Innovative Optimization of Ready to Use Therapeutic Food for Malnutrition Treatment

Garyk Brixi

August 20, 2017

ABSTRACT

Treatment of acute malnutrition typically requires the provision of ready-to-use food (RUF). RUF is effective but expensive, being manufactured from costly ingredients and shipped worldwide from few global suppliers. I developed a linear programming tool to create RUF optimized for low cost using locally grown crops while maintaining necessary nutritional goals and other constraints. My tool utilizes a database of the nutritional value, price, and water efficiency of suitable ingredients and allows to adjust constraints, including nutrients, flavor, and crop water efficiency. It is designed to: a) address nutrient requirements conforming to current standards and practice; b) optimize RUF formulae for low cost using a wide range of ingredients for nutritional value and acceptability improvement; c) ensure protein quality through protein digestibility corrected amino acid score (PDCAAS); and d) adjust RUF formulae according to locally grown crop selection, local prices and crop water footprint. The tool creates formulae free of expensive dairy ingredients, ensuring desired PDCAAS by automatically balancing proteins with complementary quantities of essential amino acids. Using publicly available data with an application to Nigeria, my tool created RUF formulae suitable for local production using local crops that meet all nutrient requirements at a fraction of the ingredient cost and water footprint of current formulae, demonstrating the tool's effectiveness. Optimization of RUF for low cost using locally grown crops will facilitate local production and reduce ingredient and transport costs so as to reach more patients. Further testing will confirm acceptability and effectiveness of optimized RUF formulae in local contexts.

ACKNOWLEDGEMENTS

I would like to thank Dr. Steve Collins and Mr. Peter Akomo, VALID Nutrition, Dr. Filippo Dibari, World Food Programme, and Dr. Yin-Yin Nwe, UNICEF, for comments and helpful feedback on current practice and research in malnutrition relief food.

Key Words Ready to use food, linear programming, optimization, malnutrition

INTRODUCTION

Problem: According to UNICEF, 16 million children around the world are affected by severe acute malnutrition (SAM), and nearly half of all child deaths are due to malnutrition. Treatment of acute malnutrition typically requires the provision of ready-to-use food (RUF), a paste like formula with varying serving sizes and composition for different treatments. Ready to Use Therapeutic Food (RUTF) is used for treatment of severe acute malnutrition while Ready to Use Supplementary Food (RUSF) is used for moderate acute malnutrition treatment.

RUF is expensive. The high cost of RUF has been found as the primary reason for donors' inability to meet the basic nutrition needs in developing countries (UNICEF, 2009). Firstly, the cost of RUF ingredients is high. Commonly used RUF, such as Plumpy'Nut® or Plumpy'Doz®, is manufactured from vegetable oil, peanuts, milk powder, sugar, and micronutrient supplements (Wagh et al, 2015). Peanuts and milk powder account for over 50% of RUF mass and for most of the total RUF ingredient cost (UNICEF, 2016). Second, the global supply chain, transport and logistics for RUF are costly. RUF ingredients are typically shipped to the global manufacturing sites, mainly in France and the United States, and then transported to communities in need (Ahmed, et al 2014). UNICEF analysis of the supply chain of Plumpy'Nut® to Africa shows that air transportation is often required, bringing transportation cost to 39% of RUF landed cost (UNICEF, 2009) and contributing to carbon emissions. Third, intellectual property protection and licensing raise cost. Plumpy'Nut® patent protection has both constrained global RUF supply and added to RUF price (Rao, 2010; Bakhsh, 2012).

Current Research: Research confirms RUF effectiveness in treating malnutrition subject to specific nutritional constraints (WFP et, al 2016; Oakley et al, 2010; Bahwere et al, 2014; Bahwere et al, 2016). Suitable caloric, oil, protein, carbohydrate, fiber, and omega-3/6 contents for recovery from severe acute

malnutrition and moderate acute malnutrition have been established (World Health Organization, 2016; Nutriset 2014).

With respect to severe acute malnutrition (SAM), some studies have shown that RUTF is more effective if it contains 25% milk powder (Oakley et al, 2010) or whey powder (Bahwere et al, 2014). More recently, alternative dairy-free RUF have been found suitable for SAM patients above 2 years of age (Irena et al, 2015; Bahwere et al, 2016), and a new dairy-free soy-maize-sorghum formula has been successfully tested for acceptability and effectiveness in malnourished patients (Owino et al, 2014; Bahwere et al, 2017). PDCAAS ≥95, which is recommended for RUTF (Nutriset, 2014), can be achieved without any dairy content (FAO, 2011).

For moderate acute malnutrition (MAM) recovery, RUSF dairy content is not a mandatory requirement in the updated codex for relief food, which instead requires a PDCAAS above 70% (WFP et al, 2016). New cereal blends, containing only 8% milk powder, and milk-free RUF are effective for MAM recovery (LaGrone et al, 2012).

The widespread use of peanuts in current RUF has been challenged by research indicating that peanuts (groundnuts) make RUF prone to aflatoxin contamination (Duclercq, 2014).

Furthermore, research suggests that sorghum, cocoa powder, almond, and yam raise acceptability when added to certain RUF (Dibari, 2012; Weber, 2016; Hathorn, 2013). Sorghum has been successfully used to create milk free legume based RUTF of suitable acceptability (Owino et al, 2014).

Finally, the World Food Programme (WFP), UNICEF, and USAID have recommended essential micronutrient supplements to be added for efficient absorption in malnourished patients for most nutrients (WFP et al, 2016). These are typically added as a standard micronutrient premix.

Research Gaps: Current RUF has not been optimized for cost, nutrients, and local contexts. Research is

limited on options to: a) select less-costly RUF ingredients and production options (Briend et al, 2015); b) enhance RUF nutrient content especially with respect to PDCAAS, omega-3, manganese, and choline (FAO, 2011; Caron, 2013); and c) determine how alternative ingredients may affect RUF acceptability. Furthermore, although there has been a discussion about the benefits of localizing RUF production close to malnourished patients (Clark and Hobbs, 2015; UNICEF, 2014; Komrska, 2012), there is limited research on adjusting RUF ingredients to the local crop selection and environmental constraints. Research on cost-effective RUF formulae alternatives and on adjusting RUF formulae to local conditions using linear programming (LP) to optimize RUF formulae is promising (Weber et al, 2016; Segre et al, 2016; Briend et al, 2015; Levesque et al, 2015; Ryan et al, 2014; Skau et al, 2014; Amegovu et al, 2013; Dibari et al, 2012), but existing tools are not equipped to ensure protein quality directly, which limits their ability to create alternative dairy-free formulae.

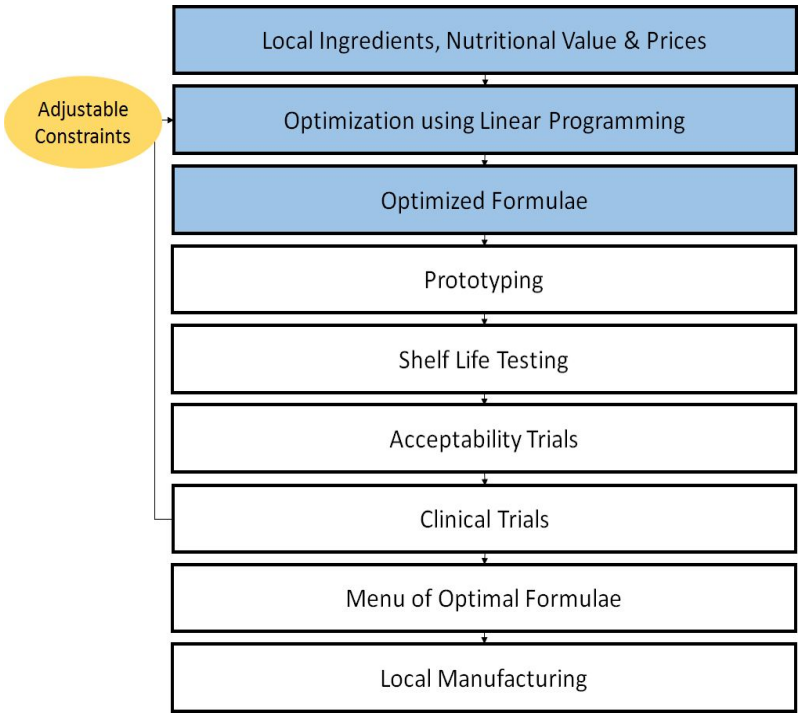
Solution: I developed LP tool to create cost-effective locally produced RUF formulae in order to make RUF more accessible and affordable for malnourished populations.

My proposed LPT seeks to: a) address necessary nutrient requirements conforming to current standards and practice; b) optimize RUF formulae for low cost using a wide range of ingredients for nutritional value and acceptability improvement; c) ensure protein quality through protein digestibility corrected amino acid score (PDCAAS) while creating dairy-free formulae; and d) adjust RUF formulae according to locally grown crop selection, local prices and crop water footprint so as to facilitate local production in proximity to malnourished populations.

Testing of the resulting optimized formulae would create a menu from which local practitioners could select RUF that best suits the needs of their communities. Based on current practice, the production of preventive formulae does not require clinical trials.

Figure 1 shows my proposed RUF development process. My research focuses on the first three steps (shaded in blue color) in the RUF development process.

Figure 1: Proposed RUF Development Process



METHODOLOGY

First, I surveyed international *crop databases* and built a database of ingredients suitable for RUF. The ingredient database utilizes publicly available nutrient data from the U.S. Department of Agriculture (USDA), Global Economic Monitor (GEM), United Nations Conference on Trade and Development (UNCTAD) and Food and Agriculture Organization of the United Nations (FAOSTAT). For all ingredients, the database includes information about crop nutrient composition, local availability, price, and crop water footprint. All ingredients are used in a form with low water content/activity (dry roast

soybeans and peanuts; and flours from cassava, yam, soy, corn, and wheat) to meet moisture constraints and ensure 2-year shelf life as required (WHO, 2016).

Second, I created *LP tool to optimize RUF* for low cost and local contexts in compliance with applicable nutrient and formulae composition standards. The solver plugin for Excel was used, as it is easily accessible to new users and has been used to create food products acceptable to patients (Dibari et al, 2012).

The tool is set to consider minimization of cost as the objective. Linear objective function is:

$$\mathrm{Y} = \sum_{i=1}^{n} b_i B_i$$

where Y is the total cost of ingredients, b_i is the cost per 1g of ingredients *i,* B_i is the amount of ingredient *i.*

The tool thus generates the ideal quantity of each ingredient available in the database to minimize the overall cost while meeting established nutritional goals and other constraints. Users are able to select local ingredients as the input for the tool. The cost per gram of each ingredient and supplement is converted from the price databases. The total nutritional value is automatically calculated by adding together the per gram nutrition of each ingredient multiplied by the quantity of each ingredient used.

Compared to previous RUF optimization efforts (Weber et al, 2016; Segre et al, 2016; Briend et al, 2015; Levesque et al, 2015; Ryan et al, 2014; Skau et al, 2014; Amegovu et al, 2013; Dibari et al, 2012), the tool includes an expanded range of ingredients for RUF nutrient composition and acceptability improvement.

With respect to acceptability in patients, the tool can be configured to automatically select and include a serving of the lowest-cost acceptability improving ingredient--or a combination of acceptability improving ingredients--such as sorghum, cocoa powder, almond, and yam (Dibari, 2012; Weber, 2016; Hathorn, 2013). This function reflects the available albeit limited data on acceptability of alternative

ingredient combinations in RUF and on the influence of specific ingredients on RUF acceptability, especially pertaining to local tastes and preferences.

The LP tool includes *novel adjustable constraints* of PDCAAS, micronutrient supplements, and water efficiency.

PDCAAS is automatically calculated and constrained in order to ensure protein quality (FAO, 2011). PDCAAS is maintained automatically by multiplying the true protein digestibility factor of each ingredient by the quantity of each ingredient and the quantities for essential amino acids within the ingredient according to the USDA nutrition database, adding the protein digestibility-adjusted totals of each amino acid in the formula, and dividing it by the total protein quantity. The resulting values are divided by the respective amino acid quantity per gram of reference protein for children, as determined by the FAO, and constrained to be not less than the desired PDCAAS score. This is expressed by the following two equations:

$$Q_a = \sum_{i=1}^{n} C_i \, a_i d_i \qquad \frac{Q_a}{P} \geq 0.95 \, (g_a)$$

where Qa is total quantity of essential amino acid a, Ci is quantity of ingredient i, ai is quantity of amino acid a per 1g protein in ingredient i, di is protein digestibility factor of ingredient i, P is total quantity of protein in the formula, ga is goal quantity of amino acid a per 1g reference protein.

The tool has two options of constraining for *micronutrient goals*; automatically calculating the best composition of a micronutrient supplement premix and minimizing cost of supplements alongside the cost of base ingredients, or requiring a certain micronutrient value without supplementation. Amino acid supplements can be enabled, and the tool will automatically include these in formulae to meet the goal

PDCAAS given.

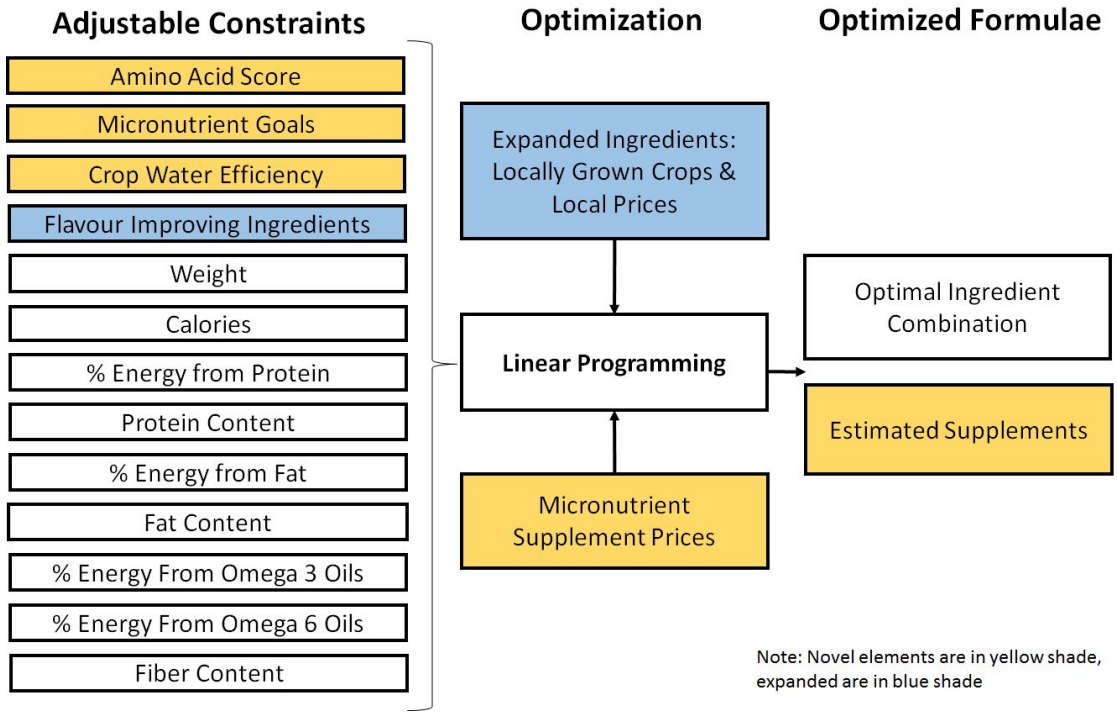
Furthermore, the tool is able to limit the *water footprint* of ingredients using UNESCO IHE water productivity data for local production in water scarce regions.

The LP tool allows users to set the macro- and micronutrient constraints according to patient condition, creating: a) RUTF formulae suitable for recovery from SAM, SAM with edema and/or cirrhosis; b) RUSF formulae for recovery from MAM; and c) specialized malnutrition prevention formulae, or any kind of food product.

Moreover, the LP tool is able to modify RUF formulae in response to exogenous changes, such as commodity price shifts and local crop availability.

Figure 2 illustrates the tool's adjustable constraints and optimization process for RUF formulae.

Figure 2: Proposed RUF Formulae Optimization Process



Source: Author

Third, I set *constraints* according to RUTF standards, effective for recovery from SAM, as shown in Table 1 below. These constraints reflect the current WFP, UNICEF, and Nutriset standards, as well as clinical trials of recovery from severe acute malnutrition: Nutriset, 2014, UNICEF 2009, World Food Programme, 2016.

Table 1: Nutritional Constraints Used to Generate Formulae

Nutrients	**Min**	**Max**
Calories	500 kcal	520kcal
Protein	13g	16g
Protein (% energy)	10%	12%
PDCAAS	≥95/100	-
Lipids	26g	36g
Lipids (% energy)	45%	60%
Omega-3 fatty acids (% energy)	0.30%	2.50%
Omega-6 fatty acids (% energy)	3%	10%
Fibre content %	-	<5%
Sugar	15g	18g
Acceptability improving ingredient servings	≥1	-

Note: Values used determined from Nutriset, 2014; UNICEF, 2009; World Food Programme, 2016.

To ensure protein quality the tool was set to maintain PDCAAS of the formulae greater than or equal to 95 (as in current RUTF), or 100; (FAO, 2011).

Fourth, I used the tool to optimize RUTF food formulae for local and international production, taking Nigeria as a case study for local production.

Case Study: I created an application of the LP tool for Nigeria. I obtained local prices of local ingredients from FAOSTAT, the Nigerian National Bureau of Statistics farmgate, and the Central Bank of Nigeria. To optimize the local RUTF formulae for Nigeria, I used the 2007 and 2013 price data (the most complete data available) and compared the optimized formulae for these years.

Finally, I compared my optimized RUTF with currently used RUTF for nutrition, ingredient cost, and water efficiency. I calculated the nutritional, ingredient price, and water efficiency value of current RUTF using the same databases as for my optimized international formulae.

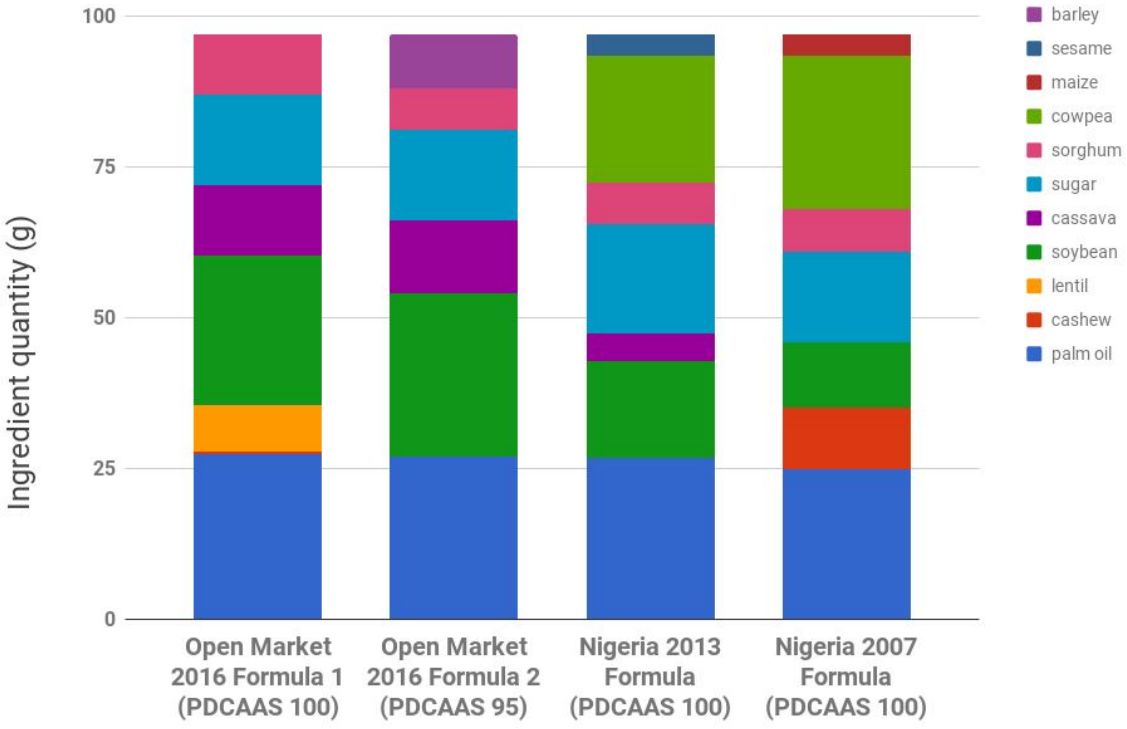
RESULTS

Based on the comprehensive survey of international and Nigerian national crop databases, I selected 26 agricultural ingredients based on their nutrient content, availability, price, and shelf stability, and entered in the ingredient database.

Drawing on the ingredient database and on the constraints set, the LP tool generated cost-effective RUTF formulae for different circumstances in the international markets and in the local markets in Nigeria. Figure 3 shows the proposed optimized RUTF formulae for international markets (using international trade prices) in 2016 and for Nigeria (using local prices in Nigeria) in 2013 and 2007.

Given the significant crop price differences between the international and Nigeria local markets, the proposed optimized RUTF formulae generated by the LP tool differ markedly. Namely, based on international prices in 2016, formula 1 (PDCAAS≥100) includes palm oil, soybean, sugar, cassava, sorghum, lentil and cashew. Formula 2 using Open Market prices for 2016 (PDCAAS≥95) includes barley instead of lentil and cashew. The optimized RUTF formulae for Nigeria 2013 is composed of palm oil, cowpea, sugar, soybean, sorghum, cassava, sesame. The optimized formula for Nigeria 2007 includes maize and cashew, with no cassava. Sorghum was included in all formulae at a serving believed to improve acceptability (Dibari et al, 2012). In addition to being shown to produce RUTF with good acceptability, servings of sorghum were found more cost effective than servings of possible alternatives.

Figure 3: Proposed RUF Formulae Ingredients



Source: Author. LP optimization using USDA and WFDAS nutrient data, and GEM, FAOSTAT, UNCTAD, and Nigeria local price data.

The proposed optimized formulae have nutritional values within RUTF requirements set by the WFP, involve lower ingredient cost and lower water footprint values compared to current practice (Table 2).

Table 2: Proposed RUF Formulae Nutrient Composition, Ingredient Price, and Water Footprint

Formulae	Open Market Formula 1 2016 PDCAAS ≥100	Open Market Formula 2 2016 PDCAAS ≥95	Nigeria 2013 Formula PDCAAS ≥100	Nigeria 2007 Formula PDCAAS ≥100	*Current RUTF (Estimates for Plumpy'Nut)*
Composition (g) *[descriptors below table]	palm oil 27.3, soybean 24.7, sugar 15, cassava 11.8, sorghum 10, lentil 7.77, cashew 0.5	soybean 27.1, palm oil 27, sugar 15, cassava 12, barley 9, sorghum 7	palm oil 26.7, cowpea 21, sugar 18, soybean 16, sorghum 7, cassava 4.6, sesame 3.6	cowpea 24.9, palm oil 24.9, sugar 15,soybean 10.8, cashew 10.3 sorghum 7, maize 3.6	*peanut, sugar, milk powder, palm oil*
Total weight (g) [excluding supplements]	97	97	97	97	*92*
Total calories	520	520	520	520	*520*
Total protein (g)	13	13	13	13	*13.4*
Total fat (g)	33.35	33.1	32.74	32.94	*34.5*
% Fiber Content	3.53	5	5	5	*<5*
% Energy from Omega-3 fatty acids	0.74	0.79	0.53	0.4	*.3 to 2.5*
% Energy from Omega-6 fatty acids	9.10	9.41	8.68	7.59	*3 to 10*
PDCAAS	100	95	1	1	*≥0.95 (Plumpy'Nut®)*
Limiting amino acid	none	lysine	none	none	*lysine*
Estimated total ingredient price (USD/serving)	0.04196	0.03813	0.0535	0.06723	*0.14 (Plumpy'Nut®)*
Water footprint (gallons per mt)	2,885.55	3,174.7	5,138	5,798	*18,159 (Plumpy'Nut®)*

Note: Prices calculated using FAO and World Bank data. Water footprint calculated using UNESCO-IHE report (Mekonnen, 2010). Plumpy'Nut® data based on Nutriset 2014 pdf.

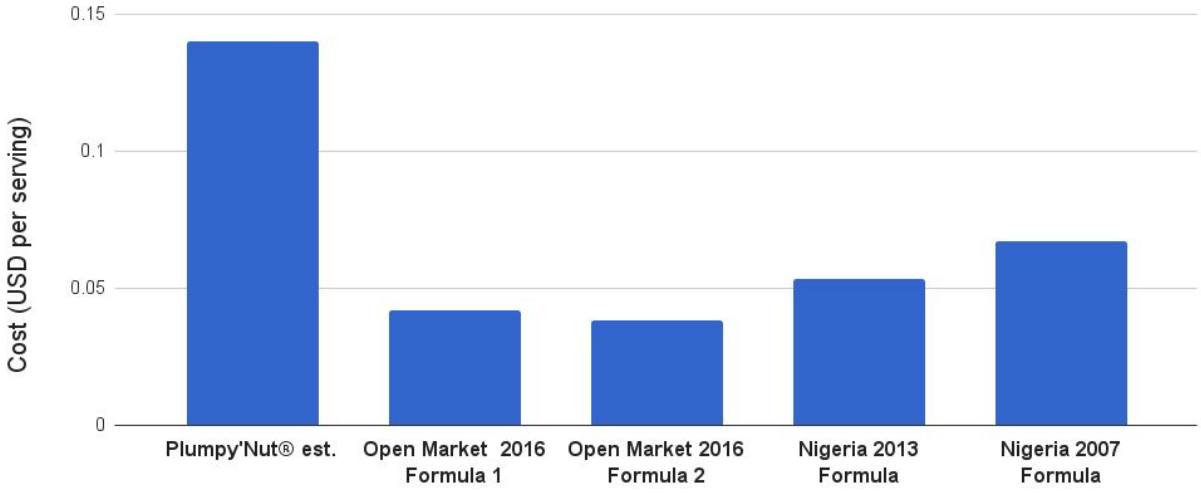
*Descriptors for USDA nutrient database- soybean: 16111, soybeans, mature, dry roasted. palm oil: 04055, oil, palm. sorghum: 20648, sorghum flour, whole-grain. sugar: sesame: 12023, seeds, sesame seeds, whole, dried. maize: 20017, corn flour, enriched, white. barley: 03181, Babyfood, cereal, barley, dry fortified. cashew: 12085, Nuts, cashew nuts, dry roasted, without salt added.

**For cassava, only raw forms were available in the USDA nutrient database, so the 11134, cassava, raw form was converted to a flour by calculation, checked against similar tuber flours, and third party sources.

Considering protein quality, the LP tool successfully created formulae with 100% PDCAAS, possible without individual ingredients with complete proteins by automatically balancing proteins with complementary quantities of the essential amino acids.

The total ingredient cost of the proposed optimized RUTF formulae for international production is about third of the estimated ingredient cost of the currently used Plumpy'Nut® formulae (Figure 4). Ingredient cost reduction in the optimized international formula is largely driven by the replacement of peanuts and milk powder. The main cost savings generated in the local formulae for Nigeria stem from the removal of milk powder and from the low local price of cowpea.

Figure 4: Total Ingredient Cost of Formulae

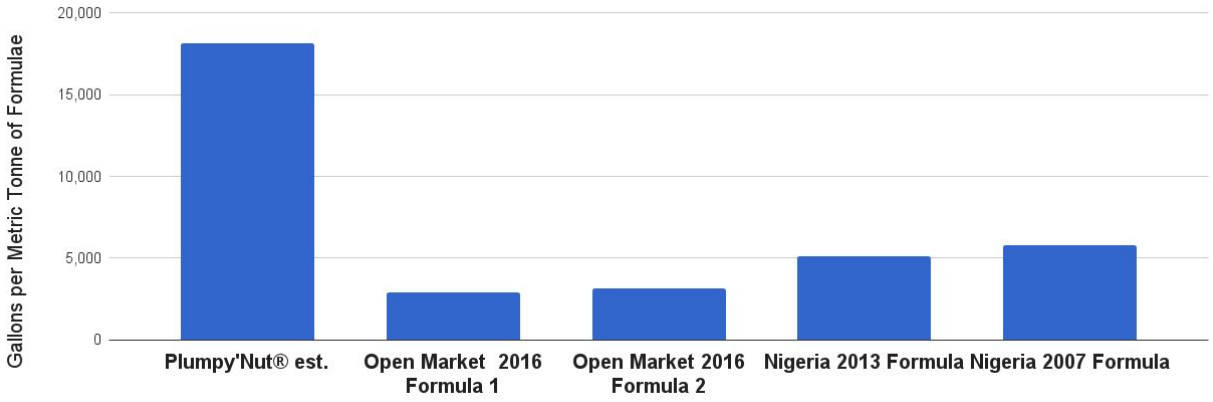


Source: Crop price databases international (FAO, IMF, UNCTAD, and World Bank) and local (Nigeria National Bureau of Statistics, Central Bank of Nigeria)

Water footprint of the proposed optimized formulae is only about one quarter to one third compared to the current formulae (Figure 5). The reduction in water footprint is largely driven by the absence of dairy

products in the optimized formulae.

Figure 5: Water Footprint of Formulae



Source: UNESCO-IHE *The Green, Blue and Grey Water Footprint of Crops*
http://wfn.project-platforms.com/Reports/Report47-WaterFootprintCrops-Vol1.pdf

DISCUSSION AND CONCLUSIONS

My LP tool successfully generated cost-effective RUF formulae applicable for booth international and Nigerian local contexts. The tool appropriately utilized an expanded range of ingredients for RUF nutrient composition and the novel adjustable constraints related to amino acid score, flavour improving ingredients and crop water footprint. The tool automatically balanced proteins with complementary quantities of essential amino acids. Following on recent success with milk-free formulae, the LP tool successfully constrained PDCAAS instead of dairy content within the formulae. The lack of true fecal protein digestibility data may, however, limit the accuracy of PDCAAS calculation when including less common ingredients.

The LP tool can be easily adjusted to require dairy protein content if needed. By requiring goal protein content, the automatic calculation of PDCAAS allows the tool to create formulae with complete amino

acid quantities at lower cost than previously achieved. The proposed tool is easy to use, allowing simple adjustment of ingredient selection and nutrient constraints.

We seek to further increase the functionality of the LP tool by including automatic calculation of the optimal micronutrient premix as part of RUF formulae optimization process. The LP optimization would automatically determine the optimal composition for supplementary micronutrient premix in accordance with UNICEF supplement standards and with further research regarding choline, manganese and omega-3. Moreover, the software supporting the LP tool can be upgraded to allow for automatic updates in international and local crop price so as to better support RUF production decisions. Further testing will help increase the accuracy of the LP tool, for example, testing for true ileal protein digestibility will allow the tool to calculate DIAAS. Similarly, testing of the nutrient values of available ingredients will prevent any mistakes due to discrepancies in ingredient nutritional value compared to current databases. Additionally, it will be important to determine which ingredients or ingredient combinations improve acceptability and palatability of RUF in local contexts. Moreover, production cost needs to be reflected in the choice between RUF formula alternatives that require a different manufacturing process. Development of a micronutrient premix, acceptability testing and--as required for RUTF--subsequent efficacy trials will serve to validate LP results and further modify and improve nutritional constraints. Based on acceptability and efficacy trials, recipes of proven alternative cost-effective RUF formulae can be developed so as to facilitate local choices and production.

The use of my LP tool can support RUF formulae optimization to reduce RUF ingredient cost (including the replacement of costly dairy ingredients), enable local production, reduce contamination risk, and cut environmental footprint (namely crop water footprint and transport carbon footprint), thus allowing improved malnutrition treatment efforts.

REFERENCES

Ahmed, T., Choudhury, N., Hossain, M. I., Tangsuphoom, N., Islam, M. M., de Pee, S., ... & West, K. P. (2014). Development and acceptability testing of ready-to-use supplementary food made from locally available food ingredients in Bangladesh. BMC pediatrics, 14(1), 164.

Amegovu, A. K., Ogwok, P., Ochola, S., Yiga, P., Musalima, J. H., & Mutenyo, E. (2013). Formulation of sorghum-peanut blend using linear programming for treatment of moderate acute malnutrition in Uganda. *Journal of Food Chemistry and Nutrition*, 1(2), 67-77.

Bahwere, P., Akomo, P., Mwale, M., Murakami, H., Banda, C., Kathumba, S., ... & Collins, S. (2017). Soya, maize, and sorghum–based ready-to-use therapeutic food with amino acid is as efficacious as the standard milk and peanut paste–based formulation for the treatment of severe acute malnutrition in children: A noninferiority individually randomized controlled efficacy clinical trial in Malawi. The American Journal of Clinical Nutrition, ajcn156653.

Bahwere, P., Banda, T., Sadler, K., Nyirenda, G., Owino, V., Shaba, B., ... & Collins, S. (2014). Effectiveness of milk whey protein‐based ready‐to‐use therapeutic food in treatment of severe acute malnutrition in Malawian under‐5 children: a randomised, double‐blind, controlled non‐inferiority clinical trial. *Maternal & child nutrition*, *10*(3), 436-451.

Bahwere, P., Balaluka, B., Wells, J. C., Mbiribindi, C. N., Sadler, K., Akomo, P., ... & Collins, S. (2016). Cereals and pulse-based ready-to-use therapeutic food as an alternative to the standard milk-and peanut paste–based formulation for treating severe acute malnutrition: a noninferiority, individually randomized controlled efficacy clinical trial. *The American journal of clinical nutrition*, *103*(4), 1145-1161.

Bakhsh, U. R. (2012). Plumpy'Nut Predicament: Is Compulsory Licensing a Solution? *Chi.-Kent J. Intell. Prop.*, *11*, 238.

Briend, A., Akomo, P., Bahwere, P., De Pee, S., Dibari, F., Golden, M. H., ... & Ryan, K. (2015). Developing food supplements for moderately malnourished children: lessons learned from ready-to-use therapeutic foods. *Food and nutrition bulletin*, *36*(1 suppl1), S53-S58.

Caron, O. (2012). RUTF product specifications. In UNICEF SD, RUTF pre-bid conference, MSF/Unicef, August (Vol. 15).

Central Bank of Nigeria (2007). PRICES OF MAJOR AGRICULTURAL COMMODITIES IN NIGERIA. [PDF]. https://www.cbn.gov.ng/devfin/prices.pdf

Collins, S., Myatt, M., & Golden, B. (1998). Dietary treatment of severe malnutrition in adults. The

American journal of clinical nutrition, 68(1), 193-199.

Clark, L. F., & Hobbs, J. E. (2015). Innovations in International Food Assistance Strategies and Therapeutic Food Supply Chains. In *Food Security in an Uncertain World: An International Perspective* (pp. 111-128). Emerald Group Publishing Limited.

Dibari, F., El Hadji, I. D., Collins, S., & Seal, A. (2012). Low-cost, ready-to-use therapeutic foods can be designed using locally available commodities with the aid of linear programming. *The Journal of nutrition*, 142(5), 955-961.

Dlamini, N. S., and W. K. Solomon. (2016). "Effect of Ingredients Ratio on Physicochemical and Sensory Properties of Sorghum, Maize and Soya Protein Concentrate Blend Extrudates." International Journal of Food Science and Nutrition Engineering 6.5 (2016): 112-120.

Duclercq, Marie-Pierre. (2014).Production of Ready-to-Use Food (RUF): An overview of the steps and challenges involved in the "local" production of RUF. CMAM Forum.

Erhardt, J. (2010, April 2). Nutrition surveys and assessment. Retrieved December 3, 2016, from http://www.nutrisurvey.de/

FAO, Consultation, R. F. E. (2011). Dietary protein quality evaluation in human nutrition. FAO food and nutrition paper, 92.

Global Economic Monitor, The World Bank

Hathorn, C. S. (2013). Development of a Peanut-Sweetpotato Ready to Use Therapeutic Food and Evaluation of Peanut Skins in Peanut Products. North Carolina State University.

Irena, A. H., Bahwere, P., Owino, V. O., Diop, E. I., Bachmann, M. O., Mbwili‐Muleya, C., ... & Collins, S. (2015). Comparison of the effectiveness of a milk‐free soy‐maize‐sorghum‐based ready‐to‐use therapeutic food to standard ready‐to‐use therapeutic food with 25% milk in nutrition management of severely acutely malnourished Zambian children: an equivalence non‐blinded cluster randomised controlled trial. *Maternal & child nutrition*, *11*(S4), 105-119.

Komrska, J. (2012). Increasing access to ready-to-use therapeutic foods (RUTF). *Field Exch*, *42*, 46-47.

LaGrone, L. N., Trehan, I., Meuli, G. J., Wang, R. J., Thakwalakwa, C., Maleta, K., & Manary, M. J. (2012). A novel fortified blended flour, corn-soy blend "plus-plus," is not inferior to lipid-based ready-to-use supplementary foods for the treatment of moderate acute malnutrition in Malawian children. *The American journal of clinical nutrition*, *95*(1), 212-219.

Levesque, S., Delisle, H., & Agueh, V. (2015). Contribution to the development of a food guide in Benin:

linear programming for the optimization of local diets. *Public health nutrition*, 18(04), 622-631.

Mekonnen, M. M., & Hoekstra, A. Y. (2010). The green, blue and grey water footprint of crops and derived crop products.

Nutriset (2014). Plumpy'Nut® [PDF]. http://www.plumpynut.com/file/c67d0472-a29f-48c9-984e-4082b5c725ca/plumpy-nut-booklet.pdf

Oakley, E., Reinking, J., Sandige, H., Trehan, I., Kennedy, G., Maleta, K., & Manary, M. (2010). A ready-to-use therapeutic food containing 10% milk is less effective than one with 25% milk in the treatment of severely malnourished children. *The Journal of nutrition*, *140*(12), 2248-2252.

Owino, V. O., Irena, A. H., Dibari, F., & Collins, S. (2014). Development and acceptability of a novel milk‐free soybean–maize–sorghum ready‐to‐use therapeutic food (SMS‐RUTF) based on industrial extrusion cooking process. *Maternal & child nutrition*, *10*(1), 126-134.

Rao, S. S. (2010). Improving Access to Patented Humanitarian Products via TRIPS: A Study of the Plumpy'nut Problem. *Mich. St. UJ Med. & L.*, *15*, 111.

Ryan, K. N., Adams, K. P., Vosti, S. A., Ordiz, M. I., Cimo, E. D., & Manary, M. J. (2014). A comprehensive linear programming tool to optimize formulations of ready-to-use therapeutic foods: an application to Ethiopia. *The American journal of clinical nutrition*, 100(6), 1551-1558.

Segrè, J., Liu, G., & Komrska, J. (2016). Local versus offshore production of ready‐to‐use therapeutic foods and small quantity lipid‐based nutrient supplements. *Maternal & Child Nutrition*.

Skau, J. K., Bunthang, T., Chamnan, C., Wieringa, F. T., Dijkhuizen, M. A., Roos, N., & Ferguson, E. L. (2014). The use of linear programming to determine whether a formulated complementary food product can ensure adequate nutrients for 6-to 11-month-old Cambodian infants. *The American journal of clinical nutrition*, ajcn-073700.

UNICEF (2009). A supply chain analysis of ready-to-use therapeutic food for the horn of Africa. A study commissioned by the United Nations Children's Fund.

UNICEF (2014) Ready-To-Use Therapeutic Food: Current Outlook. UNICEF Supply Division.

UNICEF (2016) Ready-to-Use Therapeutic Food Price Data.

Wagh, Dijay D., and Bhavesh R. Deore. (2015) Ready to Use Therapeutic Food (RUTF): An Overview. Scientific Online. Advances in Life Sciences and Health.

Weber, J., & Callaghan, M. (2016). Optimizing Ready-to-Use Therapeutic Foods for Protein Quality,

Cost, and Acceptability. Food and nutrition bulletin, 37(1_suppl), S37-S46..

World Health Organization. (2016). Microbial safety of lipid-based ready-to-use foods for management of moderate acute malnutrition and severe acute malnutrition.

World Food Programme. (2016). "Specialized Nutritious Foods." United Nations World Food Programme - Fighting Hunger Worldwide. World Food Programme,. Web. 27 Oct. 2016.

World Food Programme, UNICEF, and USAID (2016). Harmonization of Lipid-based Products. (n.d.): n. pag. Global Nutrition Cluster.