

Bio-Inspired Dietary Optimization for Chronic Disease Prevention Using Brazilian National Surveys

Thalyson G. N. da Silva

State University of Ceará

Fortaleza – CE – Brazil

thalyson.uece@gmail.com

Gustavo A. L. de Campos

State University of Ceará

Fortaleza – CE – Brazil

gustavo@larces.uece.br

Bonfim Amaro Júnior

State University of Ceará

Fortaleza – CE – Brazil

bonfim.amaro@uece.br

Ana Luiza B. de Paula Barros

State University of Ceará

Fortaleza – CE – Brazil

analuiza.barros@uece.br

ABSTRACT

This study presents a bio-inspired optimization approach to individualized dietary planning for the prevention of chronic non-communicable diseases. Using real-world data from the Brazilian Household Budget (POF) and National Dietary Surveys (INA), the algorithm adjusts each individual's recorded diet to meet nutritional adequacy targets based on WHO guidelines. Cultural and socioeconomic dietary patterns are preserved by restricting substitutions to regionally available foods. The heuristic search applies mutation, crossover, and fitness-based selection to iteratively refine food combinations and improve intake of 25 key nutrients. Results from over 400 individuals across demographic groups showed significant gains in nutrient adequacy, increasing from approximately 72% to 98% on average. The approach also revealed persistent gaps in the Brazilian diet, especially in fruit, vegetable, and dairy consumption. This work highlights the potential of combining operational research and public health nutrition to provide scalable, culturally sensitive, and data-driven strategies for dietary improvement and chronic disease prevention.

KEYWORDS. Operational Research in Health, Heuristic Optimization, Dietary Planning, Chronic Diseases, National Food Data.

Paper topics: SA - OR in Health, OA - Other Applications in OR

1. Introduction

Adequate nutrition plays a fundamental role in ensuring proper physiological development, supporting child growth, and reducing health-related risks such as pregnancy complications and the onset of chronic diseases [Mendoza-Velázquez et al., 2022]. Despite its critical importance, dietary patterns in many low- and middle-income countries (LMICs) are often characterized by insufficient intake of essential micronutrients, including iron, zinc, and vitamin A [Beal et al., 2017].

In this context, this study proposes a bio-inspired heuristic algorithm for personalized dietary planning based on real-world data from Brazilian national food consumption surveys. The proposed method aims to improve nutritional adequacy while preserving cultural and socioeconomic food preferences.

2. Proposed Bio-Inspired Optimization Methodology for Personalized Dietary Planning

This study leverages data from the *Household Budget Survey* (HBS), a comprehensive nationwide survey conducted among Brazilian households. The HBS collects detailed information on food acquisition patterns and socioeconomic characteristics.

To define the nutritional targets adopted in this study, we followed the guidelines established by the World Health Organization for the prevention of diet-related chronic diseases [Who and Consultation, 2003], supplemented by standard recommendations for essential vitamins and minerals. The *Estimated Energy Requirement* (EER) was calculated individually based on each person's sex and age, according to the dietary reference intake equations proposed in [on the Scientific Evaluation of Dietary Reference Intakes et al., 2005], which are applicable to adults aged 25 to 60 years. These estimations assume a low level of physical activity-sufficient to distinguish from a sedentary lifestyle, but without engaging in regular vigorous exercise.

Each candidate solution is represented as a one-dimensional vector $x = (x_1, x_2, \dots, x_n)$, where x_i denotes the quantity (in grams) of food item i in the diet. The initial population is generated using real dietary data from the Household Budget Survey (HBS), with each vector reflecting the quantities recorded for a given individual. This initialization strategy ensures that the search begins from culturally and behaviorally plausible dietary patterns.

The fitness function evaluates the nutritional adequacy of each candidate solution based on deviations from the recommended nutrient targets. Let NutriCurrent_j denote the total intake of nutrient j in a given solution, and NutriTarget_j its corresponding ideal value. The penalty for unmet requirements is scaled by a multiplier $\text{MULT} = 1007$, reflecting the high priority of meeting minimum and maximum thresholds. The formulation prioritizes nutrient balance and penalizes violations of recommended intake ranges. The fitness score $G(x)$ is computed as:

$$G(x) = \sum_{j=1}^m \begin{cases} |\text{NutriCurrent}_j - \text{NutriTarget}_j|, & \text{if } L_j \leq \text{NutriCurrent}_j \leq U_j \\ |\text{NutriCurrent}_j - \text{NutriTarget}_j| \cdot \text{MULT}, & \text{otherwise} \end{cases}$$

To explore the solution space, the algorithm generates new candidate solutions by applying mutation operators that increase or decrease the quantity of food items. A mutation consists of adjusting the quantity of a given food by up to MAX_UNIT units, where each unit corresponds to UNIT grams. For a set of MA available food items in a given individual's stratum, the number of potential mutations per step is $2 \cdot \text{MAX_UNIT} \cdot \text{MA}$.

3. Results and Discussion

To evaluate the performance of the proposed heuristic, a sample of 400 individuals was selected, divided into four demographic groups of 100 participants each. Group 1: Women aged

25; Group 2: Men aged 25; Group 3: Women aged 60; Group 4: Men aged 60. This stratification enabled the assessment of age- and sex-specific nutritional gaps and allowed for tailored interpretation of algorithmic adjustments across physiologically distinct populations. For all experimental scenarios, optimization was conducted over a fixed number of 10 generations, which served as the stopping criterion. The initial nutritional adequacy for groups 1, 2, 3, and 4 was 71.04%, 75.93%, 71.79%, and 74.01%, respectively. Following optimization, these groups achieved a nutritional adequacy of 98.09%, 99.04%, 98.24%, and 98.73%, respectively.

A broader evaluation across all 25 nutrients with minimum thresholds confirmed widespread improvements, with post-optimization adequacy exceeding 98% for all demographic groups. These findings validate the robustness and generalizability of the proposed approach. Notably, Group 3 (women aged 60) exhibited the highest relative improvements in calcium and magnesium intake, which are often under-consumed in older adult diets. This indicates the algorithm's capacity to address population-specific needs even when initialized with suboptimal profiles.

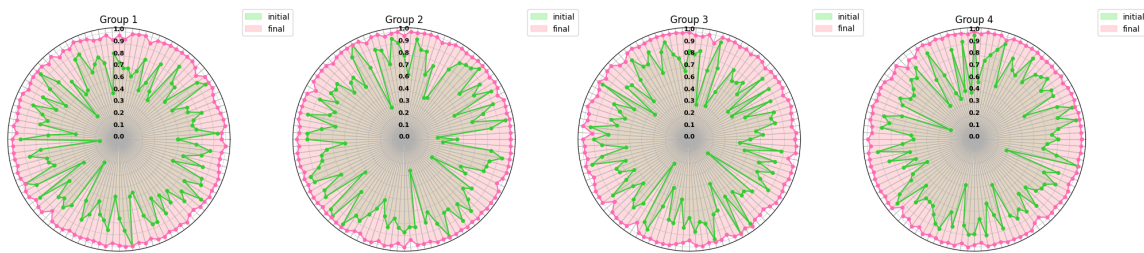


Figure 1: Diet adequacy percentage for minimum recommended nutrient values.

Compared to national averages reported by [Verly et al., 2021], which often show adequacy below 80% for key micronutrients, the proposed method demonstrates significant progress toward meeting WHO and Brazilian Ministry of Health dietary goals. While mean adequacy values exceeded 98%, the model also proved effective across individual cases with more severe baseline inadequacies. For instance, certain participants started with as little as 40% adequacy for vitamin A or fiber, which were successfully corrected within the 10-generation limit, reflecting the heuristic's capacity for personalized correction.

	Group 1	Group 2	Group 3	Group 4
Cereal products	+10%	+9%	+8%	+13%
Fat and oils	-4%	-4%	-7%	-4%
Fish and seafood	+17%	+3%	+14%	+2%
Meat and meat products	+6%	+3%	+2%	+2%
Seeds and nuts	+40%	+67%	+50%	+75%
Milk and dairy products	+274%	+262%	+326%	+224%
Fruits and fruit products	+208%	+210%	+90%	+130%
Legume products	+8%	+6%	+19%	+2%
Eggs and eggs products	+0%	-3%	-3%	-11%
Vegetable products	+244%	+204%	+259%	+218%

Table 1: Variation in food group composition after optimization (relative to baseline).

Regarding food group adjustments, Table 1 presents the relative change in consumption across ten food categories. The most significant increases were observed in fruits, vegetables, dairy products, and seeds/nuts-food groups generally underrepresented in the baseline diets. This outcome aligns with national studies on dietary inadequacies in Brazil [Verly-Jr et al., 2019, 2022]. Conversely, decreases in energy-dense items such as oils and eggs reflect the algorithm's effort to reduce excess calories and fats while improving micronutrient intake.

These compositional shifts reinforce the model's alignment with dietary recommendations from both WHO and national guidelines, particularly the emphasis on fresh and minimally processed foods. The rise in dairy consumption, exceeding 250% in all groups, was instrumental in achieving calcium and vitamin B2 adequacy, further supporting the effectiveness of food-group-level adaptations.

Furthermore, given its low computational requirements and short convergence time, the algorithm presents strong potential for integration into public health decision-support systems or personalized nutrition platforms targeting large populations. Its scalability, interpretability, and adherence to cultural constraints position it as a promising tool for real-world dietary planning and chronic disease prevention.

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