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Linear programming for instant complimentary food formulations among Tanzanian children aged 6 to 23 months

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Abstract: It is challenging to follow all nutritional requirements simultaneously. A good mathematical tool for converting nutrient-based suggestions into realistically nutritionally ideal food combinations integrating locally accessible foods is the diet optimization model. The objective of this study is to design a linear programming model that figures out how many grams of each food type need to be mixed to produce an instant meal complement for children between the ages of 6 and 23 months. The mathematical model developed computes the grams of each food type – Quelea mixed with either Green Banana or White Rice or Irish Potato and Onions, Tomatoes, Carrots and Green bell Pepper. When those foods were combined, an instant food complement will be created and entirely satisfy the preset needs of malnourished children. Thus, Tanzanian public health technologists and nutritionists may apply the linear programming approach explored in this study to create new ready-to-use food formulations.

Keywords: Malnutrition; Linear programming; Instant compliment food; Food type; Quelea.
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1 Introduction

In the underdeveloped world, especially Africa, acute malnutrition continues to be a serious public health issue since it directly endangers the lives of young children. Global Acute Malnutrition (GAM) was reported to affect 3.5% of Tanzanian children aged 0-59 months, and Severe Acute Malnutrition (SAM) affected 0.4% down from 3.8% and 0.9% respectively in 2014 [14]. In 2018 there were 90,000 children with severe acute malnutrition and 440,000 children with moderate acute malnutrition [15].

Furthermore, chronic undernutrition affects more than one-third of Tanzanian children below the age of 2 years [23]. The frequency of iron, anemia and vitamin A insufficiency among children aged 6-23 months is 42%, 73% and 33%, respectively. Micronutrient deficits in children are prevalent [27]. One of the key reasons why childhood malnutrition is so common in the nation is because of poor infant and young child feeding (IYCF) practices. The Tanzania Demographic Health Survey (TDHS) data analysis revealed that sugary foods (13%) are

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consumed more frequently than micronutrient-rich foods including fortified infant cereals (4%), eggs (8%) and fruits (0%), which are high in vitamin A [9].

Ready-to-use foods (RUF), which are high fat, energy-dense paste-like formulas frequently made from a combination of peanuts, milk powder and/or soy, sugar, oil, and micronutrients, are typically required for the treatment of acute malnutrition. RUF come in a variety of serving sizes and compositions to treat various forms of malnutrition [13] [7]. SAM is treated with ready-to-use therapeutic food (RUTF), whereas moderate acute malnutrition (MAM) is treated with ready-to-use supplementary food (RUSF) [5].

Linear programming has been used extensively as a tool for nutritional recommendations. It has been also used to formulate balanced diets at minimum cost and complying with a set of nutritional restrictions Optimal Diet Decision Using Linear Programming [16]. Additionally, it has been used to develop therapeutic and complementary meals that are fortified [3], to evaluate the financial worth of supplemental foods [4], and to determine the affordability of diets that adhere to dietary advice on nutrient intake [2].

In order to identify the ideal daily meal combination for a given population under a range of limitations, linear programming methods are used [11]. For instance, the Thrifty Food Plan (TFP), a form of an LP model developed by the US Department of Agriculture, aims to find the cheapest nutritionally appropriate diet while taking into account one's current eating patterns [20][24]. Nutritionally ideal diets can also be created for populations, population subgroups, or even individual responders when sufficient dietary data are available [8]. The optimized diets typically need to satisfy nutritional and energy needs at a reasonable cost while limiting departure from standard diets [6].

The study by [17] applied the LP approach to develop complimentary feeding recommendations (CFR) for 9- to 11 months Indonesian infants to identify the nutrients that will remain low in their diets. A four-phase process based on linear and goal programming methods was used to build the CFR. Results demonstrated that the method may be applied to create population-specific CFR and pinpoint the main issue nutrients to improve the planning and implementation of nutrition programs.

The study by [16] showed how linear integer programming may be used to solve a human diet decision problem faced by dieticians working in the medical field. It specifically looked in details the issue of choosing a diet for the people of ages between 40 and 45 while keeping a budget in mind. To choose the patient's diet with the least amount of expense, it applies operation research tool integer programming, identifies the objective, structures the mathematical model, and describes the constraint of the problem.

[26] presented the use of linear programming tool to design Ready to Use Food (RUF) based on local ingredients for the treatment of moderate acute malnutrition in Côte d'Ivoire. The results showed that local formulas optimized from linear programming were cheaper than the reference feed with respective costs. The use of linear programming has made it possible to provide local formulas of RUF that are cheaper and in line with international specifications. Therefore, the production of these food formulas could allow the treatment of a large number of children malnourished in Côte d'Ivoire.

[12] created a linear programming model that selects an individual weekly diet that matches current nutrient recommendations and approximates a person's food intake pattern. According to the findings, a large percentage of adults would need to broaden their weekly food repertoire in order to meet nutrient standards.
In 2017, [10] used linear goal programming to create the best formulas for Tanzanian children between the ages of 6 to 23 months that included regional and culturally appropriate foods. They effectively produced dietary recommended intakes (DRI) for the group's 20 nutrients, and they did so while taking into account the cost of

the observed food's purchase. Their recipes included a variety of locally available fruits and vegetables as well as wholegrain cereals, Irish potatoes, legumes, nuts fish and poultry meat.

[10] employed linear programming to find the least expensive combination of food ingredients that satisfies a set of nutritional needs at Kilimanjaro region in Tanzania. A 5-point Likert scale was used to assess the sensory quality of seven recipes (banana puree with either minced beef, fish, pumpkin, or milk as well as maize and composite flour porridges). They came to the conclusion that employing inexpensive, readily available and culturally acceptable ingredients, LP was proven to be an effective way to increase the nutritious content of complementary foods.

Unfortunately, there are few studies on the application of linear programming techniques to optimize food formulations based on local available crops to treat different types of malnutrition in Tanzania. The goal of this research is to develop a linear programming model that calculates the amount of each type of food that must be combined to create an instant food complement for children aged 6 - 23 months. It specifically attempts to increase protein, fat, vitamins A, zinc, iron, magnesium, and calcium while minimizing energy values such as carbohydrates. The instant complementary food that is enhanced with nutrients from quelea birds mixed with irish potato, white rice, and green bananas combined with onions, tomatoes, carrots, and green bell pepper will be formulated.

2 Materials and Methods

The energy values and nutrient intake data of children aged 6 to 23 months for each food type (Quelea, Green Banana, and Irish Potato) were collected. The linear programming models were formulated to minimize the energy value of the food type while maximizing the micro nutrients (protein, fat, vitamins A, zinc, iron, magnesium, and calcium). Furthermore, the constructed model will also make sure that the recommended daily allowances for the set of 13 nutrients for that group are satisfied.

The minimum or maximum of the healthiest diet were determined using linear programming. With respect to a specific assumption of proportionality, nonnegativity, and additivity, the theory of linear programming is concerned with scientific procedures for arriving at the best design given the technology, the necessary specifications, and the stated objective. It also uses this theory to describe the relationships between the components of a system [18].

In practice, linear programming minimizes or maximizes a linear function (objective function) under a set of restrictions (constraints). For the purposes of the diet problem, the objective function is the food expenditure subject to the restrictions, which are the required daily allowance of nutrients [1].

2.1 Mathematical Model Formulation

Considering nutrients requirements of this group of children, we will implement the dietary issue of these group as a linear programming problem to minimize energy needed. The group’s nutritional requirements, including minerals, vitamins and other macronutrients should be addressed.

The required daily allowable (RDA) for this group were the constraints for the formulated model. The lower limit and upper limit of all the nutrients were set based on RDA. These constraints, together with the energy of each food type and nutrient composition were fed into the formulated optimization model. Once the model ran, the selected amount of food type with its energy were considered as a sample model. The selected amount of food type when mixed up will produce the instant complementary food for children aged 6 – 23 months with the RDA of the group.

2.2 Decision Variables

The decision variables in the model are the amount in grams of food type i. In this mathematical formulation, the decision variables are X_i where $i = 1, 2, 3, \ldots, I$.

2.3 Parameters

The parameters are the predefined values or information that the model needs in order to calculate the decision variables. These parameters are:

E_i: Approximate amount of energy in 100 grams of food type i

A_{ij}: Approximate amount of nutrient j in 100 grams of food type i

L_j: Minimum allowable intake of nutrients j from food type i

U_j: Maximum allowable intake of nutrients j from food type i

I: Total number of foods used

J: Total number of nutrients used

2.4 Objective Function

The goal of this study is to reduce the calorie values of the anticipated food formulation while enhancing the macronutrients and micronutrients in order to meet the needs of this group of children. Consequently, the following is the linear optimization model for this study:

$$\text{Minimize Z} = \sum_{i=0}^{I} E_i X_i \tag{1}$$

Subject to;

$$\sum_{i=0}^{I} A_{ij} X_i \geq L_j, \qquad j = 1, 2, 3, \ldots, J \tag{2}$$

$$\sum_{i=0}^{I} A_{ij} X_i \leq U_j, \qquad j = 1, 2, 3, \ldots, J. \tag{3}$$

$$X_i \geq 0, \qquad i = 1, 2, 3, \ldots, I \tag{4}$$

Where Z is the total energy to be minimized. The sum of equation (1) is the total energy of the food type to be minimized. Equation (2) is the constraint which ensure that the sum of nutrients in food type should exceed or equal to the lower bound of the RDA. Equation (3) is an upper bound constraint, which ensures that the sum of nutrients in food type does not exceed the upper limits of RDA while equation (4) is a non-negativity constraint, which ensures that the values of the decision variable are either zero or positive.

The types of foods, nutrients from those foods and the minimum/ maximum required daily allowable (RDA) are given in Table 1 and Table 2 respectively.

Table 1: The total amount of micro and macronutrients for each food ingredient

Food type	Macronutrients (100 mg)					Micronutrients (100g)				
	Protein (g)	Fat (g)	Fibre (g)	CHO (g)	Energy (kcal)	Vit A (μg)	Fe (mg)	Zn (mg)	Ca (mg)	Mg (mg)
White Rice	1.42	0.15	0.2	14.8	68	-	0.63	1.09	28	25
Green banana	1. 09	0.33	2.6	22.8	89	-	0.26	0.15	-	0.27
Raw medium Irish potatoes	2.10	0.15	2.1	21.08	94	2	3	14	5	12
Purple onions	1.4	0.1	1.8	5.1	31	-	-	-	-	-
Tomatoes	0.88	0.2	1.2	3.9	18	42	0.27	-	10	-
Green bell pepper	0.9	0.2	1.7	4.6	20	-	0.01	-	-	0.02
Carrots	0.6	0.2	2.8	6.8	37	872	-	-	-	-
Quelea quelea	26.9	3. 0	0.3	6.0	158.6	-	34.0	7.4	154.1	4.0

Source: [21]

Table 2: The upper and lower limits of RDA based on nutrient content for children aged 6 to 23 month

Nutrient	**Recommended daily allowances**			
	Upper limit	**Lower limit**	**Upper limit**	**Lower limit**
Total complementary food amount dry weight (g)	= 60	= 60	= 100	= 100
Energy (kcal)	= 264	= 264	= 440	= 440
Energy from protein (protein–energy ratio) (%)	≤ 10	≥ 6	≤ 16.7	≥ 10
Energy from lipid (%)	≤ 40[a]	≥ 28[a]	≤ 66.7	≥ 46.7
Energy from carbohydrates (%)	≤ 66	≥ 62	≤ 110	≥ 103.3
Protein(g)	≤ 6.5	≥ 4	≤ 10.8	≥ 6.7
Carbohydrate (g)	≤ 43.5	≥ 41	≤ 72.5	≥ 68.3
Fibre (g)	= 19	= 19	= 31.7	= 31.7
Fat (g)	< 11.7[a]	> 8.2[a]	< 19.5	> 13.7
Vitamin A (µg RE)	≤ 300	≥ 180	≤ 500	≥ 300
Iron (mg)	≤ 12.5	≥ 8.5	≤ 20.8	≥ 14.2
Zinc (mg)	≤ 5.6	≥ 3.1	≤ 9.3	≥ 5.2
Calcium (mg)	≤ 200	≥ 100	≤ 333.3	≥ 166.7
Magnesium (mg)	≤ 60	≥ 40	≤ 100	≥ 66.7

RE is Retinol Equivalents, and a is a superscript explain the upper end of the range taken [Source, [22]

3 Analysis, Results and Discussions

GNU Linear Programming Kit (GLPK) was used to solve the developed model. The GLPK is a software application designed to solve issues relating to large-scale linear programming (LP), mixed integer programming (MIP), and other related issues [6]. Additionally, it includes a library of functions that solve linear problems using well-known operations research procedures. The routines carry out a variety of algorithms, including simplex, branch and bound, primal-dual and interior point. The GNU MathProg modeling language, which is used to declare linear problems, is included in the kit [25][19]. The code below demonstrates how to resolve our linear programming model, which is presented in equation (1) - (4).

```
# OPTIMIZATION PROBLEM FOR NUTRITIONAL MODEL FOR CHILDREN AGED 6 – 23 MONTHS#
# This problem finds the amount of foods type i which minimize the energy needed by this group #
/*Sets*/
set I; /* Type of foods */
set J; /* Type of nutrients */
/*Parameters*/
param A{i in I, j in J}; /*Nutrients type i from food type j*/
param E{i in I}; /*Energy from food type i*/
param L{i in I}; /* Minimum allowable intake of nutrients j*/
param U{i in I}; /* Maximum allowable intake of nutrients j*/
/*Decision Variables*/
var X{i in I} >= 0; /*Amount in grams of food type i*/
```

```
/*Objective function*/
Minimize Z: sum{i in I}E[i]*X[i];

/*RDA limitation constraints*/
s.t. RDALower{j in J}: sum{i in I, j in J}A[i,j]*X[i] >= L[j];
s.t. RDAUpper{j in J}: sum{i in I, j in J}A[i,j]*X[i] <= U[j];

/*Data section*/
data;
set I:= Queleaquelea Whiterice Greenbanana Purpleonions tomatoes carrots greenbellpepper Irishpotatoes;
set J:= Protein Carbohydrates Fiber Energy Fat Sugar VitaminA  Zinc(mg) Calcium(mg) Iron(mg) Magnesium;
.
.
.
end;
```

The dotted line before the end of the code means that the set of data given in Table 1 and Table 2 should be placed there.

Then, **glpsol** uses the file of the code written above as an input and ran to generate the results of the minimization process. The amount in grams and proportional of each food type obtained from the model are shown in

Table 3. The findings of the model will be used to formulate three different instant complimentary food products

Formulation	Amount (g) and Proportion (%)							
	Quelea meat	Green Banana	Irish potatoes	White rice	Onions	Tomatoes	Carrots	Green bell pepper
QnB	1.96596 (15.48)	4.395448 (34.61)	0 (0)	0 (0)	0.4435(3.49)	0.43509 (3.43)	5.25782 (41.40)	0.2 (1.57)
QnP	1.94149 (19.51)	0 (0)	4.33609 (43.58)	0 (0)	0.4449(4.47)	1.53843 (15.46)	1.4845 (14.92)	0.2 (2.01)
QnR	1.77245 (12.60)	0 (0)	0 (0)	5.0684 (36.02)	0.4341 (3.09)	1.34199 (9.54)	5.25782 (37.37)	0.2 (1.42)

(quelea mixed irish potato (QnP), quelea mixed with rice (QnR), and quelea mixed with green banana (QnB)), but each of those products will also be mixed with onions, tomatoes, carrots and green bell pepper. The proportional in percentage are shown in bracket.

Formulation	Amount (g) and Proportion (%)							
	Quelea meat	Green Banana	Irish potatoes	White rice	Onions	Tomatoes	Carrots	Green bell pepper

QnB	1.96596	4.395448	0	0	0.4435(3.49)	0.43509	5.25782	0.2
	(15.48)	(34.61)	(0)	(0)		(3.43)	(41.40)	(1.57)
QnP	1.94149	0	4.33609	0	0.4449(4.47)	1.53843	1.4845	0.2
	(19.51)	(0)	(43.58)	(0)		(15.46)	(14.92)	(2.01)
QnR	1.77245	0	0	5.0684	0.4341 (3.09)	1.34199	5.25782	0.2
	(12.60)	(0)	(0)	(36.02)		(9.54)	(37.37)	(1.42)

Table 3: The amount in grams and proportional of each food type obtained from the model

4 Conclusion

The linear programming method was discussed in this work and was widely applicable to the rational design of therapeutic food products. With the help of this method, the user will be able to calculate the amount of each food type (Quelea, Green Banana, and Irish Potato) should be combined to produce an instant food complement that would meet almost all of the predetermined needs for malnourished children between the ages of 6 and 23 months. Therefore, public health nutritionists and technologists in Tanzania may use the linear programming model outlined in this work to develop new RUF formulations. However, the nutritional content of the formulations created by the LP must be confirmed, first, by analyses of their nutritional composition and second, by assessments of their acceptability and clinical efficacy.

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