Exploring micronutrient deficiency risks in Africa using projections of the food system

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Abstract

Introduction

Micronutrient deficiency (MND) in vulnerable populations remains an important challenge in the 21st century, with access to nutritious food, and ending malnutrition key elements of SDG2. The consequences of MND include impaired growth and immune function. Children, and females of reproductive age, are particularly vulnerable, due to higher micronutrient needs.

For many developing countries, recent and reliable data are not available to understand the magnitude of MND, and thus difficult to contextualise risks and prepare appropriate interventions. Efforts are further complicated by the effects of and interactions between climate change, population growth, and income dynamics. These can pressure future food production, availability, and preference, even as overall caloric intake may appear adequate.

Thus, it is important to understand MND risks at different time and geographic scales, building an evidence base for investment and policy action. With this premise in mind, we examine projections of food availability in Africa under various climate and socio-economic futures using a global multi-market partial equilibrium model. Projections are prepared through 2050 and, linked to this, daily per capita micronutrient availability for a set of 13 vitamins and minerals are estimated. These are checked against recommended nutrient intakes to determine whether, on a per capita basis, micronutrient availability is adequate.

We then aim to identify major nutrient deficiencies in Africa, and the types of crops that contribute to nutrient availability. This provides a set of commodities for which fortification, biofortification, trade, and other investment may be plausible policy interventions to increase food supply or nutrient availability.

The paper proceeds as follows: section 2 provides a brief description of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), and how it is used to make projections of food availability, as well as a description of the broad climatic- and socioeconomic pathways used to frame the universe of plausible projections through 2050. As the purpose is to identify specific MND risks, no explicit scenarios of agricultural investment, fortification strategies, subsidies and other fiscal measures, are run in this study. Nevertheless, these may be necessary in assessing their impact in relieving nutrient deficiency. Section 3 explores the modelled MND deficiencies at the end of the simulation period, identifying which micronutrients tend to be more prevalent in Africa. For a selection of country-nutrient combinations, we explore the main commodities driving the change in micronutrient availability, before offering a range of considerations in taking this research further. Section 4 underlines key insights and concludes.

Model and simulations

Projections of the food system to 2050 are generated using IFPRI's IMPACT model, a global, partial-equilibrium of agricultural markets (Robinson, *et al.*, 2015). It simulates the functioning of the global agricultural sector. In this application, we explore the micronutrient deficiencies that exist at a per capita level at that point in time. IMPACT covers 159 countries and regions, 41 primary agricultural commodities, and 14 processed commodities, although for this study we focus on Africa, due to higher perceived incidences of MND. IMPACT uses the DSSAT crop model, as well as a hydrology model, to simulate crop yield and growth under the different biophysical results associated with the RCPs. Thus, climate scenarios considered here influence crop yields and farm output, which affect consumer prices. Consumer demand is affected by these price shocks, as well as alternative assumptions of future per capita income, indicated by SSP projections, which narrate alternative characteristics of global development through economic and demographic change. Consumer demand is subject to elasticities that change over the projection period. This, alongside sector demand and market prices, also influence international trade. The commodity coverage in IMPACT permits the construction of an indicator to track nutrient availability, which is a composite of the food consumption and the embedded nutrient content of different commodities. Nutrient content by commodity also takes into account country-specific characteristics.

Due to the inherent uncertainty of the effects of environmental and socioeconomic change, and differences in the results across models, we consider an ensemble of 60 scenarios, reflecting three shared socioeconomic pathways (SSPs) under four alternative representative concentration pathways (RCPs) across a handful of global circulation models. This captures a range of assumed population, income, rainfall, and temperature trajectories. The RCPs (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) are commonly used greenhouse gas concentration pathways for climate change-related assessments, and reflect different assumed radiative forcings by 2100. We use three SSPs, informed by projections by IIASA. SSP2, reflects a middle-of-the-road scenario, in which current population and economic growth trends continue over the long term. SSP1 assumes higher income growth and a more equitable distribution of income compared with SSP2, while SSP3 assumes lower economic growth and higher income inequality.

Previous studies, such as Wiebe *et al*. (2015) have examined how sensitive projections of agricultural and food production are, across a range of climate, crop, and economic scenarios. Nelson *et al.* (2018) explore nutrient deficiencies un the context of food affordability, availability, food and nutrient adequacy. This study mimics the work by Nelson *et al.* (2018), but widens the range of climate and economic scenarios to allow for a robust analysis of a wider breadth of possible outcomes.

Food availability reflects the edible portion of a food item, by weight. Using estimates of nutrient availability by weight, which account for nutrient loss during preparation, we calculate total nutrient availability by food item, aggregating across all available foods to determine the nutrient availability, adjusted to a daily quantity. The estimates of nutrient availability by weight vary by country, reflecting differences in varietals and taking into account the composition and consumption of food items that account for the consumption of the commodity.

The analysis does not assume and positive or negative changes to nutrient availability due to processing, including fortification and preservation, or climate change.

IMPACT results are represented annually, thus estimates do not take into account seasonal variations in foods consumed. Demand is also represented at a national level, and thus availability is not estimated with spatial, gendered, age, or socioeconomic disaggregation. Estimates may also be biased downwards, as food consumption covered in IMPACT may exclude items such as wild or home-grown commodities.

Notwithstanding, the projections usefully communicate potential MND risks at different time scales for different countries.

Scenarios do not consider any deliberate investments to the food system to influence food availability. Thus, the projections identify where MND might be a risk, or where interventions such as dietary diversification, fortification, or biofortification, could be warranted.

Preliminary results

Nutrient availability

The micronutrient availability results in 2050 for the 60 scenarios are analysed, and summarized in a three-colour heat map in Table 1. Each cell represents the results of nutrient availability across 60 scenarios. Cells coloured in green indicate that, for the country (row) and micronutrient (column), all 60 scenarios show a projected *per capita* nutrient availability that exceeded recommended intake in 2050. Yellow cells indicate that nutrient deficiencies persist in 2050 for some, but not all scenarios. Finally, cells shaded in black illustrate country-nutrient availability combinations in which no scenarios meet the recommended intake by 2050. In many instances, particularly related to mineral availability, nutrient adequacy was already achieved in the baseline data. Excessive intake is considered as a risk, although no projections indicated intakes higher than recommended tolerable levels.

Micronutrient availability estimated from IMPACT is compared against recommended nutrient intakes by the National Institutes of Health and World Health Organisation. The benchmarks set here correspond to the recommended intakes for adults and, where there is a difference in guideline between male and female, the higher value is taken as the recommended intake. These are summarized in Table A1. Based on this, the most prevalent shortfalls in nutrient availability in 2050, for the 13 micronutrients analysed, are found for vitamin A, riboflavin, folate, calcium, and zinc.

Calcium

Low levels of calcium and vitamin D (which aids calcium absorption) are associated with incidence of rickets. In all scenarios across all countries analysed, calcium availability remains below a minimum recommended level of 1 000mg per person day, even as most scenarios show an increase in calcium consumption. This is consistent with estimates that suggest that calcium deficiencies are widespread globally, and acute in LMICs.

In countries such as South Africa, calcium intake is heavily associated with consumption of dairy products. However, for many others, with limited affordability, storage, or culture of milk consumption, calcium intake is often driven by the consumption of vegetables, sweet potatoes, cassava, and beans, which are less dense in calcium. Although higher per capita income drives demand for dairy over the projection period, these are often from very low bases.

Stacked bar chart: comparison of main sources of calcium in different countries

Riboflavin

Riboflavin deficiencies hinder the digestion of macronutrients, and metabolism of vitamins and minerals such as niacin and vitamin B6. As indicated in Table 1, riboflavin availability or deficiency depends on the scenario considered. In Benin, riboflavin adequacy is reached around 2040 in SSP1 scenarios, around 2050 in SSP2 scenarios. Under SSP3 scenarios, per capital riboflavin intake does not meet RNIs by 2050.

This indicates that income growth influences the food choice and eventual availability of riboflavin. Comparing the set of SSP1 scenarios with those of SSP3 scenarios for Benin, we find that higher income growth under SSP1 permits higher demand for yams and vegetables which, although not especially dense in riboflavin, are the major sources of riboflavin in the average “plate” in 2050. Under SSP3, per capita food availability of yams is also higher than 2005, although at a much slower rate than SSP1.

Bar chart: average annual growth in riboflavin-rich foods, and main sources of riboflavin in Benin

Similarly, riboflavin adequacy in Ethiopia is influenced by the type of socioeconomic trajectory assumed. Under SSP1 scenarios, riboflavin availability is boosted by strong demand for pulses, for which food availability increases by approximately 1.8 per cent per annum over 2005-2050, compared with around 1.1 per cent per annum across SSP1 scenarios.

Folate

Folate deficiencies are projected to remain a challenge in several countries in Africa. Synthetic fortification of staple foods, such as flour and maize meal, is a common, low-cost intervention in several countries.

Vitamin A

Vitamin A deficiencies are considered a major health problem affecting children, and a major contributor to childhood blindness. High-dose vitamin A supplementation is a low-cost intervention aimed at children aged under 5-years. Major food sources of vitamin A include sweet potatoes, eggs, and vegetables.

Table 1: Summary of micronutrient availability results from ensemble of 60 SSP-RCP-GCM combinations

	Vitamin A	Thiamin	Riboflavin	Niacin	Vitamin B6	Folate	Vitamin C	Calcium	Iron	Magnesiu	Phosphoru	Potassium	Zinc
Angola													
Burundi													
Benin													
Burkina Faso													
Botswana													
Central African Republic													
Ivory Coast													
Cameroon													
Democratic Republic of Congo													
Congo Republic													
Djibouti													

	Vitamin A	Thiamin	Riboflavin	Niacin	Vitamin B6	Folate	Vitamin C	Calcium	Iron	Magnesiu	Phosphoru	Potassium	Zinc
Algeria	Black	Green	Green	Green	Green	Green	Green	Black	Green	Green	Green	Green	Green
Egypt	Black	Green	Green	Green	Green	Green	Green	Black	Green	Green	Green	Green	Green
Eritrea	Black	Green	Black	Yellow	Yellow	Black	Black	Black	Green	Green	Green	Black	Yellow
Ethiopia	Black	Green	Yellow	Green	Green	Green	Green	Black	Green	Green	Green	Green	Green
Gabon	Green	Green	Yellow	Green	Green	Yellow	Green	Black	Green	Green	Green	Green	Yellow
Ghana	Green	Green	Yellow	Green	Green	Green	Green	Black	Green	Green	Green	Green	Yellow
Guinea	Green	Green	Yellow	Green	Green	Yellow	Green	Black	Green	Green	Green	Green	Green
Gambia	Green	Green	Black	Green	Green	Black	Black	Black	Green	Green	Green	Black	Yellow
Guinea Bissau	Green	Green	Black	Yellow	Green	Black	Green	Black	Green	Green	Green	Yellow	Yellow
Equatorial Guinea	Black	Black	Black	Black	Green	Black	Green	Black	Black	Green	Yellow	Green	Black
Kenya	Green	Green	Yellow	Green	Green	Green	Green	Black	Green	Green	Green	Green	Green
Liberia	Green	Green	Black	Green	Green	Yellow	Green	Black	Yellow	Green	Green	Green	Yellow
Libya	Green	Green	Green	Green	Green	Green	Green	Black	Green	Green	Green	Green	Green
Lesotho	Black	Green	Yellow	Green	Green	Black	Black	Black	Green	Green	Green	Green	Green
Madagascar	Black	Yellow	Black	Yellow	Green	Black	Green	Black	Yellow	Yellow	Green	Yellow	Yellow
Mali	Green	Green	Yellow	Green	Green	Yellow	Green	Black	Yellow	Green	Green	Green	Yellow
Morocco	Green	Green	Green	Green	Green	Green	Green	Black	Green	Green	Green	Green	Green
Mozambique	Yellow	Green	Black	Green	Green	Black	Green	Black	Green	Green	Green	Green	Yellow
Mauritania	Green	Green	Green	Green	Green	Yellow	Black	Black	Green	Green	Green	Green	Green
Malawi	Black	Green	Yellow	Green	Green	Green	Green	Black	Green	Green	Green	Green	Yellow
Namibia	Black	Green	Green	Green	Green	Black	Green	Black	Green	Green	Green	Green	Green
Niger	Yellow	Green	Green	Green	Green	Green	Yellow	Black	Green	Green	Green	Green	Green
Nigeria	Green	Green	Green	Green	Green	Green	Green	Black	Green	Green	Green	Green	Green
Rwanda	Green	Green	Green	Green	Green	Green	Green	Black	Green	Green	Green	Green	Green
Sudan	Black	Green	Green	Green	Green	Yellow	Green	Black	Green	Green	Green	Green	Green
Senegal	Black	Green	Black	Green	Green	Black	Yellow	Black	Green	Green	Green	Yellow	Green
Sierra Leone	Green	Yellow	Black	Yellow	Green	Black	Green	Black	Green	Yellow	Green	Yellow	Black
Somalia	Black	Yellow	Green	Yellow	Yellow	Black	Black	Black	Yellow	Yellow	Green	Yellow	Yellow

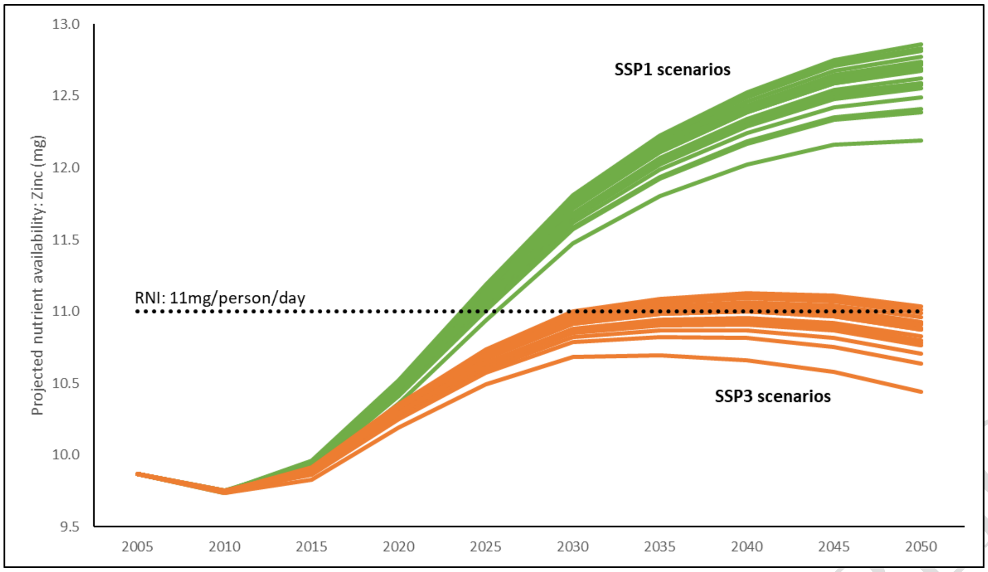
	Vitamin A	Thiamin	Riboflavin	Niacin	Vitamin B6	Folate	Vitamin C	Calcium	Iron	Magnesiu	Phosphoru	Potassium	Zinc
Eswatini	■ black	■ black	■ yellow	■ green	■ green	■ black	■ green	■ black	■ green	■ green	■ green	■ yellow	■ green
Chad	■ black	■ green	■ black	■ green	■ green	■ yellow	■ black	■ black	■ green	■ green	■ green	■ green	■ green
Togo	■ yellow	■ green	■ yellow	■ green	■ green	■ green	■ green	■ black	■ green	■ green	■ green	■ green	■ green
Tunisia	■ green	■ green	■ green	■ green	■ green	■ green	■ green	■ black	■ green	■ green	■ green	■ green	■ green
Tanzania	■ green	■ green	■ yellow	■ green	■ green	■ green	■ green	■ black	■ green	■ green	■ green	■ green	■ green
Uganda	■ green	■ green	■ yellow	■ green	■ green	■ green	■ green	■ black	■ green	■ green	■ green	■ green	■ yellow
South Africa	■ black	■ green	■ green	■ green	■ green	■ black	■ black	■ black	■ green	■ green	■ green	■ green	■ green
Zambia	■ green	■ green	■ yellow	■ green	■ green	■ black	■ green	■ black	■ green	■ green	■ green	■ yellow	■ yellow
Zimbabwe	■ yellow	■ green	■ yellow	■ green	■ green	■ black	■ black	■ black	■ green	■ green	■ green	■ yellow	■ green

Food availability

The results show that nutrient deficiency profiles vary by country. This is unsurprising given heterogeneous climate, cultural preferences, and food availability across Africa. Thus, policy, public health, and investment responses to encouraging dietary diversity could be more effective if they support the affordability and access of food commodities that deliver these nutrients.

Yellow-filled cells in Table 1 indicate that only some of the climate-income scenarios yield sufficient *per capita* micronutrient availability. Often, this is a result of differences in per capita income. Figure 1 illustrates the differences in projected zinc availability in Cote d'Ivoire. Regardless of RCP or GCM, scenarios under the more favourable growth environment indicate that per capita zinc availability exceeds recommended levels in the mid-2020s. This is expected to be driven by increased food diversification associated with higher incomes. In scenarios with lower-than-trend income growth, zinc availability generally falls short of recommended intake levels. In contrast, the projections indicate that zinc deficiencies may exist in most SSP3 scenarios in 2050. Additional examples, for other countries and micronutrients, are illustrated in Panel A2.

Figure 1: Analysis of SSP1 and SSP3 scenarios of zinc availability in Cote d'Ivoire, 2005-2050



Source: Own calculations

Next steps and ideas for future research

This work contributes to a multi-disciplinary project called Micronutrient Action Policy Support (MAPS). MAPS aims to provide estimates and scenario analyses of MNDs and food system interventions, at national and sub-national levels in Africa. By providing a rich set of food consumption patterns, cost assessments of different interventions, and food system projections, the effort aims to contribute to improved planning and resource allocation. There is also potential to harmonise interventions with agriculture and food systems development and trade strategies.

A shortcoming of the partial equilibrium framework is that indirect and induced price and other effects in non-agricultural markets are not modelled. For this analysis, the distortionary external impacts of climate and demographic change, not already considered, on the food system is considered to be small. If large, these can drive important trade-offs on assumptions of income and price movements, and assumptions into IMPACT would need to adjust for these impacts.

Further disaggregation of households, by income group or location, for example, would permit more nuanced identification of MNDs, and appropriate interventions.

Concluding remarks

The availability of detailed dietary and household surveys remains a challenge in assessing the level of micronutrient deficiencies in developing countries. Projections of food systems can provide useful insights on the characteristics of nutrient deficiencies.

In this paper, we demonstrate the use of a global partial equilibrium model in providing plausible projections of food and nutrient availability to mid-century. Although several factors can influence the ultimate bioavailability of micronutrients to consumers, we believe that these estimates offer a useful reference to identify which micronutrient deficiencies may need the most attention for public health policy. Sectoral policy development can also benefit from these projections of domestic food production, demand, when considering integrated policies that respond to national health, socio-economic, and trade priorities.

In Africa, we find that calcium availability is inadequate across all countries analysed. This suggests that, regardless of climate change or socio-economic trajectory, additional intervention may be required to close gaps in calcium availability. The intervention options, which include agricultural development, fortification and biofortification strategies, measures to influence consumer prices and preferences, may require further assessment to determine trade-offs such policy action may have on the rest of the economy.

Although both have an effect on nutrient availability, we find that assumptions of per capita income are more consequential than climate change. This is observed for a range of micronutrients for which nutrient availability in 2050 shows distinct patterns when filtered across SSP assumptions.

References

Nelson, G., Bogard, J., Lividini, K., Arsenault, J., Riley, M., Sulser, T.B., Mason-D'Croz, D., Power, B., Gustafson, D., Herrero, M., Wiebe, K., Cooper, K., Remans, R., and Rosegrant, M. 2018. Income growth and climate change effects on global nutrition security to mid-century. *Nature Sustainability*. Vol (1):773-81. https://doi.org/10.1038/s41893-018-0192-z

Robinson, S., Mason-D'Croz, D., Islam, S., Sulser, T.B., Robertson, R., Zhu, T., Gueneau, A., Pitois, G., and Rosegrant, M. 2015. *The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). Model Description for Version 3.* IFPRI Discussion Paper 01483. Washington, D.C. International Food Policy Research Institute (IFPRI). http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129825

Wiebe, K., Lotze-Campen, H., Sands, R., Tabeau, A., van der Mensbrugghe, D., Biewald, A., Bodirsky, B., Islam, S., Kavallari, A., Mason-D'Croz, D., Muller, C., Popp, A., Robertson, R., Robinson, S., van Meijl, H., and Willenbockel, D. 2015. Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios. *Environmental Research Letters.* Vol 10(2015): 085010. https://doi.org/10.1088/1748-9326/10/8/085010

Table A1: Assumed micronutrient recommended intakes

Micronutrient	Assumed daily recommended nutrient intake
Vitamin A (RAE)	700 mcg
Thiamin	1.2 mg
Riboflavin	1.3 mg
Niacin	16 mg
Vitamin B6	1.3 mg
Folate	400 mcg
Vitamin C	90 mg
Calcium	1 000 mg
Iron	18 mg
Magnesium	420 mg
Phosphorus	700 mg
Potassium	3.4 g
Zinc	11 mg