National food production cannot address nutrient gap in African countries

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Editor's summary

Most studies assessing food self-sufficiency look at calories and neglect nutrient gaps. Comparing food demand and potential food production under land and water constraints, this study quantifies nine key nutrient gaps for each of African's 54 countries.

Abstract

This study quantifies nine key nutrient gaps by comparing national demand and domestic production in each of Africa's 54 countries. While different countries exhibited varying degrees of nutrient gaps for different nutrients, all countries were deficient in at least one nutrient, with eight being deficient in all nutrients. Following current agricultural productivity, only 7 African

nations could satisfy their nutrient gaps through production expansion given water and land constraints.

Main

Insufficient food supply and malnutrition affect one-third of the global population[1] and is especially prevalent in Africa, with 24% of the population of sub-Saharan Africa being undernourished in 2020[2]. Food trade plays an important role in food and nutrient supply in the region[3], enhancing food availability, access and diversity[3]. For example, 84% of wheat demand is met through import in Eastern Africa[4]. However, countries that rely on food trade to meet their needs are also more vulnerable to shocks, including pandemics, conflicts, and natural disasters which impact food production and supply chains[5]. In 2022, for example, the price of bread in Cameroon and Nigeria increased by 40% and 34.11% respectively as a result of the Russia-Ukraine conflict[6].

Improving food and nutrient self-sufficiency is therefore important for food security in Africa [7], but requires substantial resource input – particularly land and freshwater[8]. Over the past decades, Africa's agricultural growth has largely relied on land expansion[9], with limited improvements in land and water productivity[10]. In this context, two critical questions emerge: 1) what is the exact magnitude of nutrient gaps currently faced by African countries given their nutritional demand and domestic production; and 2) whether such nutrient gaps could be reduced through domestic expansion of agricultural production given land and water constraints. The existing literature focuses primarily on the gap between national consumption and demand (defined in terms of physiological requirements) using an apparent consumption approach[1,3]. A previous study on domestic supply potential focused on land-availability to achieve EAT-Lancet diet targets without considering current actual production and nutrient supply structures[5].

Here, we quantify nutrient gaps between national demand and production for nine key nutrients – namely proteins, carbohydrates, calcium, riboflavin, niacin, folate, iron, zinc, and Vitamin A – across each of Africa's 54 countries, based on local production data for 162 food items. These items were further categorized into 11 subgroups: cereals, oilseeds and pulses, meat, roots and tubers, milk, fruits, vegetables, nuts, sugar crops, spice, and aquatic products. Since nutrients could be lost during food preparation and household cooking activities[11], we focused on nutrients ready for consumption (after all losses) rather than embodied in national production. This enabled a direct link with local diet choices. Furthermore, we investigated the potential of reducing nutrient gaps by expanding national production under local land and water constraints, ultimately aiding policy design for improved nutrient supply.

Our results show that nutrient gaps between national demand and production are prevalent in Africa. All studied countries were deficient in at least one key nutrient (Fig. 1), in stark contrast to most developed countries' nutrient self-sufficiency rates found in previous research[3,12,13] and here illustrated by France, the Netherlands, and the United States (Supplementary Figure 1). Iron deficiency was found in every African country, reaching > 80% (Fig. 1 and Supplementary Figure 2) in 26 of them and 67% at continent level (calculated as domestically produced nutrients divided by nutrient demand).

Calcium and zinc deficiency was also widespread, affecting 53 and 52 countries respectively. The deficiencies of protein, folate, and riboflavin were found in between 41 and 48 countries. Even though the deficiency rate of Vitamin A and niacin at continent level was estimated to be only 4%, it was present in 40 countries, reflecting the spatial concentration of nutrient production. Carbohydrate was the only sufficiently produced nutrient at continental level, but 14 countries showed deficiency rates (ranging from 4% to 94%). Eight countries (Eritrea, Botswana, Libya, Gambia, Lesotho, Somalia, Cape Verde, Djibouti) were deficient for all nutrients. Lesotho and Djibouti were found to have the largest deficiency rate between nutrient production and demand (Fig. 1).

At national level, deficiency rates for protein (a key macronutrient) and iron (a key micronutrient) are largely explained by low production quantity rather than quality of nutrients, therefore constituting a 'magnitude' rather than a 'structure' effect. The protein gap was mostly attributed to low food production in 38 out of 54 countries (Supplementary Figure 3a), whilst this was the case for all 54 countries where an iron gap was identified (Supplementary Figure 3b).

We further investigated the potential of reducing key nutrient gaps through the expansion of agricultural production under current yields, considering national land and water constraints (here taken as the thresholds for sustainable agricultural land use and water consumption - see Methods). This represents the potential for increased nutrient supply without surpassing sustainability thresholds under current production patterns and resource productivity (Fig. 2). We found that satisfying nutrient gaps in Africa would require expanding production by at least 287% of what was produced in 2020, based on current production patterns (Supplementary Figure 4). This expansion would require considerable additional water resource and agricultural land (Supplementary Figure 4). Such large nutrient gap and limited production space under water and land constraints indicates that relying solely on production expansion without productivity improvements could make it difficult to fill the nutrient gap in many

African countries. Specifically, we found that 22 countries have no operating space to reduce their nutrient gaps to any extent (Fig. 2). This was because their usage of water and land has already exceeded their water and land constraints, leaving no room for further sustainable production. Amongst these countries, Algeria, Cabo Verde, Egypt, Eswatini, Libya, Morocco and Tunisia already go beyond their land and water constraints. Meanwhile, 25 countries could reduce their nutrient gaps by 1.4% to 75.7% within their water and/or land constraints. Only 7 countries were found to possess sufficient water and land to fully meet their nutrient gap through domestic production without exceeding their land and water sustainable usage thresholds. However, their nutrient production needs to be expanded by > 50% based on current production and efficiency patterns. In addition, we found that, compared to water, the magnitude of available land was the main limiting factor to reducing nutrient gaps in most African nations (Fig. 2).

A feasible solution for African countries to sustainably increase their production without exceeding current land and water constraints is to improve land and water productivity, given the considerable potential for productivity gains across the continent [9,14,15]. Hence, we examined the potential for reducing key nutrient gaps by expanding production while improving land and water productivity to global average levels through three counterfactual scenarios (see Methods). We found that solely improving land productivity (Scenario 1) would enable 17 more countries to fill their current nutrient gaps, whereas solely improving water productivity (Scenario 2) would allow only one more country, Mali, to do so (Supplementary Table 1). When both national land and water productivity improve to the global average level (Scenario 3), 22 more African countries could meet their nutrient demand without exceeding current land and water constraints. These scenarios highlight the critical importance of improving both land and water productivity for African countries.

Malnutrition is a persistent concern in Africa, where the shortage of staple food supply has been well documented[10]. Our study further shows an important gap of micronutrients in domestic supply; iron, calcium, and zinc are the three most deficient nutrients, contributing to widespread anaemia, malaria, and higher rates of infant and child mortality[16]. The rate of anaemia in western Africa, in particular, is close to 50%[17].

To advance sustainable development in Africa, micronutrient deficiency must be addressed[18]. While enough carbohydrates are produced at continent level, greater intracontinental trade and better access across different social groups are key to alleviating the shortage of carbohydrates in local settings[19]. When it comes to micronutrients, however, achieving self-sufficiency through domestic food production may be more challenging; in fact, even if production were to be optimized, more than half of all African countries would not be able to meet their own demands due to land limitations[5].

Based on the above, and in light of global uncertainties, a critical measure to enhance Africa's own nutrient supply would be to improve agricultural productivity, particularly in sub-Saharan Africa. Over the past decades, agricultural growth in the region has primarily relied on cropland expansion rather than productivity improvements, resulting in deforestation and environmental degradation[9]. Low agricultural productivity has been linked to several factors in sub-Saharan Africa, such as ineffective farm management practices, insufficient soil moisture, soil infertility, and soil degradation[8]. Integrated Soil Fertility and Water Management (ISFWM) has proven effective in several sub-Saharan African countries. Designed to enhance soil fertility, water retention, and overall crop productivity, this approach combines a range of conservation farming practices, the application of both organic and inorganic fertilizers, the use of improved seeds, and the promotion of irrigation techniques.[8,10,20]. Additionally, investments in agricultural research and development are crucial for Africa to support productivity gains and adapt to a rapidly changing climate[10].

A second critical measure to enhance Africa's nutrient supply concerns the reduction of food loss and waste throughout the food supply chain, which reduce total nutrient availability consumption by 9-15% (Supplementary Table 2). Improving infrastructure such as storage facilities, transportation, refrigeration and packaging can reduce nutrient loss and waste in supply chains[19]. Since supply chain improvements may have limited effect on the scarcest micronutrients in Africa in the absence of productivity improvements, promoting cheap micronutrients supplements such as ferrous sulphate is a third, complementary measure that could help narrowing Africa's micronutrients gap.

Our study has several uncertainties and limitations that must be acknowledged. First, people's nutrient demands are based on some assumptions. For example, if nutrient bioavailability levels were to be considered (particularly their absorption/digestion via normal pathways in the human body)[21], the number of countries with gaps in zinc and iron would be greatly alleviated (Supplementary Figure 5). Second, our nutrient gap estimates do not imply insufficient nutritious food intake among all people; rather, they indicate national average situation. This is because food intake also depends on several variables not investigated in this study, such as food distribution within country and social equality[19]. Third, national-scale research does not account for regional variations in land and water availability. In many cases, effectively utilizing water resources from African rivers is challenging due to inadequate water infrastructure[22]. Factors such as crop rotation and land suitability are not considered, which results in land use increasing in direct proportion to production. Additionally, climate change and the resulting heat and water stress, are not considered in this study[23]. Given the anticipated population growth and worsening heat and water conditions in the future, ensuring an adequate nutrient supply in Africa may become increasingly difficult unless productivity improves significantly[20]. Therefore, our results are conservative, and the actual challenge of bridging the nutritional gap may be even greater. Fourth, our results indicate that wild fisheries are an important source of nutrients for certain island and coastal countries, such as Seychelles, Mauritania, and Namibia (Supplementary Figures 6-8). However, due to data limitations, we were unable to include other wild food sources, such as foraged and hunted foods. While wild foods can play a significant role in nutritional supply for some countries[24], climate change and ecological degradation driven by overexploitation have rendered this approach increasingly unsustainable[25]. Finally, FAO data are the most appropriate and updated data available at the time of this study, concerns have been raised about potential inaccuracy and missing values[26].

Methods

We investigated the nutrient gaps for nine key food nutrients derived from 162 food types (cereals, oilseeds and pulses, meat, roots and tubers, milk, fruits, vegetables, nuts, sugar crops, spice, aquatic products, Supplementary Table 3) between national demand and domestic production in 54 African countries in 2020. The nine key nutrients included two macronutrients (proteins and carbohydrates) and seven micronutrients (calcium, riboflavin, niacin, folate, iron, zinc, and Vitamin A)[1,3]. Furthermore, we evaluated the potential of reducing nutrient gaps by expanding production under national land and water availability constraints.

Nutrient gaps between national demand and domestic production

The nutrient gap investigated here compares the magnitude of food 'ready to be consumed' after preparation and cooking processes, with that needed by a given population. The first step was to exclude (from primary production) all agricultural products that do not reach human consumption, such as animal feed, seeds, non-food uses (such as oil for making soap), losses, wastes, and cooking loss (Supplementary Methods 1.1). Some items may be processed prior to consumption, for example, groundnuts can be used raw or transformed into oil before consumption. We used food supply data (kcal/cap) from the FAO Food Balance Sheet to account for the fraction of food items available (supply) in raw or processed form (Supplementary Methods 1.2). The next step was to estimate the edible portion of all unprocessed (as processed products have already excluded inedible parts) items by applying the refuse factor of each food[21]. In third step , food preparation and cooking methods were considered to calculation the nutrient availability for human consumption[11]. We included all possible cooking methods such as drying, steaming, roasting, boiling, and baking. Also 'fresh' is included as a preparation option for consumption. Any method that included other foods was not considered (e.g., frying with oil, fat, or butter) to avoid double counting of nutrients provided by both the main item being cooked and the item used for cooking. To obtain the nutrient content profile for each food type, we matched each food item obtained in the previous steps with the United States Department of Agriculture (USDA) Food Composition Database and the West African Food Composition Table. Finally, we multiplied the edible quantities produced by the average unit nutrient content, considering different subspecies and cooking methods, to yield the ready-to-eat nutrient production for each item and for each African country.

The nutrients demand was obtained by multiplying the Recommended Nutrient Intake (RNI), relevant to age and sex, by the population relevant to each country. We used the RNI for all nutrients, except protein, at a standard weight. We further considered the weight relevant to population age and sex when estimating the RNI for proteins. This was done as follows: for people under 18 years, we used global reference weights considering age groups and gender[27]. For adults older than 18 years, we calculated the body weight relevant to sex using data from the NCD Risk Factor Collaboration (NCD-RisC)[28]. The recommended amount of protein per unit of human body weight was then multiplied by the calculated body weight.

The nutrient gap was obtained after subtracting the nutrients demand by the population from those obtained at the household level, for each African country and nutrient. In addition, we also used the decomposition method to identify the contribution of food production quality and quantity to the nutrient gaps (Supplementary Methods 1.3).

Potential to fill nutrient gaps through increasing production under land and water constraints

We introduce an indicator named the potential reduction rate (PRR) to assess the potential for filling the nutrient gaps by increasing production under the current water/land productivity and water/land constraints, as follows:

$$PRR_r = \frac{RC_r - RU_r}{RD_r} = \frac{RC_r - P * URF_r}{M * URF_r}$$

where PRR_r is the potential reduction rate of nutrient gaps under the resource *r* constraints. *r* here refers to water or land. The PRR_r of a given country is the lower value between the results from PRR_{water} and PRR_{land}. RC_r, RU_r, RD_r refer to the resource constraints, resources used in current production, and resources required to fill the nutrient gaps, respectively.

The resource constraints refer to the thresholds for sustainable agricultural land use and water consumption at the national level. The water constraint is defined as 20% of the nation's total runoff[29-32]. The water constraint for agricultural water consumption is obtained by subtracting industrial and service water consumption from the total water constraint. The land constraint for agricultural land use is defined as the potentially available cropland[33]. More details for the water and land constraints can be found in the Supplementary Methods S1.4. RU_r is calculated by multiplying the amount of current food production (P) by the unit resource footprint (URF_r). The URF_r is the reciprocal of water/land productivity (ton/m3). Please see Supplementary Methods S1.5 for more details about the calculation of URF_r. RD_r is obtained by multiplying the minimal amount of food to fill nutrient gaps (M) (Supplementary Methods S1.6) by the URF_r. Note that RU_r may exceed RC_r, indicating that the country has no room left to expand production under current productivity levels and resource constraints. In such case, the PRR_r is set to 0.

Furthermore, given the significant disparity between Africa’s current land and water productivity and its potential productivity, we developed three counterfactual scenarios to evaluate the land and water requirements for closing the nutrient gaps under improved land and water productivity. Scenario 1: Africa's land productivity is elevated to the global average level (nearly double the current per-unit land productivity, with variations by country). Numerous studies have demonstrated that this can be achieved through effective field management practices[8,10,15]. Scenario 2: Africa's water productivity (mass production per unit of water consumption) is raised to the global average level. According to previous studies, this can be achieved under current technological and climatic conditions[14]. Scenario 3: A combination of Scenarios 1 and 2.

Data sources

Food production data were obtained from the FAO and Agriculture Organization (FAOSTAT) Statistics Division[34]. These data indicate the magnitude of several food products consumed annually. We selected 162 food items for which African country production data were available. Disaggregated data on food production was used instead of aggregated data from the food balance sheet because it was found to be more accurate[21]. Population data were obtained from the UN-DESA[35]. We used the United States Department of Agriculture (USDA) Food Composition Database[36] and the West African Food Composition Table[37]to determine the nutrient content of food commodities. The RNI estimates the daily nutrient intake needed to provide the requirements of 97.5% of healthy individuals in a particular population group and is tailored for global assessments[21]. The RNI depends on population weight and age and was obtained from the FAO and WHO[38]. Because the FAO and WHO do not include all nutrients, other sources were used[39,40]. The reference year for all data, unless otherwise indicated, was 2020.

Data availability

Food production data is publicly available from FOASTAT (https://www.fao.org/faostat/en/#data/QCL). Population data is available from (https://population.un.org/wpp/downloads). The nutrient content of food is available from http://www.ars.usda.gov/ba/bhnrc/ndl and ref[36]. The RNI is available from https://www.ncbi.nlm.nih.gov/pubmed/30844154 and refs[38,39].

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Author Contributions Statement

X.Z. and P.T. designed this study. H.F.N., P.T. and S.C. performed the analysis and prepared the manuscript. X.Z., P.T. and N.Z. coordinated and supervised the project. All authors (H.F.N., X.Z., P.T., P.H., X.X.Z., A.H., M.R.T., I.O., S.C., H.Z., K.F., and N.Z.) contributed to writing and reviewing the manuscript. These authors contributed equally: H.F.N. and X.Z. Correspondence to X.Z. (xuzhao@sdu.edu.cn); P.T. (tianpp@sdu.edu.cn); N.Z. (nz293@cam.ac.uk).

Competing interests

The authors declare no competing interests.

Figure Legends

Fig. 1 Nutrient deficiency rates (expressed in %) for African countries based on national food production and nutrient requirements. Negative values (red) indicate a nutrient deficit, whilst positive values (green) indicate surplus production. The maps are ranked in decreasing order of the number of countries found deficient.

Fig. 2 Potential reduction rate under national blue water and land constraints in African countries. "Potential reduction rate" refers to the extent to which the nutrient gap can be reduced within national resource boundaries. Section A refers to countries where gaps can be fully filled with national blue water and land constraints. Section B refers to countries where gaps can be partially filled with national blue water and land constraints. Section C refers to countries whose current consumption of water or land already exceeds national constraints and have therefore no capacity to expand production on a sustainable basis.

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