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Measuring nutritional diversity of national food supplies

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ABSTRACT

Improvements in agricultural production have drastically increased grain yields in the past half-century. Despite this growth in productivity and calories available per capita, malnutrition – both undernutrition and, increasingly, overweight – remains pervasive. Though nutrition is critical to human health, it has yet to be systematically integrated into assessments of agricultural and food systems. Using three complementary diversity metrics, we find strong associations between nutritional diversity of national food supplies and key human health outcomes, while controlling for socio-economic factors. For low-income countries the diversity of agricultural goods produced by a country is a strong predictor for food supply diversity; for middle- and high-income countries national income and trade are better predictors. Our results highlight the importance of diversity in national food systems for human health. We provide metrics for agricultural and food security policies to consider nutritional diversity.

1. Introduction

In addition to producing sufficient calories, a major often overlooked challenge in agricultural and food systems is to provide an adequate diversity of nutrients, necessary for a healthy life. A human diet requires at least 51 nutrients in consistently adequate amounts continuously (Graham et al., 2007). Diet diversity has long been recognized as important for adequate nutrient intake (Shimbo et al. 1994; Hatloy et al., 1998; Foote et al., 2004; Steyn et al., 2006; Moursi et al., 2008) and human health (Arimond and Ruel, 2004; Kant et al., 1993; Slattery et al., 1997; Levi et al., 1998), but the concept of nutritional diversity has yet to be integrated into planning and assessments of agricultural and food systems and policies. Success of agricultural systems is evaluated primarily by metrics of crop yields, economic output and cost-benefit ratios (IAASTD, 2009). Yet these metrics do not reflect the diversity of nutrients provided by the system and required for a healthy diet. While grain yields have increased drastically in the past half century (Evenson and Gollin, 2003), it has been argued that changes in agricultural production systems from diversified cropping systems towards ecologically simpler, cereal-based systems have contributed to poor diet diversity, micronutrient deficiencies and resulting malnutrition (Welch and Graham, 1999; Frison et al., 2006; Negin et al., 2009; DeClerck et al. 2011).

In this paper we apply ecological diversity metrics at global level to explore the relationships between nutritional diversity of national food supplies, food production and nutrition-related health outcomes among countries. We address three central questions: (1) What is the distribution of nutritional diversity – both produced and supplied – across nations? (2) What is the contribution of nutritional diversity of national food supplies to nutrition-related health outcomes at the national scale? (3) Do countries with more diverse food production systems have greater diversity in their food supply and how does this relationship vary across an economic gradient?

2. Methodology

2.1. Data

To address these three questions we integrated agricultural, economic, and health data for low to high income countries from the Food and Agriculture Organization (FAOSTAT) and the World Bank database (Worldbank database) for two time periods: 2000–2009

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(results in main paper) and 1990–1999 (Supplementary Information). We compiled information on crop and livestock production and supply at the national level from FAOSTAT (FAOSTAT, 2013). Production data included the quantity of each crop and livestock/animal-based product produced in a country. Supply data covered the per capita supply of each food item available for human consumption in grams per capita per day. Supply per capita data take into account production, import, export, feed and waste to calculate the food available for human consumption. We paired this dataset with food composition data (FAO International Network of Food Data Systems INFOODS, 2013) for seven key nutrients for which dietary intake is often inadequate and food composition data are available: carbohydrates, protein, vitamin A, vitamin C, iron, zinc, and folate. From the nutrition database, we calculated the percent of dietary reference intake for each nutrient in each food item. We then multiplied this value by the amount of the crop/animal-based product produced or supplied in each country and for which data is available at FAOSTAT.

We further compiled data on nutrition-related health outcomes and socio-economic variables at the national level from the World Bank database (World Bank database). For nutrition-related health indicators, we included percent stunting (height-for-age z-score < -2), percent underweight (weight-for-age z-score < -2), percent wasting (weight-for-height z-score < -2), and percent overweight (body mass index > 25) among children less than five years of age.

Guided by the UNICEF framework that outlines the determinants of child and maternal nutrition (UNICEF, 1990), and based on data availability, we included the following variables as major confounding factors: log gross national income (GNI) per capita, calories available per capita per day, Gini index, percent of the population with access to an improved water source, percent of the population living in urban areas, literacy rate, number of physicians per 1000 people, export of goods and services as percent of gross domestic product (GDP), import of goods and services as percent of GDP, agricultural import/export, and food import/export as percent of GDP. Data for all confounding factors were obtained from the World Bank database (World Bank Database, 2013).

To integrate the datasets and take into account yearly fluctuations, we used averages from ten-year time periods for the available data: the average from 2000–2009, results of which are reported in the main paper, and the average from 1990–1999, results of which are reported in Supplementary Information. Data for several of the key variables, including the nutrition-related health indicators, were too scarce for earlier or later 10-year time periods.

2.2. Calculating diversity metrics

To assess nutritional diversity of food production and supply, we used two ecological diversity metrics – Shannon Entropy and Modified Functional Attribute Diversity (MFAD) – and the percent of energy coming from non-staples (Text box 1).

Text box 1–Three complementary diversity metrics

Shannon Entropy diversity metric (Shannon), or species diversity: reflects how many different types of food items there are in a certain country, and how evenly these different types are distributed

Modified Functional Attribute Diversity (MFAD), or functional diversity: reflects the diversity in nutrients provided by the different food items based on the nutritional composition and amount of each food item present

Percent of energy coming from non-staples (% energy non staples): indicates the proportion of energy derived from food items that are not grains or tubers.

Shannon Entropy (Shannon, 1948) is a commonly used diversity metric that weights the richness of species – food items in this case – by the evenness of their distribution. As such, it is a measure of the relative abundance of each food item within a country. The metric identifies the diversity of crops in each country without explicit consideration of their nutrients.

The use of functional diversity metrics has grown in ecology to measure the diversity of functional traits in a given area (Petchey et al., 2009; Schleuter et al., 2010; Weiher, 2012). We use a measure of functional attribute diversity (FAD), which is defined as the sum of the pairwise functional dissimilarities of a collection of species (Walker et al., 1999; Petchey and Gaston, 2006) measuring the dispersion of species within a functional trait space (Ricotta, 2005). The functional attribute approach has the advantage of not needing to know the entire species pool in order to calculate the metric. This is preferable in this study because not all of the food items produced by or available in a country are represented in the FAOSTAT database. We use a modified version of the original functional attribute approach (Walker et al., 1999) that meets two essential criteria that functional diversity should not increase with functionally identical species, but should increase with functionally dissimilar species (Schmera et al., 2009). Modified Functional Attribute Diversity accomplishes this by weighting FAD by the number of functional types. It is given as (Schmera et al., 2009):

$$MFAD = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}}{N}$$

where n is the number of species – or food items, in this case – and d is the dissimilarity between species i and j as defined by multiple traits – or nutritional components – measured using some distance algorithm, such as Euclidean distance. N is the number of functional units (Ricotta, 2005), such that different species that are identical in their trait composition are considered the same functional unit. For example, if there are two food items with the same nutritional composition, then they are not counted twice.

To facilitate interpretation and comparison between countries, regions and metrics, the Shannon and MFAD metric were scaled to a 0–1 scale, with 0 representing no diversity (only one food item or food items of the same composition) and 1 representing the highest value among the countries.

The percent of energy coming from non-staples represents the percent of the total energy of food items supplied and available in a country coming from non-staple crops, this is food items different from grains and staple tubers.

These three metrics provide distinct but related pictures of global food diversity. For example, countries in West Africa show high Shannon Entropy diversity of food items produced, yet these items, most of which are staples (e.g. rice, maize, sorghum, plantain), tend to be similar in nutrient composition, resulting in a low functional diversity (MFAD) and a high percent of energy coming from staples. Taken together, these three metrics provide a more comprehensive view of nutritional diversity than any single metric.

2.3. Models and statistical analysis

To test for differences in means between regions, we apply one-way Analysis of Variances (ANOVA).

To assess relationships between variables, we fit the variables into linear regression models assuming a Gaussian distribution. All independent variable coefficients were standardized to compare the magnitude of their effects on the response variable. Collinearity was systematically checked using variance inflation factors. Variables with a variance inflation factor of less than five were retained in the model.