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Optimization of a local ingredient-based ready to use food using linear programming for the treatment of moderate acute malnutrition in Côte d'Ivoire

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ABSTRACT

Côte d'Ivoire has a higher prevalence of moderate acute malnutrition (MAM) than severe acute malnutrition (SAM). Ready-to-Use Foods (RUFs) play a vital role in the treatment and/or prevention of malnourished children but still expensive. Thus, linear programming tool is used to create alternative formulas that are determined acceptable on multiple levels: low costs, ingredient acceptability, availability, stability and nutrient requirements. The objective of the present study was to use linear programming tool to design Ready to Use Food 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 ($ 0.22) with respective costs of $ 0.11; $ 0.15, $ 0.16 and $ 0.19 for Local Formula 1, 2, 3 and 4 (LF-1, LF-2, LF-3 and LF-4). In addition, following the nutritional needs analysis, LF-3 and LF-4 formulas were chosen because it covers almost all the specific needs predefined for children under five suffering from moderate acute malnutrition. 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.

Introduction

Acute malnutrition (or wasting) is still a major public health problem throughout the developing world, including Africa because it is a form of malnutrition which directly threatens the lives of young children. Acute malnutrition can be classified as moderate or severe depending on anthropometric and clinical status. Moderate acute malnutrition (MAM) is defined as weight-for-height [WHZ] between -2 and -3 standard deviation (SD) and/or a mid- upper arm circumference (MUAC) between 115 and 125 mm. Severe acute malnutrition (SAM) is defined as WHZ <-3 SD and/or an MUAC <115 mm and/or presence of nutritional edema (UNICEF/WHO, 2009). Like some developing countries, Côte d'Ivoire has seen improvements in poverty rates and food security over the recent years (INS, 2015), but many children continue to suffer from acute malnutrition. The latest national survey highlighted the need for urgent action, with 6% of children under 5 years and closed to 10% (9.77%) from children aged 6 to 24 months being acutely malnourished out of which respectively 4.8% and 7,44% are affected by MAM (INS, 2017). Therefore, MAM is more prevalent than SAM. So, in order to limit the progression toward SAM, the management of MAM should be a public health priority.
Treatment of acute malnutrition typically requires the provision of ready-to-use foods (RUF), which are high fat, energy-dense, paste-like formulae often made from a combination of peanuts, milk powder and/or soy, sugar, oil, and micronutrients (Manary, 2006; De Pee & Bloem, 2009) from with varying serving sizes and composition for treatment of different forms of malnutrition. Ready-to-use therapeutic food (RUTF) is used to treat SAM, whereas ready-to-use supplementary food (RUSF) is used for MAM (Brixi, 2018).

In developing countries the demand of RUSF has strongly increased firstly because the prevalence of MAM is much higher than SAM (Pelletier, 1995; Nikièma *et al.,* 2014) and secondly because these supplements are one of the most effective strategies in the treatment of MAM (Lazzerini *et al.,* 2013; Lenters *et al.,* 2013). However, the cost of RUSF remains an important factor in the management of MAM because of the high number of children to be care for and the limited available budget at the global and national levels (De Pee & Bloem, 2009). In addition, availability and price variability of some animal-source foods such as milk and its by-products makes it important to have other versions of RUSF that do not contain these ingredients and that are specifically designed for children with MAM (Golden, 2009; WHO, 2012). Furthermore, research confirms that the efficacy of RUSF in treating MAM is affected by some specific nutritional constraints such as caloric, lipid, protein, carbohydrate, omega 6 and 3 contents (WHO, 2012; WFP, 2016; Brixi, 2018). However, these recommendations do not include several nutrients like choline, caffeine, flavanols, arginine, preformed long-chain polyunsaturated fatty acids as well as protein quality in terms of essential amino acids measured by Protein digestibility corrected amino acid score (PDCAAS) methods which importance greatly contribute to enhance immunity system and cognitive performance (Roberts *et al.,* 2017), linear growth and recovery rates in children suffer from acute malnutrition (Ghosh & Uauy, 2016; Manary *et al.,* 2016; Callaghan *et al.,* 2017; Brixi, 2018; Callaghan-Gillespie & Mui, 2018).

Thus, when formulating an efficient ready to use food (RUF), its cost and nutritional quality that can cover all the nutritional requirements in children suffers from MAM must be considered. Then, to fill these nutritional constraints and minimize the cost of final product, the majority of RUF is optimized using linear programming (Ahmed *et al.,* 2014; Ryan *et al.,* 2014; Brixi, 2018). In mathematical terms, linear programming is "a tool to optimize (minimize or maximize) a linear function of a set of decision variables while respecting multiple linear constraints" (Nestel *et al.,* 2003). This tool is a computer-generated mathematical formulae data program to list all the ingredients, their nutritional composition, price and availability in country in order to create therapeutic and supplementary foods for the treatment of nutritional diseases in developing countries (Ryan *et al.,* 2014; Callaghan-Gillespie & Mui, 2018).

Unfortunately, in Côte d'Ivoire, there is a dearth study on the use of LP tools to optimize food formulas based on local crop to treat various forms of malnutrition. The aim of this study was to develop this optimization tool to create and identify formulas for RUF whose local production may be more accessible and less expensive for people with MAM. This work evaluated and compared the application of LP tools using only local ingredients as well as the combination of available data in the development of new RUF formulas for moderate acute malnourished children in Côte d'Ivoire. It also proposed a new amino acid reference pattern for RUSF in children from 6 to 59 months which taking into account of physiopathology status of children with MAM.

Materials and methods

Materials

In this study, the material used consists of:

- A laptop
- Excel software version 2013
- Documentation: laboratory reports, published scientific article, International Food Composition Database (USDA, 2018) and Food Commodity Assistance Office (OCPV) files

Methods

Example of local RUF formulation optimized by linear programming

The overall formulation of RUF includes the stages of theoretical formulation, production, biochemical and microbiological analyses, stability test as well as preclinical and clinical tests. It consists of five successive phases (Fig. 1), the first two of which allowed achieving optimized formulae by LP.

Phase A

Selection of ingredients

A list of potential, available and commonly consumed ingredients in Côte d'Ivoire has been compiled from data from the Food Commodity Assistance Office. Only ingredients that can be used in the development of RUF has been listed. A final selection was obtained from this list. It is based on the nutritional value of each ingredient, their availability (available quantity, regular supply, seasonality, relative price stability) and their cost. Potential ingredients selected as a result of this final selection are: cocoa, cashew, soybean, rice, chicken egg, palm oil and sugar.

Data on nutritive composition of food ingredients

The source of nutritive composition database for the ingredients (Table 1) was obtained from a combination of data from our laboratory reports, some published scientific articles and International Food Composition Database (USDA, 2018).

Table 1. Source of data used for the formulation of local Ready to Use Foods

Ingredients	Macronutrients*	Total Fatty Acids (TFA)	Total Amino Acids (TAA)
Cocoa		Abouo *et al.,* 2015	Adeyeyé *et al.,* 2014
Cashew nut		Griffin & Dean, 2017	Niyi, 2014
Soybean	Laboratory reports	USDA, 16116, Soy flour, full-fat, roasted	
Rice		USDA, 20061, Rice flour, white, unenriched	
Poultry eggs		Kouakou *et al.,* 2015	USDA, 01133, Egg, whole, dried
Palm oil	USDA, 04055, Oil, palm		
Sugar	USDA, 45360541, White Granulated Sugar, UPC: 041512147609		

* It include the content of dry matters, proteins, lipids, carbohydrates, ashes, fibres and caloric values

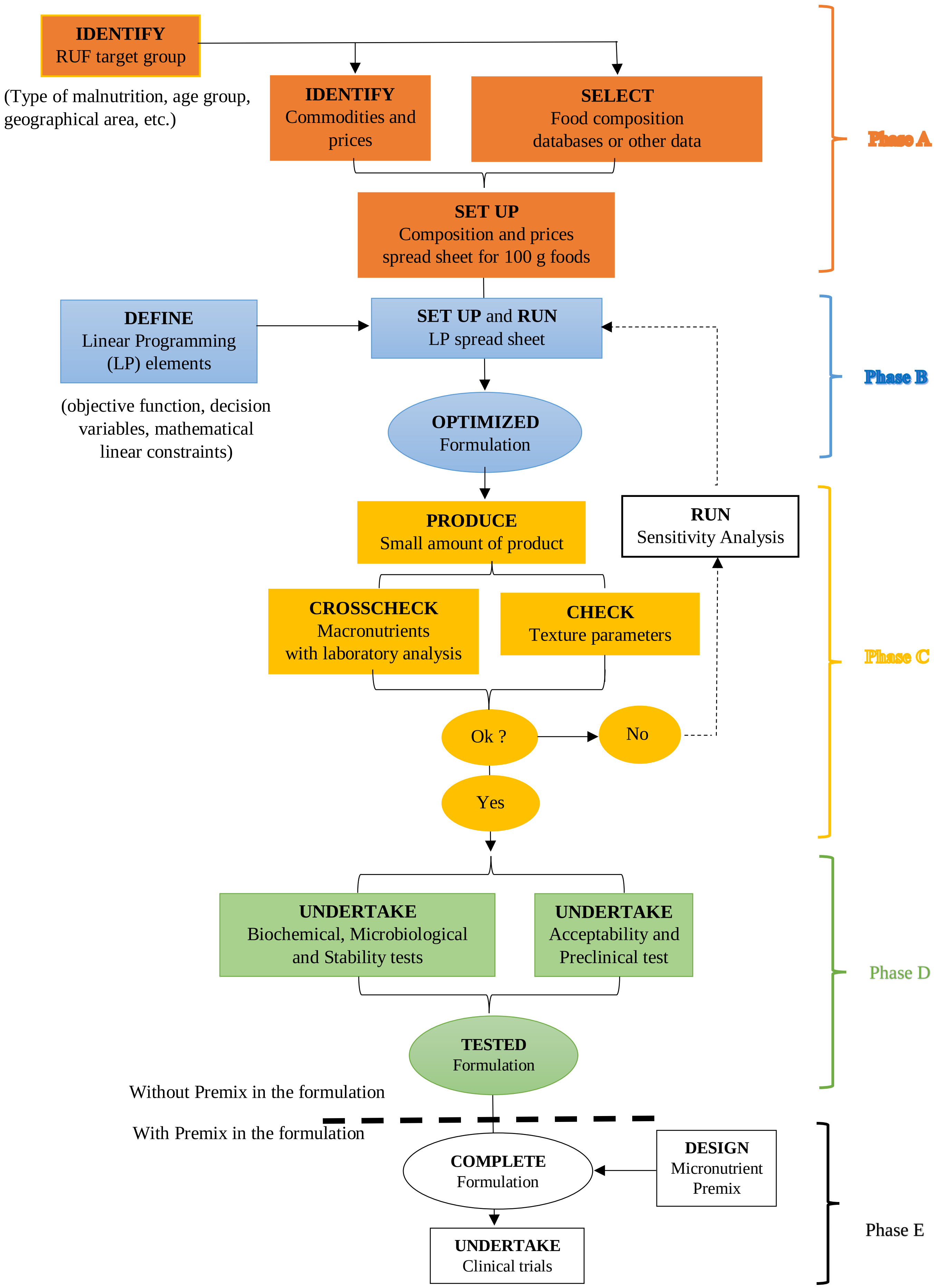

Fig. 1. Proposed model and method for the formulation of novel ready-to-use foods (RUF) (modified and adapted from Dibari *et al.*, 2012)

Data layout

Three tables were created on Excel from the collected nutritive composition database and ingredient price data for 100g of food. The first table (Table data) has listed the nutritive composition of the selected ingredients from the above sources and their price from OCPV. For table 2 (Table of computing), it was created to represent the food basket or quantity of desired food ingredients with their price and their nutrient contents. As for the last table (Table of recommendations), it was allowed to mention the specific minimum, exact and maximum values of each constraint as well as the nutritional recommendations of WFP for RUSF (WFP, 2016).

Phase B

Definition of the elements of linear programming

In this study, the objective function (OF) consisted in identifying the lowest price given by the sum of the cost of each food ingredient (C_1, C_2, … C_n), multiplied by the decision variables (DV) that take into account the quantity of food ingredients (Q_1, Q_2, ... Q_n), while respecting the different groups of predefined constraints:

- Energy value and macronutrient contents
- Total amount of food ingredients
- Palatability
- Texture
- Protein quality expressed by the PDCAAS method
- Reference profile of amino acids.

Constraint related to energy value and macronutrient contents

This constraint has been introduced to ensure that RUF formulations can meet the specification of basic nutrient composition given by WFP for RUSF (WFP, 2016).

Constraint related to the total amount of food ingredients

The reference recipe for RUF contains 4% premix (Weber and Callaghan, 2016).The latter is divided as follows: 2% for the Micronutrient Premix and 2% for the emulsifier. Therefore, a total quantity of 96g was fixed for the food ingredients.

Constraint related to palatability

In this study, two (2) ingredients were optimized for the palatability criterion. These were soybean and sugar. Based on acceptability trials (Irena *et al.,* 2015; Tekele *et al.,* 2015; Bahwere *et al.,* 2016), the amount of soybean was fixed at 27 g/ 100 g of food ingredients. Concerning the amount of sugar added in RUF, the literature indicates variable values of 15 to 28 g/ 100 g of food. However, we chose to fix the amount of sugar in this study between 10 to 20 g.

Constraint related to texture

The texture is a function of the solid particles size and the quantity of lipid. Only the latter can be fixed in the tool. Thus, the lipid content must be varied between 28 and 36% to meet the desired texture in the RUF (Dibari, 2015).

Constraint related to protein quality expressed by the PDCAAS methods

PDCAAS was introduced as a constraint to ensure the quality of protein (FAO, 2013) in the formulas created. It was determined from the following two equations (Brixi, 2018):

$$\mathbf{Q_a = \sum_{i=1}^{n} C_i \times a_i \times d_i} \quad \mathbf{(1)}$$

$$\mathbf{\frac{Q_a}{P} \geq 0,70\ (g_a)} \quad \mathbf{(2)}$$

Avec, $\mathbf{Q_a}$ = Total amount of amino acid a, $\mathbf{C_i}$ = Amount of ingredient i, $\mathbf{a_i}$ = Amount of amino acid a per gram of ingredient i, $\mathbf{d_i}$ = Protein digestibility factor of ingredient i, $\mathbf{P}$ = Total amount of protein in the formula, and $\mathbf{g_a}$ = Target amount of amino acid per gram of the reference protein. This constraint is a non-linear constraint which can be taking into account when selecting the linear motor to identify the optimized LP model.

Constraint related to the reference profile of amino acids

The proposed amino acid reference pattern is calculated from protein and amino acid requirement and based on the age group of 1-2 years for the follow up formula for young children (FUF-YC) and on the preferred weight gain 5g / kg / day for MAM children (WHO, 2012) receiving RUSF in recovery. Thus, this new reference is calculated by considering the following criteria:

- Maintenance requirement that takes into account the need advocated for children of 1-2 years, which is also recommended in adults (0.66 g/ kg/ day) multiplies by a safety level of 1.24 which holds account for intra- and inter-individual variations (WHO/FAO/UNU, 2007),
- Growth requirement that takes into account the body composition of weight gain which is 73:27 (lean body mass/ body fat) equivalent to 14% protein or deposited tissue (adjusted for a 70% efficiency of utilization) and 27% fat (FAO, 2018).

Optimization of the linear programming model

In the process of creating and executing the PL model, the following successive steps have been performed:

- Creation of the data layout on a Microsoft Excel spreadsheet

- Activation of add-in Solver Function, which is supplied with standard installations of Excel
- Assignment of the OF, DV, and constraints described previously
- Activation of the Solver Function in selecting the non-linear GRG motor to identify the optimized LP model
- Activation (if needed) of the Sensitivity Analysis function, which is supplied with the standard installation of the Microsoft Excel Solver add-in

Optimized formula

Four formulas based on the ingredient selected, were optimized and noted local formula 1, 2, 3 and 4 (LF-1, LF-2, LF-3 and LF-4). LF-1 and LF-2 were respectively formulated based on cocoa and cashew nut without including an animal source food while LF-3 and LF-4, were also respectively formulated based on cocoa and cashew nut but with the inclusion of animal source food.

Results and discussion

In this study, the linear programming method has been used successfully to design RUF candidate formulas for the rehabilitation of children under five years suffering from moderate acute malnutrition in Côte d'Ivoire.

Composition and cost of food formulas

The composition of the food formulas and their cost are presented in Table 2. The quantities of ingredients were all different except that of cocoa (15 g), cashew nut (10 g) and enriched egg powder in omega 3 (3 g). The price of food ingredients can vary between 50 to 75% of the price of the final product. According to UNICEF (2009) cited by Dibari, (2015), the price of ingredients represents 68% of the final product of Plumpy'Nut or Plumpy'Sup. Thus, a box (15 Kg) of Plumpy'Sup contains 150 packets for a cost of 50 dollars (Nutriset, 2019) that is $ 0.33/ packet. This suggests that the price indicated for the ingredients was 0.22 $/ sachet at least. Thus, the cost of ingredients were respectively 0.11, 0.15, 0.16 and 0.19 $; which is probably and considerably less expensive even after adding the premix. As a result, the ingredients used thus help to reduce the overall price of our formulas compared to the price of the reference feed by 50, 36, 27 and 18% respectively for FL-1, FL-2, FL-3 and FL-4. The least expensive formula was FL-1. The reduction and stability of formula prices are therefore key goals in the search for alternative formulas (Osendarp *et al.,* 2015).

In addition, reducing the cost of transport and importing Plumpy'Sup through local production could probably and possibly influence the cost of the local RUF bag. This local production actively contributes to the strengthening of local agricultural supply chains and producers. However, more robust methods for the economic evaluation of local formulas are needed to support the decision of the producer. The cost of the product may vary as there may be increase or decrease in the cost of raw materials as per season. To solve this problem in this study, OCPV data for the year 2018 and the first quarter of 2019 were used and an average price was applied to the selected ingredients in order to have a product whose price remains stable. It should be noted that other formulations based on spot availability ingredients (sweet potato and wild-type yams) could be further reduce the final cost of the above formulas. The results of this study show the importance of using LP as a valuable tool to minimize the cost of local RUF formulas.

Constraints of the linear programming model

The predefined constraints were presented in Table 3. Thus, the constraints related to moisture, texture, maximum quantity of ingredient and protein quality represented by the PDCAAS measurement method were respected in all formula. In addition, the palatability constraint, which was also respected in all formula, was introduced to approach in the same direction as other LP studies in human nutrition (Briend *et al.,* 2003; Dibari *et al.,* 2012). However only a study of acceptability can confirm its accuracy in the formulas optimized by the LP. Regarding nutrients not included in current WHO and WFP specifications for RUSF (WHO, 2012; WFP, 2016), we used ingredients like cocoa for their content of caffeine and flavanols, cashew nuts for arginine and omega 3 enriched eggs for their content of preformed long chain polyunsaturated fatty acids content and their equilibrium profile in essential amino acids (EAA).

As for the quality of protein, it is particularly neglected in food aid products (Michaelsen *et al.,* 2009). To compensate this deficit, it has been introduced in this study PDCAAS method and the use of a new proposed amino acid reference pattern for MAM children. The essential amino acid in all formula was lysine. Regarding the essential amino acid profile (EAA) retained as reference for children less than five years (which was for children aged 1 to 3 years), it was respected in all optimized formula. However, for the profile of the EAA proposed in this study, only the quantity of lysine could not be respected. However, LF-3 presented the best profile with 95% coverage of the amount of lysine followed by LF-4 formulas, LF-2 and LF-1. This profile was proposed because the profile chosen for children under five years of age is not adapted to the coverage of the EAA requirements of children with MAM. Therefore, it was important in view of recent studies, as it was the case for severely acute malnourished children (FAO, 2018), to propose a new reference profile of EAA that takes into account their physiological status. Moreover, the addition of animal source food which was powdered chicken egg enriched in omega 3 by the seed of euphorbia, allowed on the one hand to balance the EAA profile of the formulas and on the other hand to increase their quantity and their quality in polyunsaturated fatty acids especially those with preformed long chain (EPA, DHA, ARA and DPA).

Table 2. Ingredients and cost of the 4 optimized formulas and standard reference

Parameters	Ingredients		Formulation					
			LF-1	LF-2	LF-3	LF-4	Plumpy'Sup	RUTF standard[a]
Decision Variables	Rice		15.82	21.13	14.83	20.25		
	Cocoa paste		15		15			
	Cashew paste			10		10		
	Peanut						n.a.	27
	Soybeans		27	25	27	24.86	n.a.	
	Egg enriched in Ω3		00	00	03	03	n.a.	
	Milk						n.a.	25
	Palm oil		19.68	22.12	18.45	20.93	n.a.	15.80
	Soya oil						n.a.	2.90
	Sugar		18.50	17.78	17.72	16.96	n.a.	26
Premix	CMV						n.a.	2
	Emulsifier						n.a.	2
Total	Total quantity		96	96.03	96	96	100	100
Objective function	Ingredient costs	FCFA/ 96 g	64.63	83.08	89.15	107.58	124.3	
		US $/ 96 g[b]	0.11	0.15	0.16	0.19	0.22	

[a] source : Weber et Callaghan, 2016
[b] 1 US $ = 565 FCFA
n.a.: not available
RUTF: Ready to Use Therapeutic Food; Plumpy'Sup: reference food to treat moderately acute malnourished children

Table 3. Constraints of Linear Programming model for the formulation local RUF

Constraints in 100g of formulas	Target requirements		Optimized solution			
			LF-1	LF-2	LF-3	LF-4
Energy and nutrients (WFP, 2016)	*Min*	*Max*				
Energy, kcal/100g	510	560	510	510	510	510
Protein, g/100g	11	16	11,51	11,00	12,89	12.35
Fat, g/100g	26	36	35.54	32,44	35,60	32.50
Ω-6 fatty acids, g/100g	2.6	6.1	5.77	6,1	5,78	6.1
Ω-3 fatty acids, g/100g	0,3	1.8	0.57	0,55	0,69	0.66
Ω-6/Ω-3 ratio	9	4	10.12	11.09	8.38	9.24
Moisture		2.5	2.5	2.49	2.5	2.5
Palatability						
Sugar (sweetness), g/100g	10	20	18,50	16,71	20	15,94
Soyabean (acceptability), g/100g	00	27	27	25	27	25
Texture						
Fat contents, g/100g	28	36	35,54	32,53	34,22	30,68
Maximum food ingredient weight						
Final total weight, g	96	96	96	96,03	96	96
Preformed long chain PUFA						
Total weight, mg			0	0	33,56	33,56
Protein quality						
PDCAAS, %	70	70	79,08	76,98	81,25	80,14
Limiting amino-acid			Lysine	Lysine	Lysine	Lysine
Essential Amino-Acids (EAA) profil	Children 1 to 3 years	Proposed MAM <5 y				
Trp, mg	07	09	13,30	11,90	13,68	12,41
Thr, mg	27	34	38,51	36,70	39,23	37,63
Ile, mg	31	33	42,12	41,44	43,15	42,57
Leu, mg	63	68	77,28	70,81	78,64	72,66
Lys, mg	52	61	56,50	52,44	58,05	54,59
Met, mg						
Cys, mg						
AAS, mg	25	29	27,15	32,45	30,64	34,96
Phe, mg						
Tyr, mg						
AAA, mg	46	57	83,81	81,15	85,19	82,60
Val, mg	41	45	45,70	45,97	47,89	47,90
His, mg	18	21	24,84	23,30	24,87	23,50

Thus, the formula for LF-3 was the formula that generally met all the constraints predefined. In sum, the constraints made it possible to identify the LF-3 and LF-4 formulas as adequate to cover almost all the specific nutritional needs of the target group.

Conclusion

This study has described a linear programming method which is widely applicable for the rational design of therapeutic food products at lower cost. This method allowed identifying and validating the production of two local formulas LF-3 and LF-4 respectively based on cocoa and cashew nut to cover almost all of the specific needs predefined for children under five year suffering from moderate acute malnutrition. The cost of local RUF (based only on food ingredients) was cheaper than the reference product. Therefore, the production of these food formulas could allow the treatment of a large number of children malnourished in Côte d'Ivoire. Thus using the methods described here, public health nutritionists and technologists in Cote d'Ivoire should apply these steps to conceive of other RUF formulations. However, the nutrient contents of the formulas developed by the LP necessarily need to be confirmed on the one hand by their nutritional composition analyzes and on the other hand by their acceptability test and clinical effectiveness.

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