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Optimization of a High-Protein Energy Bar Formulation using Linear Programing

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Abstract
Nutrition plays a fundamental role in maintaining and promoting human health, influencing physical performance, mental well-being, and overall quality of life. A balanced diet that provides adequate amounts of macronutrients—carbohydrates, proteins, and fats—as well as essential micronutrients such as vitamins and minerals, is crucial for supporting normal physiological functions and preventing chronic diseases. This study presents the use of linear programming in Microsoft Excel (via the Solver tool) to optimize the formulation of a high-protein energy bar. The goal was to maximize protein content in a 50 g serving while meeting constraints on energy (≤ 250 kcal), sugar (≤ 12 g), and cost (≤ €0.80). Six commonly used ingredients—oats, whey protein powder, honey, peanut butter, dried fruits, and mixed nuts—were analyzed. The results highlight the potential of simple and accessible optimization methods to support rational food product design, promoting the development of sustainable and nutritionally enhanced formulations.
Keywords: Protein bar, linear programming, optimization, nutrition formulation, Excel Solver.

1. Introduction

Proper nutrition is one of the most effective and affordable strategies for reducing the burden of numerous diseases and their risk factors, including obesity. Research in nutrition is essential for deepening our understanding of the causes of obesity and its related conditions, offering great potential to significantly improve global health and economic outcomes [1].

Protein bars are supplemented food products made from cereals and other high-energy ingredients. They have a sweet and pleasant taste and serve as a source of essential nutrients such as protein, fiber, vitamins, minerals, and complex carbohydrates. The ingredients must be carefully combined to ensure they complement each other in terms of flavor, texture, and physical properties [2].

Nutrition bars meet these criteria. They are formulated to provide substantial amounts of crude fiber and protein, making them ideal for consumers engaged in sports, fitness activities, and weight management [2].

The primary challenge in developing a high-quality energy bar lies in combining ingredients that provide essential functions - such as minerals, protein, vitamins, fiber, and binding agents - while producing a product with desirable characteristics, including appearance, taste, and texture, and achieving targeted nutrient levels. Product development can therefore be viewed as an optimization problem. In seeking the optimal formulation, the main goal is to identify the ideal levels of key ingredients, which serve as

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independent variables, while the response or dependent variable represents the objective to be optimized [3].

Nutrition plays a key role in maintaining health and supporting physical and mental performance. A balanced diet that provides the right amounts of proteins, carbohydrates, fats, vitamins and minerals is essential for preventing diseases and promoting overall well-being. In recent years, people have become more aware of the importance of healthy eating and an active lifestyle [3].

In this context, protein bars have become increasingly popular. They are easy-to-consume products that provide energy and essential nutrients, especially proteins that help build and repair muscles. These bars are used by athletes, active individuals, and anyone seeking a healthy alternative to traditional snacks. By combining cereals, nuts, fruits, and other natural ingredients, they offer both taste and nutritional value, supporting a balanced and healthy lifestyle [3].

The final product supports muscle protein synthesis due to its high-quality protein content and contributes to glycemic control and satiety through its fiber-rich and low-sugar formulation. By promoting balanced metabolic processes, it serves as a healthier and more cost-effective alternative to many commercial snack options, aligning with consumer demands for convenient yet nutritious food products [4].

Moreover, the regular consumption of protein bars offers several advantages. They provide a convenient source of essential nutrients, particularly for individuals with active lifestyles or limited time for meal preparation. Their high protein content aids in muscle repair and recovery following physical activity, while the presence of dietary fiber supports digestive health and helps regulate appetite. Additionally, protein bars can assist in weight management by promoting a prolonged feeling of fullness and reducing unhealthy snacking behaviors. Many formulations are also fortified with vitamins, minerals, and functional ingredients, contributing to overall nutritional adequacy and enhancing energy levels throughout the day [4].

2. Materials and method

According to Micula and Rotaru [5,6] an optimization model consists of three parts as follows:

1. The variables of the model are positive real numbers to be determined. Let's have x1, x2, …, xn. There are models where these variables are positive integers, and may represent for instance the livestock in a farm.

2. The constraints to the model are m equations and inequalities containing the variables x1, x2, …, xn. The right of each member is the resource limit restrictions addressed by restriction. This part of the mathematical model is also known as the system of restrictions.

3. The objective function contains the decision variablesx1, x2, …,xn and must be maximized/ minimized or otherwise optimized.

A system of positive values for x1, x2, …, xn which meets the restrictions is called a possible solution, and those possible solutions that optimize the objective function are called the optimal solution.

SOLVER is an Excel tool used in solving and re-optimization of linear programming problems. The method for solving linear programming is called "Simplex algorithm", which is programmable and for which there is a lot of software products (such as Matlab, Maple).

Six main ingredients were selected for the formulation: oats, whey protein powder, honey, peanut butter, dried fruits, and mixed nuts.

3. Results and discussion

Nutritional data for protein, energy, sugar, and cost were collected for each ingredient (Table 1). The six variables in our problem are initially initialized with the value zero, and after the Solver is applied, they will take the value that leads to the optimization of the efficiency function, that is, the maximize total protein.

Objective function:

Maximize total protein (g) per 50 g bar:

$$P = \sum_{i=1}^{6}(p_i * x_i / 100)$$

Subject to the following constraints (restriction 1)

1. $\sum_{i=1}^{6} x_i = 50$ (total mass fixed at 50 g)
2. $\sum_{i=1}^{6}(c_i * x_i/100) \leq 250$ (total energy ≤ 250 kcal)
3. $\sum_{i=1}^{6}(s_i * x_i/100) \leq 12$ (total sugar≤ 12 g)
4. $\sum_{i=1}^{6}(k_i * x_i/100) \leq 0.80$ (total cost ≤ 0.80 €)
5. $0 \leq x_i \leq x_i,max$ (ingredient limits)

The model was implemented in Excel using the SUMPRODUCT and SUM functions (Table 2).

Table 1. Data needed to obtain maximum function for a protein bar

	A	B	C	D	E	F	G
1	**Ingredient**	**Protein_per_100g (p_i)**	**Calories_per_100g (c_i)**	**Sugar_per_100g (s_i)**	**Cost_per_100g (k_i)**	**Max_amount_g (x_i,max)**	**Amount_g (variable) (x_i)**
2	Oats	13	389	1	0.3	50	0
3	Whey protein powder	80	400	5	2.5	40	0
4	Honey	0.3	304	82.1	1.2	30	0
5	Peanut butter	25	588	9	0.9	30	0
6	Dried fruit	3	240	60	1.5	20	0
7	Nuts (mixed)	20	607	4	1.8	30	0

Table 2. The formulas and constraints of the problem

H	I
Constraints	**Formula_or_Value**
Total weight (g) formula (I2)	=SUM(G2:G7)
Target weight (g)	50
Total protein (g) formula(I4)	=SUMPRODUCT(B2:B7,G2:G7)/100
Total calories (kcal) formula (I5)	=SUMPRODUCT(C2:C7,G2:G7)/100
Total sugar (g) formula (I6)	=SUMPRODUCT(D2:D7,G2:G7)/100
Total cost (€) formula (I7)	=SUMPRODUCT(E2:E7,G2:G7)/100
Max calories per bar (kcal) (H8)	250
Max sugar per bar (g) (H9)	12
Max cost per bar (€) (H10)	0.80

Table 3. The ingredients obtained in grams and the optimal total proteins, after applying the Solver

	A	G	H	I
1	**Ingredient**	**Amount_g (variable) (x_i)**	**Constraints**	**Formula_or_Value**
2	Oats	10	Total weight (g) formu	50
3	Whey protein powder	20	Target weight (g)	50
4	Honey	5	Total protein (g) formu	19.715
5	Peanut butter	5	Total calories (kcal) fo	205.85
6	Dried fruit	5	Total sugar (g) formula	8.855
7	Nuts (mixed)	5	Total cost (€) formula	0.8
8			Max calories per bar (I	250
9			Max sugar per bar (g)	12
10			Max cost per bar (€) (H	0.80

Solver was configured with the following settings:
Objective = total protein cell (maximize), (formula I4)
Variable cells = ingredient quantities, (G2:G7)
Constraints = as listed above (restriction 1)
Solving method = Simplex LP.
The optimization results indicated that whey protein powder and oats were the primary contributors to achieving the desired protein level while maintaining the constraints on calories, sugar, and cost. Honey and dried fruits were reduced to minimize sugar content, while peanut butter and nuts provided additional calories without exceeding the total energy limit.
These results can be viewed in Table 3 where the quantities of ingredients in grams were obtained (H2:H7), the total protein (formula I2) and it is also observed that the restrictions are verified (I2:I7). Thus, to make 100 grams of protein energy bar you need: 10 g of oats, 20 g of whey protein powder, 5 g of honey, 5 g of peanut butter, 5 g of dried fruit and 5 g of nuts and the total protein is equal to 19.715 g. The optimal formulation achieved a balanced cost-to-nutrition ratio, demonstrating the efficiency of the Solver approach.

The purpose of this study was to demonstrate the feasibility of using linear programming in the preliminary formulation of functional foods. Important factors for a food product—such as taste, texture, shelf life, and consumer acceptance—were not addressed, as the focus was on maximizing the protein content of an energy bar based on the quantities and costs of the ingredients included in its composition.
The mathematical model provides theoretical efficiency; however, future research will include the experimental validation of the optimized formula. Laboratory-scale production will evaluate sensory properties (taste, texture, flavor), shelf life, and consumer acceptance.
The assumption of linear ingredient costs was maintained for the sake of model simplicity. Nevertheless, bulk purchasing, supplier discounts, and logistical costs may introduce nonlinear behavior. Future work will explore piecewise-linear or nonlinear optimization approaches using the GRG Nonlinear Solver and heuristic algorithms to better capture real-world pricing structures.
This method offers a reproducible and efficient approach for product formulation analysis and can be extended to other functional foods.

4. Conclusions

Mathematical modeling is a very powerful and flexible tool that finds applicability in many fields. The complexity of this software is given by the fact that it is able to solve problems where there are a large number of unknowns and restrictions. Microsoft Excel Solver enables the practical application of linear programming in food formulation design. The proposed model effectively maximized protein content while maintaining strict nutritional and economic constraints. The method serves as a valuable educational tool for students and researchers, linking food technology with optimization principles and extending this approach to other food systems can support the development of sustainable, cost-efficient, and nutritionally optimized products.

Conflicts of interest / Competing interests: No conflict of interest.

Ethics approval: No ethic situation.

Availability of data and material: The data have been reviewed depending on the literature.

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