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Une diète adéquate est-elle économiquement accessible en Afrique ? Une étude de 4 pays africains.

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Résumé. Entre 702 et 828 millions de personnes ont été touchées par la faim dans le monde en 2021. La sous-alimentation continue de frapper sans cesse le monde, et en particulier l'Afrique subsaharienne. Cette recherche présente une approche d'optimisation de diète pour analyser l'accessibilité économique des diètes nutritionnellement adéquates dans 4 pays africains : Éthiopie, Kenya, Afrique du Sud et Ouganda. La population ciblée comprend des dyades de femmes en âge de procréer et leurs enfants âgés de 6 à 24 mois. L'approche permet de contraster les résultats du modèle avec les données des enquêtes sur la consommation alimentaire dans les villes primaires et secondaires de chaque pays. Les résultats fournissent des apports alimentaires (par groupes d'aliments) permettant une adéquation nutritionnelle tout en minimisant les changements dans les préférences de consommation, sinon, les résultats indiquent quelles recommandations nutritionnelles ne peuvent être atteintes dans le cadre du scénario actuel. Nous évaluons l'impact nutritionnel du maintien d'un régime alimentaire économiquement abordable et incluons des scénarios avec des ressources extrêmement limitées. Les conclusions comprennent des pistes pour la poursuite du développement de la modélisation et pour soutenir la discussion sur les futures lignes directrices en matière d'alimentation.

Mots clés : Optimisation de diètes – Programmation mathématique - Santé et bien-être - Accessibilité économique des diètes

Is an adequate diet affordable in Africa? Evidence from 4 African countries.

Abstract. Between 702 and 828 million people were affected by hunger worldwide in 2021. Undernourishment relentlessly continues to hit the world, and particularly Sub-Saharan Africa. This research presents a diet optimization approach to analyse economic affordability of nutritionally adequate diets across 4 African countries: Ethiopia, Kenya, South Africa and Uganda. The targeted population includes dyads of women in reproductive age and their children between 6 and 24 months. The approach allows contrasting the outcomes of the model with data from food consumption surveys in primary and secondary cities of each country. Results provide food intakes (by food groups) enabling nutritional adequacy while minimizing changes to consumption preferences, otherwise, the outcomes indicate which nutrient recommendations are unattainable under the current scenario. We evaluate the nutritional impacts of maintaining diet affordability, and include scenarios with extremely scarce resources. Conclusions include paths for further modelling development and for supporting discussion for future dietary guidelines.

Keywords: Diet optimization - Mathematical programming - Health and Welfare - Diet affordability.

Classification JEL: C6, I1.

1. Introduction

In 2020, an estimated of 22% of children under five years of age worldwide were stunted and 6.7% were wasted. Projections show that nearly 670 million people will still be facing hunger in 2030 (8% of the world population). The problem is that the current rate of progress on child stunting, low birthweight, anaemia in women of reproductive age, and breastfeeding is insufficient. Actually, the COVID-19 pandemic has likely affected the prevalence of multiple forms of malnutrition (FAO, IFAD, UNICEF, WFP and WHO, 2022). Further efforts are therefore required to empower vulnerable consumers and ensure their access to healthier diets.

Several efforts have been done to optimize the economic affordability of diets (Drogue et al., 2020; Gazan et al., 2018; Stigler, 1945). Recent studies address the issue at a large scale, for instance Hirvonen et al. (2020) carried a global assessment of EAT–Lancet benchmark diets affordability by comparing the total cost of the diet (a global median of US$2·84 per day) to each country's mean per capita household income, and to a least-cost diet that meets essential nutrient requirements. Drewnoski also drew on the EAT-Lancet stressing that diet affordability also depends on the relation between local food prices and household food budgets. His calculations of diet affordability by relating diet costs to national incomes produced results consistent with Engel's Law: an increase in the income of a family decreases the proportion of which the income is spent on food (2020). Masters et al. (2018) presented a method to measure diet affordability based on price indexes. The authors evaluated the affordability of nutritious diets in two African countries by comparing the cost of a diversified diet, calculated as the lowest-cost way to include at least five different food groups, with the cost of nutrient adequacy, estimated as the lowest-cost way to meet nutrient requirements. Bai et al. (2021) compare minimum cost of nutrient adequate diets both to a subsistence cost of dietary energy, and to a per-capita spending on all goods and services in 177 countries worldwide. Our main contribution in regard to existing literature consists in exploring a more complex angle of evaluating economic affordability of diets. This is, not focusing on minimizing costs of a diet with average nutritional requirements, but accounting affordability of diets with adequate nutritional requirements and optimizing cultural acceptability.

The objective of this research is comparing affordability of adequate diets across the selected countries using a mathematical programming model. Particularly, this study addresses the following research questions: Is reaching nutritional adequacy feasible for each of the selected cities and population groups? What are the implications for food choices? Is it possible to design nutritionally adequate diets that are also affordable and culturally acceptable? Which nutrient recommendations are more difficult to comply with? And ultimately, are there similar diet sustainability issues within the selected countries?

2. Data

Data was organized in food groups elaborated according to data provided by each country - thus facilitating comparison across countries (21 food groups, see Table 1).

Table 1. Food groups

1	Cereals	12	Oils_and_Fats
2	Roots_and_Tubers	13	Nuts
3	Legumes	14	Sugar_and_SweetenedProducts
4	Vegetables	15	HotBeverages
5	Fruits	16	InfantFoods
6	FreshFruitJuices	17	Insects
7	Dairy	18	Spices
8	BreastMilk	19	SweetenedBeverages
9	Meat_and_Poultry	20	BeveragesUnsweetened
10	Eggs	21	Other
11	Fish_and_SeaFood		

2.1. Baseline diet

First, a baseline diet was estimated using a survey data. The baseline diet includes food groups consumption and nutrients intake in each location. It includes women between 17 and 45 years old and their child between 0.5 and 2 years old (1573 dyads).

2.2. Food prices

The food prices dataset was built using data provided by the International Comparison Program (ICP). Non-aggregated food prices for each country were obtained by application. The most recent available data was from the 2017 cycle, listing up to 125 available food items.

2.3. Food composition tables

Food composition tables were provided for each country, accounting for around 30 nutrient components and above 700 food items. A mean nutrient composition was calculated for each food group.

2.4. Nutritional recommendations

The model incorporates both lower bounds and upper limit thresholds of nutritional recommendations. Parameters were selected in accordance with an energy target, set to 2100kcal for women, and 990kcal for children. Parameters were established in consensus between experts with basis on international reports (EFSA, 2017; WHO and FAO, 2004).

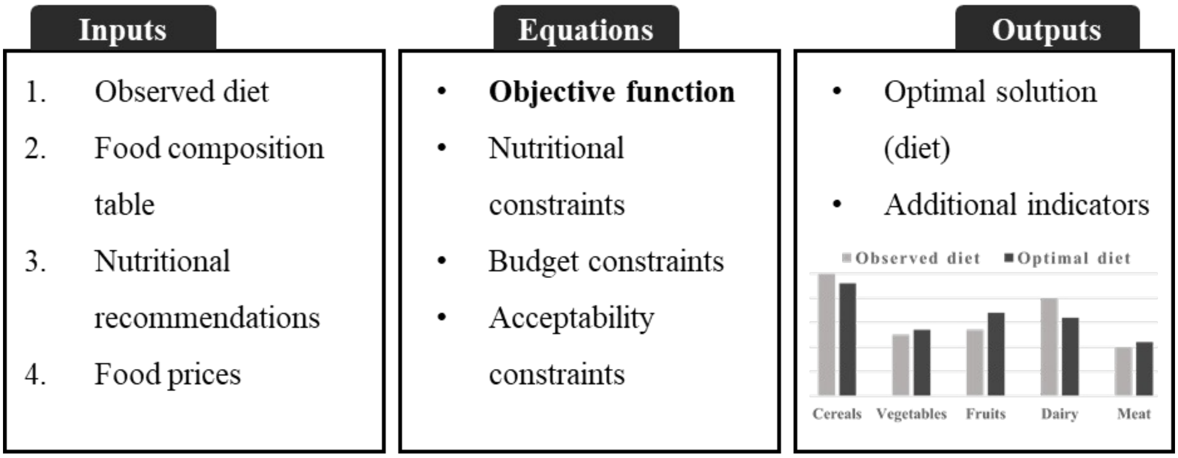
3. Method

3.1. Model

We developed a mathematical programming diet optimization model to assess nutritional sustainability of children and mothers in the four selected countries. The modelling approach includes three main components (See Figure 1). First, it is fed by four input datasets: (1) observed diet, (2) food composition, (3) nutritional recommendations, and (4) food prices. Second, the model comprehends a group of equations defining the optimization problem.

Third, the solution provides a theoretic optimal diet, as well as additional indicators that allow drawing conclusions concerning nutritional recommendations.

Figure 1 : Structure of the modelling approach

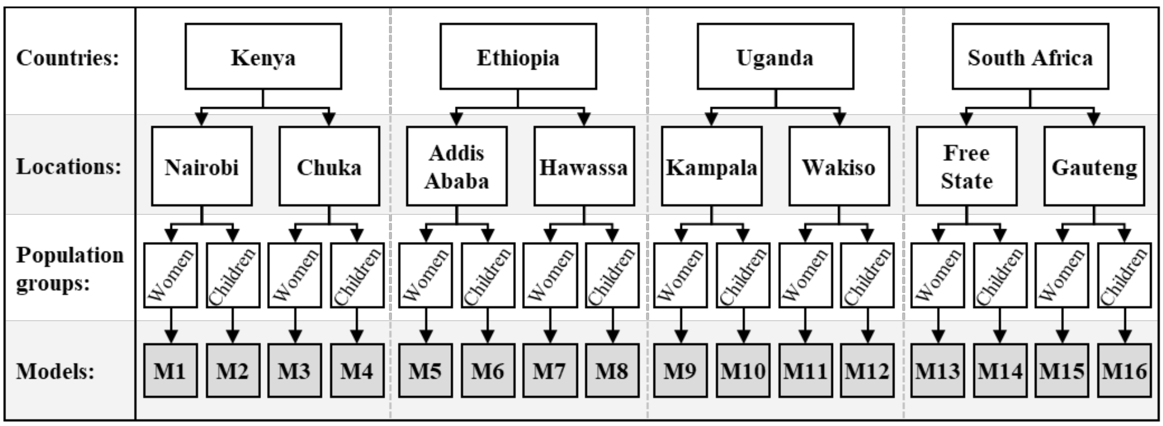


Diet adequacy was assessed by accounting for cultural acceptability (objective function and constraints), fulfilment of nutritional recommendation (set of nutritional constraints), and diet affordability (budget constraint).

The objective function is a minimization of the sum of squared relative differences between the optimal diet and the observed diet. It is designed to account for consumers' preferences (i.e. acceptability) reflected in observed food choices as it induces the model to find the minimal variations from the observed diet (Drogue et al., 2020).

We built a generic model to be replicated for each study case (including two different locations and two population groups). Then, the strategy included carrying a different model for each sample, adding up to 4 models per country and 16 models in total (See Figure 2). Additional scenarios of each model were developed when nutritional requirements were found unattainable - thus obtaining best-near optimal solutions. The significant number of models justified choosing a subpopulation-based optimization over an individual-based optimization(Gazan et al., 2018). The methodology provides results to contrast theoretically optimal solutions by country, location and individual type. The model was run using CONOPT solver in GAMS software.

Figure 1. Case studies and scope of the modelling



3.2. Equations

This section details how the modelling addresses the nutritional adequacy assessment of diets. First, the model is oriented to find culturally acceptable solutions by minimizing the sum of the relative squared deviations from the observed diet (See Objective function). The nutritional adequacy of the solution is achieved through a set of nutritional constraints. Diet affordability is given by a budget constraint. To emphasize cultural acceptability, a set of constraints are added to bind the model's food choices above the 2.5th percentile of the observed diet.

Objective function

The objective function of the model is a minimization of the sum of squared relative differences between the optimal diet and the observed diet (See Eq. 1). It is designed to account for consumers preferences (i.e. acceptability) reflected in observed food choices as it induces the model to find the minimal variations from the observed diet (Drogue et al., 2020). More precisely, by squaring relative changes, large changes are more penalized than small changes, meaning that solutions will prioritize more smaller changes rather than fewer larger changes (Cleveland et al., 1993; Shankar et al., 2008).

$$MIN\ Z = \sum_i \left(\frac{X'_i - X_i}{X_i} \right)^2 \qquad \text{Eq. 1}$$

Where X' is the quantity, expressed in grams, of the ith food group in the optimized diet, and X is the quantity, expressed in grams, of the ith food group in the observed diet. Please note that X and X' are also implicitly indexed on each location and population type. For sake of simplicity, the notation only includes these additional indexes when it is needed for discussion.

Nutritional constraints

The role of nutritional constraints is to restraint results to solutions incorporating nutrients intake within ranges set by the minimum nutritional recommendations for the lower bounds and upper limit thresholds. The nutritional minimum and maximum parameters are based on the recommendations established by the WHO, FAO, & UNU joint report on human energy requirements (2001), the WHO, FAO, & UNU joint report on protein and amino acid requirements in human nutrition (2002), and the WHO & FAO report on vitamin and mineral requirements in human nutrition (2004).

$$\sum_i X'_i \times \alpha_{i,kcal} = \varepsilon \qquad \text{Eq. 2}$$

Where $\alpha_{i,kcal}$ is the level of energy component ($kcal$) in each food group (i) found within the corresponding food composition table, and ε is the energy target selected for each population type.

$$\forall n \quad \sum_i X'_i \times \alpha_{i,n} \geq lr_{n,p} \qquad \text{Eq. 3}$$

$$\forall n \quad \sum_i X'_i \times \alpha_{i,n} \leq hr_{n,p} \qquad \text{Eq. 4}$$

Where $\alpha_{i,n}$ is the level of nutrient component (n) in each food group (i) found within the corresponding food composition table, $lr_{n,p}$ is the lower limit requirement (i.e. minimum nutritional recommendations) of the nutrient (n) for each population type (p), and $hr_{n,p}$ is the upper limit of the nutrient (n) for each population type (p).

Note that Eq. 4 only applies for nutrients with an identified upper limit. In addition, please note that Eq. 3 and Eq. 4 are only effectively accounted for when the food composition table provides data for the nutrient component parameter ($\alpha_{i,n}$).

Budget constraint

The role of the budget constraint (Eq. 5) is to ensure the affordability of the optimized diets by setting a maximum total budget equal or lower than the observed diet budget. The observed diet budgets were calculated using observed diets and food prices according to each case study. Equation 5 and 6 show how the parameters of the observed diet budget were calculated.

$$\sum_{i} (\omega_i \times ¿ X'_i) \leq OB ¿ \qquad \text{Eq. 5}$$

Where OB is the observed diet budget. ω is the average price, expressed in US$_{2017}$/gr, of the i th food group. X' is the quantity, expressed in grams, of the ith food group in the optimized diet. And X refers to the observed diet.

$$OB = \sum_{i} (\omega_i \times ¿ X_i) ¿ \qquad \text{Eq. 6}$$

The input to the model is the average prices for each of the aforementioned food groups (ω_i).

Acceptability constraints

As the objective function minimizes the differences between the optimized and observed diet, this does not imperatively avoid changes. Cultural acceptability is further controlled by a constraint giving a minimal level of consumption for each food group, which is determined by the 2.5th percentile of the observed diet data (Eq. 7).

$$\forall i \qquad X'_i \geq X_{025\,thi} \qquad \text{Eq. 7}$$

Where X is the quantity, expressed in grams, corresponding to the 02.5th percentile of the ith food group in the observed diet.

Additional modelling constraints

The modelling includes 6 additional equations to align the outputs with well-known nutritional guidelines:

Equations 8-10 are built to prevent the model to find solutions lowering key food groups.

Equation 11 is included to prevent the model to find solutions with unusual intakes of the fresh fruit juices food group since the varying qualities and complex classification of its underlying food products may result into a misleading recommendation. Where X' is the quantity, expressed in grams, of the respective food group in the optimized diet, and X is the quantity, expressed in grams, of the respective food group in the observed diet.

Equation 12 is built to ask the model to find solutions including at least 400grs of total intake between the fruits and vegetables food groups. This constraint was added to ensure a minimal account for nutrients that were not included within the nutritional constraints.

Equation 13 is meant to limit the total food intake of children to a maximum gastric capacity referential value of 1500 grams (excluding breastmilk). Where j represents food groups excluding breastmilk.

$$X'_{'legumes'} \geq X_{'legumes'} \qquad \text{Eq. 8}$$

$$X'_{'fruits'} \geq X_{'fruits'} \qquad \text{Eq. 9}$$

$$X'_{'vegetables'} \geq X_{'vegetables'} \qquad \text{Eq. 10}$$

$$X'_{'freshfruitjuices'} \leq X_{'freshfruitjuices'} \quad \text{Eq. 11}$$

$$\sum_{fruits \wedge vegetables} X'_{fruits \wedge vegetables} \leq 400\,gr \quad \text{Eq. 12}$$

$$\sum_{j} X'_{j,'children'} \leq 1500\,gr \quad \text{Eq. 13}$$

3.3. Scenarios

4. Results and discussion

Figure 3 presents the results of the optimization of Hawassa's women diet. Where the main changes are reducing the intake of cereals and significantly increasing the intake of vegetables and fruits.

Figure 3. Results of the Hawassa's women diet

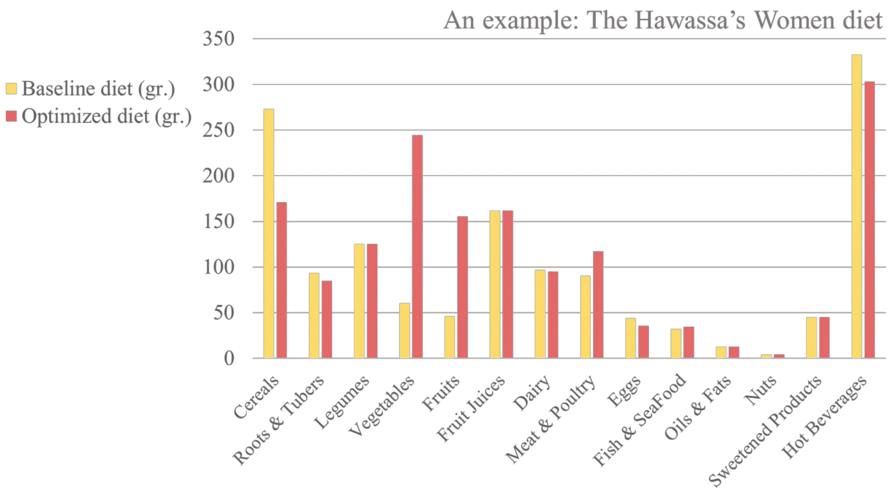


Table 2 presents the average variations after the optimization of diets. Where main changes are consistent with the case of Hawassa's women.

Table 2 Average diet variations across the 16 models

Cereals	▽ -67%	Eggs	▽ -29%
Roots & Tubers	▽ -38%	Fish & SeaFood	▽ -15%
Legumes	△ 103%	Oils & Fats	△ 56%
Vegetables	△ 891%	Nuts	△ 21%
Fruits	△ 180%	Sweetened Products	▽ -29%
Fruit Juices	▽ -37%	Hot Beverages	▽ -14%
Dairy	▽ -40%	Insects	▽ -54%
Breast Milk	△ 1%	Spices	△ 7%
Meat & Poultry	△ 16%		

Based on the observed food intake patterns and the nutrient deficiencies, the outcomes propose new diets modifying food intake (organized in food groups) in order to achieve nutritional adequacy while minimizing food intake changes, or, if applicable, the outcomes indicate which nutrient recommendations are unattainable under the current model setup. In average, our results show that nutritional adequacy can be attained by increasing the intake of legumes, vegetables and fruits, while moderately reducing the intake of cereals, roots and tubers. Additionally, we found that the model struggles to find a solution for Folate deficiency for women in South Africa, where the gaps are enough to suggest that nutritional complementation may be required. Another example is given with Uganda diets both for women and children, where even in our best scenarios there is still a relatively small deficiency in Calcium as compared to our recommendation. In Ethiopia, our diet solutions for children admitted lower intakes of lipids as compared to the recommendations.

As for diet affordability, in all cases solutions include diets for which total expenditures do not exceed our estimations of the current observed budget. In some cases, we managed to find solutions that include a significant reduction of the budget. Our results indicate that, within our observations, Uganda is the country that allocates less resources for food, whereas South Africa has the least affordable observed diet. We show that diet affordability does not necessarily implicate an unfeasible context for improving the nutritional adequacy of diets. Finally, we complement our findings in diet affordability by showing how the model can be used to explore viable solutions with extremely scarce resources (1$ a day), and what are the possible nutritional implications of these precarious conditions in each country.

5. Conclusion

Je m’excuse de déposer une version non finie du papier. Si présentation orale est retenue, je viellerai à envoyer la version finale de l’article qui est prévue pour mi-octobre.

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