297	13·4	542	21·6
Household size†				
1 or 2	1502	16·2	532	21·3
3 to 5	4879	51·4	1151	50·4
6+	3070	32·4	680	28·3
Agricultural extension office†				
No	6332	67·1	1764	74·8
Yes	3119	32·9	599	25·2
Agro-ecologic zone				
Sub-humid	3445	33·4	767	28·9
Tropical highlands	1712	17·4	414	18·6
Region				
Northern	1372	10·7	210	8·0
Central	3525	42·9	888	41·8
Southern	4554	46·4	1265	50·2

Means	Top four quintiles *n*	Top four quintiles Mean	Top four quintiles SE	Bottom quintile *n*	Bottom quintile Mean	Bottom quintile SE
Total expenditure/year (Kwachas)**	9451	267 549	8631	2363	105 657	2664
Agricultural landholding (acres)*	9451	1·8	0·1	2363	1·5	0·0
Distance to nearest road (km)**	9451	8·7	0·4	2363	12·5	0·8
Distance to population centre (with >20 000 residents)**	9451	32·6	0·9	2363	38·6	1·1
Distance to daily market**	9451	6·9	0·5	2363	8·6	0·6

The sample *n* is the number of households surveyed without weighting, but the percentages were calculated using survey weights which accounts for the differences in distributions.
*P value for t test $< 0·05$ comparing mean of the highest four quintiles with that of the lowest quintile.
**P value for t test $< 0·0001$ comparing mean of the highest four quintiles with that of the lowest quintile.
†Differences between categorical distributions were tested using the Rao–Scott χ^2 test. All results were significant at the $P < 0·001$ level.

had statistically significantly lower landholdings than households in the top four quintiles by an average of 0·3 acres (0·12 ha). Households in the lowest quintile were statistically significantly more likely to be further from a primary or secondary road, further from a population centre of greater than 20 000 residents and further from a daily market.

The results of a logistic regression model predicting inclusion in the bottom quintile of total NFD scores (Table 3) found that after adjustment for covariates, some of the differences that were significant in Table 2 were no longer significant. Households with a head younger than 30 years of age were less likely to fall into the lowest quintile by 21 % while households with heads older than 50 years of age were more likely to fall into the lowest quintile of total NFD by 35 %. Lack of a primary-school education increased the odds of being in the bottom quintile by 23·9 %. However, there was no significant effect found for households headed by a woman or for households headed by a married person. The logistic regression model found that each additional person in a household was associated with an increase in odds of being in the lowest quintile by 21·8 %. Each additional 1000 Kwachas of real annual household expenditure reduced the odds of being in the lowest quintile by 1·8 %. Compared with the Southern Region, households in the Central Region were 63 % more likely to fall into the lowest quintile while households in the Northern Region were similar to those in the Southern Region.

After adjustment for the covariates in the model, the distance to a daily market was no longer a significant predictor of being in the bottom quintile, but distance to the nearest primary or secondary road was associated with an increased risk of 1·2 % for each additional kilometre.

Households interviewed during the growing season were more than twice as likely to have total NFD scores

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Table 3 Logistic regression results showing all terms included in the model predicting inclusion of households in the lowest quintile of total Nutritional Functional Diversity scores, 2010–2011 Malawi Third Integrated Household Survey (IHS3)†

Variable	OR	95 % CI
Household head younger than 30 years	0·792	0·678, 0·926
Household head older than 50 years	1·345	1·140, 1·588
Female-headed household	1·099	0·945, 1·278
Household head did not complete primary school	1·239	1·028, 1·494
Married household head	0·834	0·684, 1·016
Number of people in household	1·218	1·166, 1·272
Total household expenditure/year (1000 Kwachas)	0·982	0·979, 0·985
Northern region	0·907	0·672, 1·225
Central region	1·629	1·358, 1·955
Distance to daily market (km)	1·004	0·997, 1·011
Distance to nearest road (km)	1·012	1·005, 1·019
Growing season (Dec–Mar)	2·203	1·835, 2·646
Harvest season (Jul–Nov)	1·159	0·938, 1·431
Household agricultural land (acres)	0·987	0·956, 1·019
Agricultural extension office in village	0·822	0·681, 0·993

†The model incorporated sampling weights and design characteristics to provide nationally representative estimates.

falling in the bottom quintile (OR = 2·2). Landholdings were not a significant predictor of being in the bottom quintile of total NFD, but the presence of an agricultural extension office in the village where the household was located reduced the risk by 17·7 %.

Discussion

We applied the NFD score that has previously been used to link agrobiodiversity to diverse diets to demonstrate how it can be applied to national-level household consumption data. The results of the present analysis show that the NFD score is capable of discerning differences in dietary diversity over time, geography and socio-economic factors, and can be used to identify sub-populations at risk of nutritional deficiencies. Purchased foods are important in contributing to dietary diversity as evidenced by NFD scores for purchases being consistently higher than those for home production. The effect of declining NFD as the distance from surveyed households to either roads or population centres increased also supports the conclusion that market access is important to diverse diets. The logistic regression analysis estimated that households with low annual expenditure had lower NFD which may reflect insufficient purchasing ability at markets to meet the dietary diversity of those households.

Although it is difficult to compare our results with those of previous studies that employed the NFD indicator due to differences in context and application, there are some consistencies and contrasts. Remans *et al.*[26] found that the NFD indicator was able to identify variability in nutritional diversity across farms and villages as their analysis found variability across demographic, geographic and temporal factors. Remans *et al.* did not find an association between farm-level NFD and household dietary diversity, which may be due in part to the role of markets in achieving diverse diets as evidenced here.

In addition to the empirical results on dietary diversity in Malawi, the present paper demonstrates the application of the NFD indicator to identify determinants of dietary diversity within households. The NFD indicator can be calculated from household consumption data such as are available in many nationally representative household surveys including the World Bank's LSMS. Since the NFD indicator is based on the presence/absence of foods in any context, it can be calculated at any scale to inform at what level policies should operate to best improve diets of the population.

Population disaggregation by geography or socio-economic group allows policy makers to weigh the relative effectiveness of agricultural extension and support programmes to promote diverse cropping systems against infrastructure or market linkage investments that expand the availability of diverse foods to reach populations with low nutritional diversity. Agricultural extension and advisory services can emphasize agro-ecological approaches and specific crop diversity that add nutrient-rich foods to cash and staple cropping systems found in highly rural areas[30]. Mapping regions with low NFD due to difficult access can identify regions where the diversification of home production has the greatest potential impact. Facilitating the access of extension agents to these regions, and arming them with specific information on agro-ecological limitations, matched with nutritional needs of those communities, has promise for increasing the targeting and efficiency of nutrition interventions. Gomez and Ricketts[31] discuss how the lack of post-harvest and distribution infrastructure may limit the ability of diverse cropping systems to provide micronutrient-dense foods to consumers year-round. Continued monitoring of market NFD across both space and time can document whether change in product availability contributes to or compromises human health.

There are some limitations of the NFD score as well. Adequate nutrition depends on an individual's nutrient requirements, absorption and utilization, which are not captured by NFD. Thus, NFD should be thought of as a measure of nutrient availability not adequacy. NFD is based on the presence/absence of a food, whether on a farm or in a market or diet. This does not allow consideration for relative amounts of foods, so that the nutritional contribution of some foods could be negligible or insufficient in a diet, but still be counted in the NFD if they were consumed at all. This is similar to the minimum quantities problem that has been described in dietary diversity studies[13]. One approach used in that line of research that could be employed in future studies of this type is to exclude foods for which a minimum amount has not been consumed[32].

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A second limitation is that the NFD score is not an intuitive measure, as there is no simple interpretation to the score, and it is a relative rather than absolute measure (i.e. the higher the score the greater the functional diversity). To understand how well the NFD score performs, future studies should validate it against established indicators of dietary diversity. This will aid in the interpretation of the NFD score and make it more useful as a policy tool.

The current analysis demonstrates the usefulness of the NFD indicator as a metric for facilitating progress towards the SDG on dietary diversity and nutrition (SDG2) and on sustainable production and consumption (SDG12)[2]. As described above, using NFD within the context of a national monitoring system, and combined with an integrated analysis of agro-ecological systems, market access, and other population and geographic factors, enables policy makers to target national policies towards specific areas of need. This can lead to improvements in agricultural practices and market linkages that can, in turn, improve population-level nutritional diversity and thus progress towards meeting the SDG.

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