Optimising locally made Ready-to-use Therapeutic Food (RUTF) formulations. MSc Thesis. Nutrition for Global Health, London School of Hygiene and Tropical Medicine

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Optimising locally made Ready-to-use Therapeutic Food (RUTF) formulations for Sierra Leone

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Abstract

Background: Severe acute malnutrition (SAM) is a serious public health problem in Sierra Leone with 9% of the children under five wasted. The government has set a priority to tackle it. Ready-to-use-therapeutic food (RUTF) has been a success over the last twenty years to treat SAM. Developing RUTF from locally produced foods is more sustainable and may be cheaper than importing RUTF. Sierra Leone has a diverse agroecological system potentially enabling the cultivation of various food crops that could be used as ingredients. The objectives are to identify combinations of local ingredients that could meet RUTF requirements based on cost, nutritional content, and aflatoxin level.

Methods: Potential ingredients (n=22) were identified and their cost obtained from literature and in-country partners. Nutritional composition of ingredients was obtained from INFOODS and USDA databases and aflatoxin level from literature. Linear programming (LP) was applied to identify suitable formulations that could meet nutritional and aflatoxin requirements at the minimum cost. Various formulations with animal products or not and with producer and market prices were tested using two methods for calculating omega 3 and 6 fatty acids.

Results: All the possible formulations contained an animal product (fish, eggs or both) and none of the vegan formulations met the requirements. This is because a major limiting factor was the concentration in omega 3 and also omega 6. Previous successful vegan options contained - for example - soybean and groundnuts that are rich in those unsaturated fatty acids. Soybean (oil or flour) was not readily available locally, and groundnut amount was limited by the constraint on aflatoxin in our model.

Conclusions: The options proposed by LP contained dried eggs that are expensive commodities or dried fish that may not be sensorially acceptable. More research is needed to find suitable local ingredients and develop affordable processing technologies.

Acknowledgments

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Project development: I initially identified the area for investigation from a project from my job. I first met my LSHTM supervisor (Dr. Elaine Ferguson) in July to discuss the topic and the scope. I also skyped with my external supervisor (Dr Filippo Dibari). I then developed the topic independently, but with advice from my supervisors. A key input by Filippo was the sharing of the method for linear programming (his PhD and a 4-page manual instruction by Briend).

Contact, input and support: I have had about 3 meetings with each of my supervisors, face to face and via skype with Elaine and via WhatsApp with Filippo. In the first meeting, we discussed the topic, the second meeting, the progress, and the last meeting, the results.

Main research work: Elaine helped me define the scope of work. I discussed with Filippo the outline of the thesis, the constraints to enter in the linear programming model, and the limitations of the tool. Using their advice, I developed the model independently.

Writing-up: I wrote the work alone. I received detailed comments and excellent reviewing from my supervisors who played a significant part in structuring the thesis (Elaine) and strengthen the results and discussion, in particular (Filippo and Elaine).

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Abbreviations and acronyms

RUF	Ready-to-use food
RUTF	Ready-to-use therapeutic food
RUSF	Ready-to-use supplementary food
SAM	Severe Acute Malnutrition
MAM	Moderate Acute Malnutrition
MUAC	Middle- Upper Arm Circumference
LP	Linear Programming
CMAM	Community based Management of Acute Malnutrition
LMICs	Low- and Middle-Income Countries
UNICEF	United Nations Children's Fund
FAO	Food and Agriculture Organization
WHO	World Health Organization
WFP	World Food Program
IRD	Institut de Recherche pour le Développement (Research Institute for Development)
PBP	Peanut Butter Project
PUFA	Polyunsaturated fatty acid
n-3 PUFA	Omega 3 fatty acid
n-6 PUFA	Omega 6 fatty acid
UL	Tolerable upper intake level
TFD	Total Faecal Digestibility

1 Introduction

1.1 Background of the study

Severe acute malnutrition is a current public health issue in Sierra Leone, one of the poorest countries in the world (ranking 184th out of 189th in the human development index). Sierra Leone has high rates of child mortality and undernutrition amongst under-five children (9% wasted; 38% stunted and 16% underweight) [1]. In addition the country is coming out of the Ebola crisis (2014-16) and needs to build back its economy. Addressing undernutrition is a core priority on the country's national agenda[2].

Ready-to-use-therapeutic food (RUTF) has successfully been used for the treatment of severely acutely undernourished children [3,4] . Over the last 20 years, the development of RUTF has revolutionised the treatment of child severe acute malnutrition (SAM). In the past, treatments used dried milk formula such as F75 and F100 that required in-hospital stay because the formula had to be prepared by qualified medical personal due to the risk of using contaminated water and inadequate dosage. RUTF has made the treatment possible and safe at the community level by the distribution of 'ready-to-use' food products that could be consumed without any preparation. The use of RUTF has also dramatically improved the recovery rate of malnourished children. The use of a lipid-based food product makes the density of the product greater than an aqueous-based formula [5], and possibly nutrients such as vitamins (i.e. vitamin A) and minerals (i.e. iron) more absorbable [6]. RUTF can be also used as a supplement at lower doses in moderately acutely malnourished children to prevent them from becoming severely malnourished[7].

Standard RUTF formula is a peanut-based paste ('Nutella'-like appearance) containing vegetable oil, powdered milk, sugar, and a premix of vitamins and minerals, and has a low water activity, and a shelf life up to 2 years [8]. The formulation of RUTF has been based on the same nutritional requirements as F100 [4]. The major RUTF on the market – Plumpy'nut - was invented by a French Paediatric Nutritionist, André Briend from the Institut de Recherche pour le Développement (IRD) in collaboration with a private company, Nutriset. Today the company is still producing about 50% of the RUTF in the world[9].

Over the last ten years there has been a move towards the development of locally produced - that is in-country where it is consumed - RUTF[9] that is more sustainable in the long term and would be cheaper to produce than purchasing imported RUTF.

The use of linear programming – a mathematical method that either minimises or maximises a linear objective function under a set of constraints- has helped advance the development of novel combinations of locally produced foods that also ensure international specifications are met [8,10,11].

Understanding the local context such as agricultural production, crop seasonality, and crop prices (producers, processors, market) is important for the formulation of an affordable, locally-produced RUTF.

1.2 Agricultural resources in Sierra Leone

Sierra Leone is situated on the Western coast of Africa, bordered by Liberia (south) and Guinea (north). The country benefits from a diverse agroecological environment, substantial natural (e.g. precious minerals) and agricultural resources but the experience of the 11 year-civil war (1991-2002) that resulted in the displacement of a third of its population and the Ebola outbreak (2014-16) significantly weakened its economic infrastructure [12]. More than half of the population is living on less than US$1.90 a day [13].

The main agricultural resources are rice (primary staple crop) (with a production of about 1.6 million tonnes per annum) , cassava (second-most consumed staple crop) (4.7 million tonnes), maize, millet, sorghum, sweet potato and groundnuts [12]. Smallholder farmers are responsible for most of the agricultural production. Other crops in Sierra Leone are palm oil, citrus, cocoa, coffee, coconut and sugar cane [12,14] (Appendix 1).

Fish is also an important commodity in Sierra Leone, for food security and business. Wild fish production is about 120,000 tonnes per year and aquaculture that has been developed in the 1970s still has potential for expansion. Fish can be consumed fresh but because of its limited shelf life, it is often dried, salted and dried, or smoked [12].

The egg market is also in expansion: according to newspapers articles from last year, the government of Sierra Leone is investing $60 million dollars in developing the poultry and egg sector [15,16].

The following table shows the seasonality of the same crops and the occurrence of rainy and dry season (Table 1).

Understanding seasonal variations are important for the selection of ingredients.

There are seasonal crop variations causing a hunger period between June and August, which coincides with the planting season for rice [12].

Table 1. Seasonal variations in the food crops of Sierra Leone that can cause a hunger gap

Seasons	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Rainy												
Dry												
Hunger						*	*	*				
Food crop harvest												
Rice												
Cassava												
Sweet potato												
Yam												
Maize												
Sorghum												
Groundnut												
Millet												
Vegetables												
Fishing (coastal)												
Livestock diseases and pests												
Cash crop marketing												

Source: [12]

Grains including rice are scarce between June and August. Harvest times for upland and lowland rice are between August and January. Harvest times for upland and lowland cassava are between October and January and June and July, respectively. The harvest times of other crops (i.e. sweet potato, yam, maize, sorghum, groundnut, millet and vegetables) vary by region. Palm oil is scarce in the autumn towards December and pulses, nuts and seeds are less available late spring (May-June). Banana has limited production in August. Fishing's high season is between September and January and low season between February and April. The low season for fresh fish is in the summer (July-August) because of weather conditions. Hence the availability of dried and smoked fish is low in September[12].

The food-based dietary guidelines for Sierra Leone [17] gives national guidance for healthy eating in Sierra Leone based on the foods most commonly consumed. Rice and fish are at the core of the diet but Sierra Leone also has a variety of pulses, vegetables, fruits, that are available locally. Micronutrient-rich foods i.e. rich in iron and those containing high quality proteins such as animal foods (*i.e.* fish), vitamin A-rich foods (*i.e.* fruits and vegetables), PUFA-rich foods (i.e. oils, nuts and seeds) are recommended for young children (< 2 years) [17].

Understanding the nutritional situation of the country and the groups most at risk is important to tackle malnutrition.

1.3 Nutritional targets and requirements for RUTF

1.3.1 Nutritional situation in Sierra Leone

Almost a quarter of the Sierra Leonean population is undernourished. Hence food security and nutrition are on the top of the country's national agenda [12]. Young children are the most affected because they have high nutrient needs to support rapid growth and development. According to the DHS 2013 Survey [1], on average 38% of children under five year-old are moderately stunted (height for age ≤ 2SD) and 18% are severely stunted (height for age ≤ 3SD).

A critical proportion of children (9%) are wasted (weight-for-height z-score < -2 SD) with 4% among them are severely wasted (weight-for-height Z-score ≤-3 SD). Wasting reaches a peak between the age of 9 and 11 months with 18% of children being wasted[1] and therefore this age period is a critical window of intervention for those children suffering from MAM[18] and SAM[19].

> **Moderate Acute Malnutrition (MAM)** : Low weight-for-height between –3 and –2 Z-scores of the median of the WHO child growth standards / MUAC 115-125 mm in children aged 6–59 months + without oedema (WHO 2012) [18]
>
> **Severe Acute Malnutrition (SAM)** : Low weight for height (≤-3z scores of the median of the WHO growth standards) / MUAC ≤ 115 mm in children aged 6–59 months + or the presence of bilateral pitting edema, or both (WHO 2007) [19]

Anaemia is extremely high with 80% of children 6-59 month-old being anaemic [1]. Malnutrition rates are higher overall in rural regions compared to urban areas. Breastfeeding is common (97% of children) but exclusive breastfeeding is not (only 32% of children under 6 months) and only 7% of children 6-23 months meet the Minimum acceptable diet [1] (Minimum dietary diversity of 4 or more food groups per day plus Minimum meal frequency).

1.3.2 RUTF requirements

The specification for the nutrient content of RUTF, for the treatment of uncomplicated SAM for 6-59 month-children, are from the World Health Organization Statement on Community-based management of SAM [19]. These specifications also include maximum levels for toxins, and thus address both nutritional and food safety aspects of the product (Table 2).

Table 2. Nutritional composition and Maximum toxin levels of RUTF

Nutritional composition	
Moisture content	2.5% maximum
Energy	520–550 Kcal/100 g
Proteins	10%–12% total energy
Lipids	45%–60% total energy
Sodium	290 mg/100 g maximum
Potassium	1,110–1,400 mg/100 g
Calcium	300–600 mg/100 g
Phosphorus (excluding phytate)	300–600 mg/100 g
Magnesium	80–140 mg/100 g
Iron	10–14 mg/100 g
Zinc	11–14 mg/100 g
Copper	1.4–1.8 mg/100 g
Selenium	20–40 µg
Iodine	70–140 µg/100 g
Vitamin A	0.8–1.1 mg/100 g
Vitamin D	15–20 µg/100 g
Vitamin E	20 mg/100 g minimum
Vitamin K	15–30 µg/100 g
Vitamin B1	0.5 mg/100 g minimum
Vitamin B2	1.6 mg/100 g minimum
Vitamin C	50 mg/100 g minimum
Vitamin B6	0.6 mg/100 g minimum
Vitamin B12	1.6 µg/100 g minimum
Folic acid	200 µg/100 g minimum
Niacin	5 mg/100 g minimum
Pantothenic acid	3 mg/100 g minimum
Biotin	60 µg/100 g minimum
n-6 fatty acids	3%–10% of total energy
n-3 fatty acids	0.3%–2.5% of total energy

Maximum toxin levels	
Aflatoxin level	5 ppb maximum
Microorganism content	10,000/g maximum
Coliform test	negative in 1 g
Clostridium perfringens	negative in 1 g
Yeast	maximum 10 in 1 g
Moulds	maximum 50 in 1 g
Pathogenic Staphylococci	negative in 1 g
Salmonella	negative in 125 g
Listeria	negative in 25 g

In addition, there are specifications about the texture of the product: the product must *be "soft or crushable and should be easy for young children to eat without any preparation"* [19]. The mineral and vitamin premix should also be soluble with the product and follow the *"Advisory List of Mineral Salts and Vitamin Compounds for Use in Foods for Infants and Children of the Codex Alimentarius Standard CAC/GL 10-1979".*

The 2007 WHO statement[19] states that at least 50% of the proteins must come from dairy products. However more recently formulations that are exclusively from plant foods have been developed [10,20,21] with the adequate protein quality.

Another important aspect is food safety. Because RUFs are consumed by young children (who may be more vulnerable than adults to toxins) they must comply strict food safety criteria (Recommended International Code of Hygienic Practice for Foods for Infants and Children of the Codex Alimentarius Standard CAC/RCP 21-1979).

There have been debates on whether the aflatoxin limit in RUTFs should be set to 5 or 10 ppb (µg/kg). Various versions of the WHO (2007) statement have either 5 or 10 ppm as a limit. There has not yet been a consensus on the aflatoxin limit in RUTF and there is not yet a clear rationale for the limit or the type of aflatoxin (total or specific types) [22].

1.4 Aflatoxins and food safety

About 25% of the crops worldwide are affected by fungi or molds and a proportion of them produce toxic substances [23]. Mycotoxins are secondary metabolites liberated by fungi, which growth is favoured by hot and humid conditions such as in the tropics. They are several types: aflatoxins, fumonisin, ochratoxins, deoxynivalenol, zearalenone. Mycotoxins can be highly toxic to humans and animals causing symptoms that range from mild symptoms such as nausea, vomiting, diarrhea to more serious damage such as stunting in children, liver and gastrointestinal damage, enzymatic damage, and cancer [24,25]. Mycotoxin contamination can occur at all stages in the food chain, which makes it a serious problem for human health. It can affect many types of primary agricultural commodities such as crops but also secondary food products such eggs, milk, and fish (if farmed). The risk is greater in low-middle income countries where climatic conditions or storage for raw ingredients are often inadequate [26,27]. Some crops (e.g. groundnuts, maize) are more prone to mycotoxins but most foods can be affected, and levels of contamination vary per crop and location [25,28] , making them difficult to quantify.

There are limited solutions because mycotoxins are resistant to processing (aflatoxins decompose at temperatures superior to 200-300°C) although it has been reported that extrusion could significantly reduce aflatoxin levels [24,29].

In Sierra Leone, market samples of roasted nuts (n=100 including 50 cashew nuts and 50 groundnuts) analysed in two locations showed high levels of mycotoxin (i.e. aflatoxins) contamination. The average level of aflatoxin reported was 487.8 ppb (µg/kg) and the maximum was 5,729 µg/kg. A third of the aflatoxin-contaminated groundnut samples had levels of aflatoxins above 4ppb (European regulation) [30].

Although low levels of aflatoxin did not clearly show an association with reduction of linear growth in young children[31], maternal consumption of aflatoxin-contaminated products was associated with small-for gestational age in children[32] that could cause stunting

It is, therefore, critical to manage the risk when using food ingredient such as peanuts that are prone to aflatoxin contamination and carefully monitor the levels in RUTFs [27]. UNICEF and other partners are now investing in the local production of RUTF and aflatoxin has major impact on the selection of locally-sourced ingredients. RUTF private investors in Kenya decided not to use local groundnuts because of the aflatoxin risk but Ghana has invested into the food production of aflatoxin-free groundnuts for RUTFs [33].

1.5 Locally produced therapeutic food in Sierra Leone

In Sierra Leone, a non-profit organisation called the Peanut Butter Project (PBP) has been set-up. It is funded by USAID and also has factories in Malawi and Ghana producing RUTF. The PBP is led by Dr. Manary - a leading scientist in the research against child undernutrition – and has links with Nutriset. The project in Sierra Leone makes standard RUTF that contains powdered milk and peanuts and requires about 100 million tonnes of roasted peanut or peanut butter annually [34]. There have been attempts to use local peanuts but there is a food safety concern about the high levels of aflatoxin that are carcinogenic in the locally available groundnuts [34]. Currently peanuts are imported (Shamit Koroma, A., Pers. Comm.).

There is increasing interest in the scientific community to develop local formulas that are better optimised e.g. in terms of linear growth [4], that contain alternative ingredients to peanuts (because of the aflatoxin risk, which is high in countries with poor infrastructure such as Sierra Leone) and with lower milk content (because of the high cost of powdered milk) [4]. However a challenge is that these alternative formulas do have to meet nutritional adequacy (WHO requirements[19]).

A couple of studies with local RUTFs have been conducted in Sierra Leone: for example, clinical trials to compare standard RUTF with alternative RUTF containing oats, peanuts, sugar, milk powder, vegetable oil and a vitamin and mineral premix are currently being carried out (https://clinicaltrials.gov/ct2/show/NCT03407326). In parallel there is also a study supplementing malnourished pregnant women in Sierra Leone with a product made out of local (millet, palm oil, shelled groundnut) and imported (dried milk, whey protein, soybean oil, brown sugar) ingredients called Mama Dutasi [35].Researchers have been looking into developing alternative formulas that will also be more feasible to make locally at lower costs [36].

Because of the high cost of imported-RUTF, it may be advantageous for Sierra Leone to develop a RUTF made with local ingredients because this may – in the long term - be done at lower costs to the country, reach more children, and also help the local economy, in particular, the food industry sector. However, producing RUTF locally has a number of challenges including ensuring its nutritional quality and food safety (i.e. peanuts locally grown can be contaminated by aflatoxins), and the cost of ingredients.

2 Aims, objectives, and activities

The overall **aim** of project is to explore whether locally produced crops and commodities can be used as ingredients in RUTF formulas to treat SAM in Sierra Leone.

This work has three **objectives**:

1. Understand which crops and commodities in Sierra Leone are potentially suitable to be used in RUTF formulations
2. Identify possible combinations of local ingredients in Sierra Leone that could be used to meet RUTF requirements based on cost, nutritional content, and aflatoxin content (using linear programming)
3. Identify possible constraints of using local ingredients in local contexts that could inform the setting-up of local production

Hypothesis statement:

There are viable alternative formulas other than the standard RUTF formula that could be used in Sierra Leone for a lower cost and with safer ingredients than peanuts (that are less likely to contain aflatoxin).

These objectives were achieved through the following **activities**

1. A literature review was done to gather information about the local formulations of RUTF that have been used in previous studies to treat SAM (and MAM), about crops and commodities available in Sierra Leone and ingredient costs (Objective 1)
2. Collaborators in Sierra Leone were asked to collect ingredient cost (Objective 1)
3. Various possible RUTF formulations were tested using linear programming (Objective 2)
4. Based on activities 1-3, the most suitable options to the country situation (e.g. based on cost, accessibility, food safety etc.) were discussed (Objective 3)

3 Materials and Methods

3.1 General approach

Linear programming (LP) is a mathematical model that allows the selection of optimum values (minimum or maximum) under a set of constraints. The model has been used extensively for the optimisation ofthe nutritional composition of diets and food formulations including RUFs such as RUTF and RUSF. LP for RUF can be run using a free Microsoft Excel add-in Solver to solve linear equations.

The approach I used is based on the first two phases of the approach used by Dibari et al. (2012)[37] to develop of a low-cost RUTF using linear programming. I selected this approach because the methodology was explained in detail. Another major work in this field was by Ryan et al. (2014)[11] who expanded the use of linear programming to make cost comparisons of RUTF formulations from various countries. The primary objective of the LP models, in both studies, was to minimise cost whilst meeting the nutritional constraints for RUF.

The methodology developed by Dibari et al[37,38]. has 4 distinct phases: Phase A: selection of target groups and ingredients. Phase B: create and run the LP model using the solver add-in on Excel. Phase C: manufacture RUTF at a small scale and compare nutritional analysis obtained by LP to that analysed by a laboratory. Phase D: assess the food safety, acceptability of the unfortified RUTF formulation(s) using consumer acceptance tests and the shelf-life of the formulations. Phases C and D are not covered in this MSc project.

The LP general approach is described in more detail in a diagram[37,38] in Appendix 2.

3.2 Literature review

Prior to phases A and B, a literature search was conducted to understand the type of local formulations that have been developed in LMICs to tackle Severe and Moderate Acute Malnutrition. The following searching terms were used:

(“lipid-based” OR “ready-to-use f*” OR “RUF” OR “ready-to-use supplementary” OR “RUSF” OR “ready-to-use therapeutic” OR “RUTF” OR “lipid”) OR “plumpy nut” OR “plumpy doz” OR “nutrient dense spread” OR “fortified spread” OR “peanut paste”) AND (“malnutrition/” OR “severe acute malnutrition” OR “moderate acute malnutrition” OR “wasting” OR “stunting” OR “underweight/” OR “kwashiorkor/” OR “marasmus/”) AND (“formula*” OR “food ingredients/ OR “ingredients” OR “crop/”).

Three databases were searched using the Ovid Platform (Embase, Global Health and Medline): I obtained n=124, n=61, and n=84 references, respectively, using Embase [1974 to 2019 August 02]:, Global Health, and Ovid MEDLINE [1946 to July Week 4 2019]. References were transferred to EndNote X9. After removal of duplicates, there were 195 references to screen. After removal of un-relevant articles, the total number of articles was 141 (Figure 1).

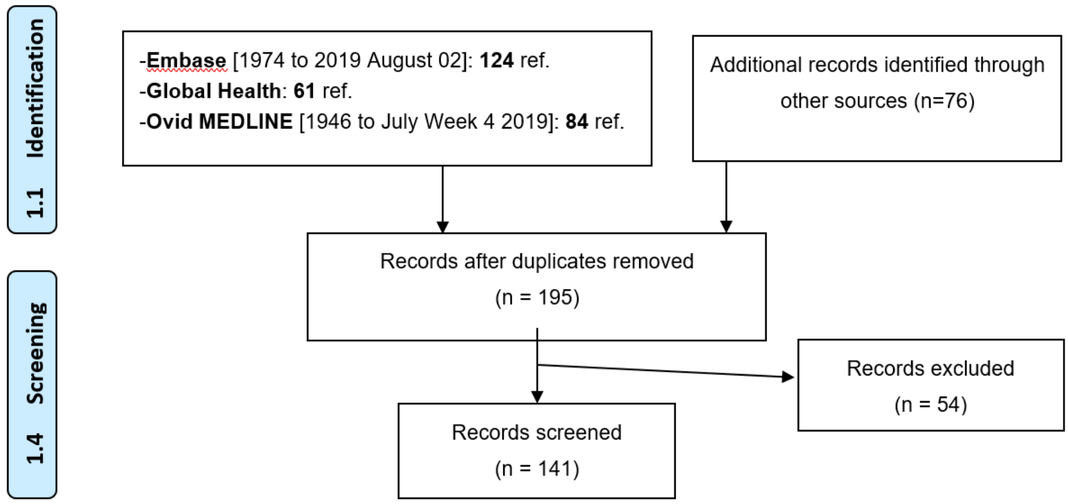

Figure 1. Process showing the selection of articles (inspired by the PRISMA diagram for systematic reviews)

The articles were used as a basis of knowledge to discuss findings in the discussion part.

3.3 Selection of the target groups, ingredients, and prices (phase A)

This is described as Phase A in Dibari[37,38]. This phase is critical for the achievement of a suitable LP model.

3.3.1 Selection of the target groups

Our principal target group are 6-59 month-children suffering from SAM with no-complications. However of RUTF fed in smaller amounts can also be used in the treatment of MAM as described by Bailey et al. [7].

3.3.2 Selection of ingredients and prices

Our criteria were that the ingredients should be:

- from various food types: at least four: cereals, pulses, sugar, oil in order to obtain a nutritionally balanced composition [10]. Seeds/nuts were also added to this.
- if possible - locally produced in Sierra Leone.
- at least produced/sold at a minimum quantity of 500 tonnes per annum in the country (this criteria was established by Ryan et al.[11].
- stable at ambient temperature for at least 6 months because they would need to be stored in large quantities[11]. Therefore these have to be dry. If those are fresh commodities (e.g. cassava, banana, sweet potato, coconut, cocoa) they would have to be dehydrated.

The partners collected local market prices in Freetown at street markets and a supermarket for imported commodities and weighed the items to determine the price per 100g (Appendix 3). Prices of imported commodities were also collected.

3.3.3 Selection of nutritional composition of the ingredients

The nutritional composition of ingredients was obtained from food composition databases (Network of Food Data Systems (INFOODS) of the FAO http://www.fao.org/infoods/infoods/en/ , USDA Food Composition Databases https://ndb.nal.usda.gov/ndb/). Establishing an accurate food composition of the ingredients is critical for the establishment of a realistic RUF formulation. I used a stepped approach (Figure 2).

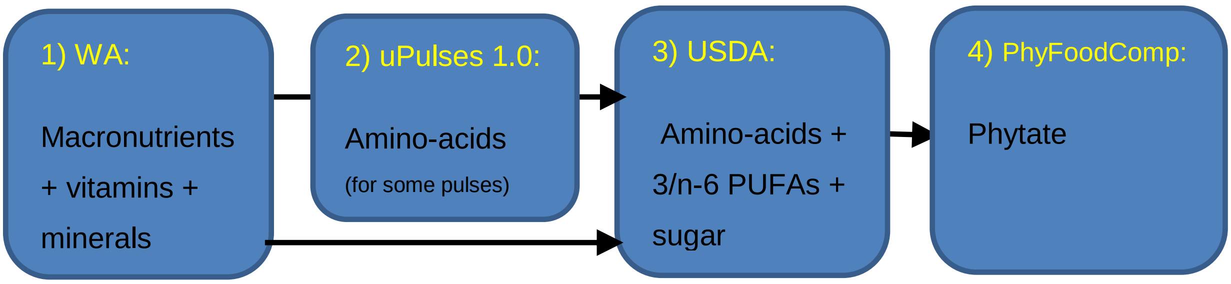

Figure 2. Database search approach to obtain the nutritional composition of ingredients

Note: West African Food Composition Table (WA), uPulses 1.0, PhyFoodComp1.0 are found on the INFOODS platform.

Initially the nutritional composition of ingredients was searched on the **West African Food Composition Table (WA)** (INFOODS) because it has a list of locally available West African foods that are common to Sierra Leonians foods. However, the WA database did not include n-3/n-6 poly-unsaturated fatty acids (PUFAs) that are needed to meet the nutritional requirements for RUF. In addition, the WA database did not have amino-acids levels that are required to calculate the protein quality. Therefore, other databases were searched to complete the food composition. For some of the pulses, the amino-acids composition was obtained from **uPulses 1.0** (INFOODS).The remaining nutrients were found in the **USDA database**. Those were n-3/n-6 PUFAs, sugar, and amino-acids levels - for those were not pulses or not found on the uPulses1.0 website.

In addition, the phytate content was obtained from **PhyFoodComp1.0 (INFOODS)**. For phytate, the values in the ingredient table (=before processing) were selected. I decided to take this conservative approach because loss of phytate with processing is highly variable, depending on the processing conditions[39]. Phytates in raw products will show the most unfavourable conditions.

3.3.4 Calculation of protein quality

Protein quality was calculated using the Protein Digestibility Corrected Amino Acid Score (PDCAAS) as described in publications in linear programming of RUTF formulations[11,37].

The formula is: PDCAAS = AAS x TFD[40-43]where AAS is the amino-acid score = mg of limiting amino-acid in 1g of protein/mg of same amino-acid in 1g of reference protein. TFD is the true faecal digestibility.

TFD of the formulation was calculated as a weighted average per quantity of protein in each of the ingredients. Amino-acids quantity per 1mg of protein was calculated and the more limiting amino acid was selected and divided by the quantity of the same amino-acid of 1g of reference protein as given by FAO/WHO/UNU (1985) in Schaafsma (2000) [40]. Essential amino-acids, which are used for amino-acid score (AAS) calculation, are divided into: isoleucine, leucine, lysine,total sulphur amino-acids (methionine & cysteine), total aromatic amino-acids (phenylalanine & tyrosine), threonine, tryptophan, and valine [40].

The methodology was adapted from WHO/FAO/UNU 1990[43]; 2007[41]. For the formulation (mixture of ingredients), a weighted average of AAS per quantity of protein (mg) was calculated for each of the individual amino acid scores (AAS) (WHO/FAO/UNU 1990, page 36[43]).

3.3.5 Calculation of n-3/n-6 PUFAs

Omega 3 (n-3) and Omega 6 (n-6) PUFAs are critical components of RUF. One of the difficulties is that the USDA database explicitly mentions n-3/n-6 PUFAs but also gives the chemical composition of other PUFAs that are not mentioned as n-3/n-6 but could be. I calculated n-3/n-6 PUFAs as indicated by the USDA database (Method 1: conservative approach) but I also recorded the potential n-3/n-6 PUFAs that could be missed from the calculation (Method 2: Liberal calculation) Table 3).

Table 3. n-3/n-6 PUFAs indicated in the USDA food composition database

PUFA name indicated in USDA database	n-3/n-6 PUFAs	Method 1:'Conservative' calculation (only n-3/n-6 PUFAs explicitly mentioned in USDA)	Method 2: 'Liberal' calculation (n-3/n-6 PUFAs may be present based on the chemical formula)
18:2 undifferentiated	May contain linoleic acid (LA) 18:2(n-6) cis-cis	-	100% (n-6)
18:2 n-6 c,c	Linoleic acid (LA) 18:2(n-6) cis-cis	100% (n-6)	-
18:2 CLAs	-	-	-
18:2 t,t	-	-	-
18:3 undifferentiated	May contain Alpha-Linolenic acid (ALA) 18:3(n-3) & Gamma-Linolenic acid (GLA) 18:3(n-6)	-	50% (n-3) 50% (n-6)
18:3 n-3 c,c,c (ALA)	Alpha-Linolenic acid (ALA) 18:3(n-3) cis-cis-cis	100% (n-3)	-
18:3 n-6 c,c,c	Gamma-Linolenic acid (GLA) 18:3(n-6) cis-cis-cis	100% (n-6)	-
18:3i	-	-	-
18:04	May contain Stearidonic acid 18:04(n-3) c-c-c-c	-	100% (n-3)
20:2 n-6 c,c	Eicosadienoic acid 20:2(n-6) cis-cis	100% (n-6)	100% (n-6)
20:3 undifferentiated	May contain Dihomo-γ-linolenic acid 20:3(n-6) & Eicosatrienoic acid (ETE) 20:3(n-3)	-	50% (n-3) 50% (n-6)
20:3 n-6	Dihomo-γ-linolenic acid	100% (n-6)	-
20:4 undifferentiated	May contain arachidonic acid (AA, ARA) 20:4(n-6) & Eicosatetraenoic acid20:4(n-3)	-	50% (n-3) 50% (n-6)
20:5 n-3 (EPA)	Eicosapentaenoic acid 20:3(n-3) (EPA)	100%(n-3)	100%(n-3)
21:5	May contain Heneicosapentaenoic acid (HPA) 21:5 (n-3)	-	100%(n-3)
22:4	May contain Adrenic acid 22:4(n-6)	-	100%(n-6)
22:5 n-3 (DPA)	Docosapentaenoic acid 22:5(n-3) (DPA)	(n-3)	100%(n-3)
22:6 n-3 (DHA)	Docosahexaenoic acid 22:6(n-3) (DHA)	(n-3)	100%(n-3)

The various n-3 and n-6 PUFAs were summed up. I decided to include both methods of calculation in the models because there may be differences. In practice, the conservative method is safer because there are limited health risks with tolerable upper intake levels (ULs) of n-3/n-6 PUFAs. On the other hand, there would be health risks for the target population if the formula did not meet the n-3/n-6 PUFA requirements.

3.3.6 Inclusion of minerals and vitamins

Minerals (calcium, sodium, phosphorus) are part of the model constraints. In addition, I recorded the amount of other minerals that are part of the WHO specifications. This included iron, potassium, zinc, copper. Manganese was not included in the list of minerals from WHO specifications. Iodine and Selenium are highly variable because depending on the soil type [44] and they were not recorded. Vitamins A,thiamin, riboflavin, niacin, pantothenic acid, B6, folate,C, D, E, K, choline were recorded whenever they were included in the food composition database. Caffeine was also included because it could have an influence on the target groups, as well as flavonoids, catechin that have antioxidative properties. The formulation of RUF with local ingredients requires a mineral and vitamin premix because the nutrient density of local foods does not achieve the required density of vitamins and minerals for RUTF[38,45]. The formulation of the fortificant premix is done by a commercial company and can be adjusted based on the vitamins and minerals present in the formulation (after acceptance test).

3.3.7 Inclusion of aflatoxin limit

Aflatoxin in peanuts in sub-Saharan African is a major hurdle to the development of locally produced RUFs [33,34,46]. In our knowledge aflatoxin level is a constraint that has not been used as a constraint in previous linear programming with RUTF in our knowledge. Aflatoxin levels can be extremely variable. I used the average aflatoxin level for groundnuts reported by Sombie et al [30] for cashew and groundnuts in Sierra Leone; this seemed a acceptable way forward because the number of samples tested for aflatoxins was significant (n=100) [30].

3.4 Running of linear programming using Excel (phase B)

The LP models were developed in the free Microsoft Excel add-in Solver (Frontline Systems Inc.). In all models, the objection function minimised cost and an identical set of constraints were used.I selected the model constraints based on previous work on LP for RUTF [11,37,47]. In addition, I added a constraint on food safety (aflatoxin level in peanuts) (Table 4)

Table 4. Model constraints for LP – based on nutritional content, density, and energy, palatability, and food safety for a RUF formulation for Sierra Leone (100g)

Model constraints based on WHO specifications	Min.	Max.
Nutrients, density, and energy		
Total quantity (g)[1]		97
Energy (Kcal)	520	550
Protein (% energy)	10	12
Lipids (% energy)	45	60
n-3 PUFAs (% energy)	0.3	2.5
n-6 PUFAs (% energy)	3	10
Fibre content (%)	0	5
Water content (%)	0	2.5
Palatability		
Added Sugar (%)	15[2]	28[2]
Sorghum/Millet level (%)	7	10
Food safety		
Aflatoxin level in groundnuts (µg/100g[4])	0	0.5
Other variables monitored but not included as constraints		
Protein quality: PDCAAS	0.75	1.2
AAS	-	-
Main limited amino-acid	-	-
Total faecal digestibility (%)		
Carbohydrate (%)	41	58
Minerals: Sodium	0	290
Calcium	0	600
Phosphorus	0	600
Anti-nutrients (before processing): Phytate	0	480[5]
Phytate: iron molar ratio	0	2.5[20]
Phytate: zinc molar ratio	0	15[20]

[1] excludes the fortificant premix (3g); [2] minimum value in [37] and maximum value in [48] [3] equal to 5 PPB (µg/kg); [4] value found in [20], which was considered acceptable

Level of sugar (15-18%) and sorghum (7-10%) have been tested in previous formulations and were proven to improve palatability [47,49]. However, Dibari et al. (2012) developed a product for adults. The current commercial RUTF (‘Plumpy’nut) has an added sugar content of 28%. Therefore I expanded the range of added sugar from 15 to 28%. I included millet as an alternative for sorghum because the cereals are similar in texture, taste, and in appearance. Millet has also been used in Sierra Leone in the formulation of RUSF for malnourished pregnant women [35]. However, in practice, it may be advisable to confirm if the replacement of sorghum by millet is acceptable using sensory testing (phase D in Appendix 2– not covered in this MSc project).

4 Results

Ingredients in Sierra Leone potentially suitable to be used in RUTF formulations were identified. Their nutritional composition, digestibility, and cost were estimated. Then, possible combinations of local ingredients for RUTF formulations were tested using linear programming.

4.1 Ingredients

An initial list of crops and commodities was determined using literature search. Our ingredient's selection for RUTF is based on a list of locally available ingredients in Sierra Leone used for the formulation of a RUSF for pregnant and malnourished women[35]. A couple of imported ingredients were also added (i.e. dry milk, dry whey protein) for comparison purposes. The list has ingredients selected according to the criteria of a minimum of 500 tonnes per annum[11]. In addition, other ingredients from FAOStat[14] were included on the basis that have been used for RUF in previous studies. FAOStat that has some of the most available crops and quantities produced per annum. The latest list of crops was checked for Sierra Leone (Appendix 1). Various ingredients can be used for RUF formulation[8,11,35,38,47,50]. Most common cereals include maize, millet, sorghum. Examples of pulses are groundnuts, cowpea, soybeans, lentils. Seeds such as pumpkin, cashew nuts can also be included. Most common oils are palm, soya, peanut, sunflower. Powdered milk or whey protein[51] are often used. Other ingredients are cocoa, sugar (brown or white). Other possible ingredients are roots and tubers: cassava[47], banana, and sweet potato[47]. Dried eggs[11] and dried fish[50] have been proposed for use in RUTF formulations.

The list of ingredients (n=40) was communicated with partners in Sierra Leone (Mrs. Aminata Shamit Koroma from the department of Health and Sanitation and Dr. Alex Blanshard, an independent consultant). From the initial list, I removed items without prices (n=5), items in duplicate (n=2), irrelevant items (n=1; kola nuts), items that I did not know about or did not know how to process for RUTF (n=3; cous, wheat flours), imported items that did not have a clear superior nutritional value (n=4) compared to locally produced items. The refined list included n=25 ingredients. From the refined list, I removed 3 ingredients (taro, cassava gari, melon seeds) that did not have a complete food composition. The final list of ingredients selected is n=22. This includes 19 local ingredients, 1 ingredient that can be found locally but was imported as flour (sorghum), and 2 imported ingredients with high nutritional value (dried milk and whey protein). Two additional ingredients (groundnut paste and soybean oil) that are ingredients in the standard formulation (Plump'nut) were added.

For each ingredient, I indicated whether it was locally produced in Sierra Leone, the type of commodity (cereal, root, pulse, oil, seed/nut), whether there is a risk of mycotoxin (i.e. aflatoxin) reported in literature, the reference where the ingredient was selected from, the food databases used, the complete wording in the food databases and the ingredient code (that will allow readers to identify the same ingredients) (Appendix 4).

The moisture content of each ingredient was adjusted across the various databases used. For example, if the moisture content of maize is 5% in the WA database and 7% in USDA and 10% in PhyFoodComp1.0, I would adjust the content of all the nutrients from USDA (typically amino-acids, sugar, and n-3/n-6 PUFAs) and PhyFoodComp1.0 (phytates) to 5% moisture. The moisture content would be always adjusted to the first food database (WA by default). In addition the moisture content of dried fish (initially at 20%) was lowered to 3.5% (a moisture level found in fish powder [52]). This is because the moisture content of the formulation is limited to 2.5%. The moisture content of the other ingredients was around 10(+/- 20%) % (which is standard for dried products) and was not further adjusted.

Total Faecal Digestibility (TFD) was selected from literature for each of the ingredients (n=22). TFD is used to calculate the protein quality. There is now consensus that the ileal digestibility is a more accurate measurement than the total digestibility [40] but TFD is still commonly in use. TFD values can be found in literature. Those were reported for the ingredients (**Error! Reference source not found.**):

Table 5. List of total faecal digestibility values selected for the various ingredients

Ingredient	Food/Source (reference)	Total faecal digestibility (TFD)
Broad beans, horse beans, dry	Broad beans[53]	0.87
Bulgur	Wheat[40]	0.91
Cassava flour, dried	Cassava[42]	0.80
Cocoa, beans	Almond defatty flour[54] (proxy)	0.92
Coconuts	Coconut meal[53]	0.89
Cowpeas (also called black eyed pea)	Cowpeas "Roasted for 15 min at 180°C, in sand bath. Dried overnight at 55°C and ground."[54]	0.77

Ingredient	Food/Source (reference)	Total faecal digestibility (TFD)
Dried egg	Egg, dried[53]	0.93
Dried fish	Heyring, smoked[54]	0.98
Dried milk, skimmed	Milk, skim, powder[54]	0.94
Groundnuts	Peanut, “"Roasted in electric oven for 30 min at 140°C and then ground."[54]	0.92
Maize, dried - whole grain	Maize meal[54]	0.82
Millet	Millet[53]	0.79
Oil, Coconut	Not applicable (NA)	0.00
Oil, palm	NA	0.00
Pigeon peas	Peas, pigeon[53]	0.76
Plantains and others	Yam and potato[42] (proxy)	0.80
Rice	Rice[42]	0.82
Sesame seed	Seeds, sesame[53]	0.82
Sorghum - whole	Sorghum, cooked[53]	0.73
Sugar white	NA	0.00
Sweet potatoes	Autoclaved sweet potato protein[55] (proxy for extruded)	0.95
Whey protein	Whey protein[53]	0.95

Sources: Schaafsma 2000[40]; WHO/FAO/UNU 2007[41]; FAO 1989[43] Bender and Millward 2017[42]; Genesis R&D software[53], Boye et al. 2012[54]

Whenever it was possible, I selected values of processed ingredients because the formulation will be processed. TFD values range from 0.73 to 0.98. Proteins from animal products are more digestible than from plants.

Ingredient price (n=22) was calculated for 100g of the dried product (taking into account the water content in the fresh product) (see Appendices 5 & 6) (Table 6).

Table 6. Market and producer prices of ingredients

Commodity	Local	Dried	Market price in $US/100g dried product(collected by partners)	Producer price in $US/100g dried product (FAOStat 2013-2015)
Broad beans, horse beans, dry	yes	yes	0.2202	0.2301
Bulgur	yes	yes	0.3854	
Cassava flour	yes	yes	0.1652	0.0498
Cocoa, beans	yes	yes	0.1652	
Coconuts	yes	**no***	**2.3078**	**0.4729**
Cowpeas	yes	yes	0.1376	
Eggs	yes	**no***	1.3080	2.3313
Dried fish	yes	yes	0.2753	
Dried milk	imported	yes	2.6425	

Commodity	Local	Dried	Market price in $US/100g dried product(collected by partners)	Producer price in $US/100g dried product (FAOStat 2013-2015)
Groundnuts**	yes	yes	0.2753	
Maize, dried	yes	yes	**0.2092**	**0.1213**
Millet	yes	yes	0.1652	
Oil, coconut	yes	yes	0.4955	
Oil, palm	yes	yes	0.1101	0.0903
Pigeon peas	yes	yes	0.1101	
Plantains & others = Bananas	yes	**no***	**0.9297**	**0.7513**
Rice, paddy	yes	yes	0.1101	0.0692
Sesame seed	yes	yes	0.1927	0.2497
Sorghum (flour)	imported	yes	0.3523	
Sugar cane	yes	yes	0.0661	0.0023
Sweet potatoes	yes	**no***	**0.3715**	**0.4154**
Whey protein	imported	yes	5.2549	

Price of groundnuts was calculated without the shell estimated to 20% of the weight.

In addition, producers' prices from local available commodities in Sierra Leone were collected by averaging years 2013, 2014, and 2015' s prices. I found only n=11 ingredients out of the final list from the FAOStat website [14] (Appendix 7).

Market prices ranged between $US 0.07 (sugar cane), $US 1.31 (dried eggs), and $US 5.25 (whey protein) and producer prices between $US 0.002 (sugar cane) and $US 2.33 (dried eggs). Price of commodities was not always cheaper with market prices *i.e.* dried eggs.

4.2 Formulations

I selected two types of formulations for linear programming: those made with ingredients (n=22) that had market prices (collected by the partners in Sierra Leone) and those (n=11) that had producers's prices and compared both. I also included the standard formulation ('Plumpy'nut) for comparison.

The formulations were the following:

- Market prices (MP_0) (n=22 ingredients)
- Market prices without fish (MP_1) (n=21 ingredients)

- Market prices without eggs (MP_2) (n=21 ingredients)
- Market prices without eggs & fish (MP_3) (n=20 ingredients)
- Market prices for vegan product (no eggs, fish, dairy) (MP_v) (n=19 ingredients)
- Market prices Standard 'Plumpy'nut' (Std) (n=5 ingredients)
- Market prices with FAOStat ingredients* (MP_{FAO}) (n=11 ingredients)
- FAOStat Producer's prices with FAOStat ingredients* (PP_{FAO}) (n=11 ingredients)

The list of ingredients was entered in the model that selected automatically the best combinations of ingredients. The constraint on the level of sorghum/millet was not applied for the MP_{FAO}/PP_{FAO} formulation and for the standard 'Plumpy'nut formulation because those formulas did not contain millet or sorghum.

The outcomes of linear programming are shown for the 8 formulations for each of the two methods used to estimate the PUFA content of each ingredient (i.e., Method 1; conservative and Method 2: liberal). The constraints were met by 4 formulations: MP_0 with the two methods of PUFAs's calculation, MP_1, and MP_{FAO} and PP_{FAO}, with the second method of PUFAs's calculation. MP_{FAO} and PP_{FAO} had the same ingredients but with a different cost because MP was calculated from market prices and PP from producers' prices (Tables 7,8,9,10).

The ingredients and respective costs for the successful formulations selected by linear programming (LP) were the following:

- MP_0 / MP_2 –method 1: cassava, cocoa, eggs, fish, millet, groundnut, palm oil, sugar ($US 0.364)
- MP_0/ MP_2 –method 2: cocoa, fish, millet, groundnut, palm oil, pigeon peas, rice sugar ($US 0.125)
- MP_1 –method 2: cocoa, eggs, cowpea, millet, palm oil, rice, sesame seeds, sorghum, sugar) ($US 0.338)
- MP_{FAO}/PP_{FAO} – method 2: broad beans, eggs, palm oil, banana, sesame seeds, rice, sugar($US 0.381 (MP) / $US 0.539 (PP))

All the successful formulations contained animal sources (egg, fish). Powdered milk or whey protein were not selected by linear programming.

A major difficulty was for formulations to meet the n-3 PUFAs constraint (minimum 0.3%). The 'vegan' formulation (without fish, eggs, milk, and whey protein) did not meet the minimum protein content of 10% and of protein quality (PDCAAS > 0.75) and n-3/n-6 PUFAs constraints. This is also because the locally available oils (palm oil and coconut oil) did not contain significant amounts of n-3 PUFAs as opposed to soybean oil; unfortunately soybean oil was not locally available; it can be imported; but the partners in Sierra Leone were not able to find the prices; I set the cost of soybean oil arbitrarily to 1$ in the standard formula.

In addition, the maximal aflatoxin level set by the model according to published data[30] (487.8 ppb in groundnuts on average) limited the options of using groundnuts that are rich in n-6 PUFAs. Formulations ‘MP_0/MP_1–methods 1 & 2’ contained groundnuts but in very limited amounts (1g). The standard (Plumpy’nut) formulation - if made with local peanuts - would have an estimated aflatoxin content of 40.5 ppb, which is almost 10 times above the requirement limit.

Phytate and molar ratios of phytate:iron or phytate:zinc were within the acceptable limits[20].

Vitamins were in lower amounts that the nutritional requirements for RUTF and would have to be complemented by a commercial premix[38,45].

Table 7. Weight of LP-tested formulations using two methods for n-3/n-6 PUFAs calculations.

	Method 1. 'Conservative' calculation (only n-3/n-6 PUFAs explicitly mentioned in USDA)								**Method 2**. 'Liberal' calculation (n-3/n-6 PUFAs may be present based on the chemical formula)							
Ingredient (quantities in g)	**MP_0**	**MP_1**	**MP2**	**MP_3**	**MP_v**	**Std**	**MP_{FAO}**	**PP_{FAO}**	**MP_0**	**MP_1**	**MP_2**	**MP_3**	**MP_v**	**Std**	**MP_{FAO}**	**PP_{FAO}**
Number of ingredients in the model	**22**	**21**	21	**20**	**18**	**5**	**11**	**11**	**22**	**21**	**21**	**20**	**18**	**5**	**11**	**11**
Broad beans, horse beans, dry				0.1											8.8	8.8
Bulgur																
Cassava flour	2.9	4.3	2.9				10.8	11.8								
Cocoa, beans	2.9		2.9	8.8	0.2				11.3	10.4	11.3		0.5			
Coconuts																
Cowpeas				0.1									0.8			
Dried egg	20.7	32.3	20.7				33.6	33.7		18.5					18.1	18.1
Dried fish	6.3		6.3						12.5		12.5					
Dried milk, skimmed				29.2		32.2						27.4		32.2		
Groundnuts*	1.0		1.0	1.0	1.0	8.3							1.0	8.3		
Maize																
Millet	10.0		10.0	10.0					7.0	3.6	7.0					
Oil, Coconut		21.5		32.4	21.7								22.6			
Oil, palm	25.1		25.1			**27.6+**	21.3	21.2	30.8	21.8	30.8	27.8		**27.6+**	22.1	22.1
Pigeon peas				0.2					2.4		2.4					
Banana (Plantain & others)		0.8			12.4		3.1	2.3				4.1	12.4		6.1	6.1
Rice (local)									5.0	5.1	5.0				2.2	2.2
Sesame seed					26.7					6.2		15.3	24.7		11.7	11.7
Sorghum - whole		10.0			7.0					3.4		7.0	7.0			
Sugar white	28.0	28.0	28.0	15.0	28.0	24.6	28.0	28.0	28.0	28.0	28.0	15.3	28.0	24.6	28.0	28.0
Sweet potatoes							0.2									
Whey protein		0.1		0.1												

Where: Market prices (MP0); Market prices without fish (MP1); Market prices without eggs (MP2); Market prices without eggs & fish (MP3); Market prices for vegan product (no eggs, fish, dairy) (MPv); Market prices Standard 'Plumpy'nut' (Std) ; Market prices with FAOStat ingredients* (MP_{FAO}); FAOStat Producer's prices with FAOStat ingredients*(PP_{FAO}). Alternative ingredients for Std: palm oil +**4.2g soybean oil** & groundnut paste instead of groundnut. There was no ingredient cost available for soybean oil so the cost was arbitrarily set to $1/100g.

Table 8. Nutritional composition, aflatoxin level and ingredient cost of LP-tested formulations using two methods for n-3/n-6 PUFAs calculations

Model constraints based on WHO specifications		Method 1. 'Conservative' calculation (only n-3/n-6 PUFAs explicitly mentioned in USDA)								Method 2. 'Liberal' calculation (n-3/n-6 PUFAs may be present based on the chemical formula)							
		MP_0	MP_1	MP_2	MP_3	MP_v	Std	MP_{FAO}	PP_{FAO}	MP_0	MP_1	MP_2	MP_3	MP_v	Std	MP_{FAO}	PP_{FAO}
Nutrients, density, and energy																	
Total quantity (g)*	97	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Energy (Kcal)	520-550	547	550	547	520	536	550	550	550	521	520	521	538	536	550	541	541
Protein (% energy)	10-12	12.0	12.0	12.0	10.3	**4.7**	10.0	12.0	12.0	10.0	10.0	10.0	10.0	**4.6**	10.0	10.0	10.0
Lipids (% energy)	45-60	59.9	59.0	59.9	60.0	60.0	58.9	59.1	59.1	60.0	60.0	60.0	60.0	60.0	58.9	60.0	60.0
Lipids (% total quantity)	26-36	36.4	36.0	36.4	34.7	35.7	36.0	36.1	36.1	34.8	34.7	34.8	35.9	35.7	36.0	36.1	36.1
n-3 PUFAs (% energy)	0.3-2.5	0.30	**0.22**	0.30	**0.02**	**0.01**	0.47	**0.22**	**0.22**	0.48	0.30	0.48	**0.10**	**0.10**	0.30	0.30	0.30
n-6 PUFAs (% energy)	3-10	3.0	4.6	3.0	**1.5**	**0.9**	3.5	3.9	3.9	5.5	8.6	5.5	10.0	10.0	9.9	10.0	10.0
Fibre content (%)	0-5	1.7	0.9	1.7	3.9	5.0	0.1	0.8	0.7	5.0	5.0	5.0	2.7	5.0	0.1	4.3	4.3
Water content (%)	≤2.5	2.5	2.5	2.5	2.5	2.5	1.6	2.4	2.5	2.5	2.5	2.5	2.5	2.5	1.6	2.5	2.5
Palatability																	
Added Sugar (%)	15-28	28.0	28.0	28.0	15.0	28.0	24.6	28.0	28.0	28.0	28.0	28.0	15.3	28.0	24.6	28.0	28.0
Sorghum/Millet level (%)	7-10	10.0	10.0	10.0	10.0	7.0	0.0	0.0	0.0	7.0	7.0	7.0	7.0	7.0	0.0	0.0	0.0
Food safety																	
Aflatoxin level in groundnuts (PPB=μg/kg)	≤5 or ≤10	5.0	0.0	5.0	5.0	5.0	**40.5**	0.0	0.0	0.0	0.0	0.0	0.0	5.0	**40.5**	0.0	0.0
Ingredient cost ($ g/100g)		**0.364**	**0.604**	**0.364**	**0.983**	**0.321**	**0.964***	**0.529**	**0.828**	**0.125**	**0.338**	**0.125**	**0.857**	**0.323**	**0.964***	**0.381**	**0.539**

There was no ingredient cost available for soybean oil so the cost was arbitrarily set to $1/100g. Figures in **red** do not meet the model constraints.

Table 9. Other nutritional constraints of LP-tested formulations using two methods for n-3/n-6 PUFAs calculations

Model constraints based on WHO specifications		Method 1. 'Conservative' calculation (only n-3/n-6 PUFAs explicitly mentioned in USDA)								Method 2. 'Liberal' calculation (n-3/n-6 PUFAs may be present based on the chemical formula)							
		MP_0	MP_1	MP_2	MP_3	MP_v	Std	MP_{FAO}	PP_{FAO}	MP_0	MP_1	MP_2	MP_3	MP_v	Std	MP_{FAO}	PP_{FAO}
Other variables monitored but not included as constraints																	
***Protein quality:* PDCAAS**	0.75-1	1.23	1.20	1.23	1.09	**0.45**	1.11	1.24	1.24	1.25	1.07	1.25	1.01	**0.47**	1.11	1.01	1.01
AAS	NA	1.34	1.34	1.34	1.18	**0.50**	1.20	1.38	1.38	1.31	1.19	1.31	1.08	**0.52**	1.20	1.13	1.13
Main limited amino-acid	Lysine	Lysine	Lysine	Lysine	Lysine	Lysine	none	Lysine	Lysine	Lysine	Lysine	Lysine	Lysine	Lysine	none	Lysine	Lysine
Total faecal digestibility (%)	NA	0.92	0.90	0.92	0.92	0.90	0.93	0.90	0.90	0.95	0.90	0.95	0.93	0.90	0.93	0.89	0.89
Carbohydrate (%)	41-58	40	40	40	43	47	43	40	40	44	44	44	40	48	43	39	39
***Minerals:* Sodium**	≤290	118	157	118	161	4	174	164	164	35	92	35	149	4	174	89	89
Calcium	≤600	123	89	123	384	267	412	98	99	144	122	144	498	249	412	170	170
Phosphorus	≤600	266	238	266	381	205	341	225	226	281	267	281	386	198	341	244	244
Bioavailable phosphorus		227	214	227	312	61	321	216	216	195	162	195	301	59	321	153	153
***Anti-nutrients (before processing):* Phytate**	≤480***	104	31	104	140	310	37	16	17	172	201	172	177	297	37	180	180
Phytate: iron molar ratio	≤2.5	1.6	1.0	1.6	1.7	2.8	0.8	0.9	1.0	2.5	2.6	2.5	1.6	2.7	0.8	1.9	1.9
Phytate: zinc molar ratio	≤15	3.7	2.3	3.7	3.7	5.1	1.8	2.1	2.3	4.1	3.7	4.1	3.1	5.0	1.8	3.2	3.2

Figures in **red** do not meet the model constraints.

Table 10. Vitamin contents of LP-tested formulations using two methods for n-3/n-6 PUFAs calculations

Model constraints based on WHO specifications	Method 1. 'Conservative' calculation (only n-3/n-6 PUFAs explicitly mentioned in USDA)								Method 2. 'Liberal' calculation (n-3/n-6 PUFAs may be present based on the chemical formula)							
	MP_0	**MP_1**	**MP_2**	**MP_3**	**MP_v**	**Std**	**MP_{FAO}**	**PP_{FAO}**	**MP_0**	**MP_1**	**MP_2**	**MP_3**	**MP_v**	**Std**	**MP_{FAO}**	**PP_{FAO}**
Vitamin A (µg)	65	97	65	5	2	5	102	102	6	56	6	5	2	5	56	56
Vit D (D2+D3) (µg)	2	3	2	0	0	0	3	3	0	2	0	0	0	0	2	2
Vit E (alpha-tocopherol) (mg)	5.0	1.5	5.0	0.4	0.4	5.6	4.7	4.7	5.0	4.2	5.0	4.5	0.4	5.6	4.3	4.3
Thiamin (mg)	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Riboflavin (mg)	0.5	0.7	0.5	0.5	0.1	0.5	0.7	0.7	0.1	0.4	0.1	0.5	0.1	0.5	0.4	0.4
Niacin (mg)	1.3	0.6	1.3	0.7	1.7	1.6	0.3	0.3	2.4	1.0	2.4	1.2	1.6	1.6	1.0	1.0
Pantothenic acid (mg)	1.4	1.9	1.4	0.0	0.0	0.0	1.9	1.9	0.4	1.1	0.4	0.0	0.0	0.0	1.0	1.0
Vit B6 (mg)	0.1	0.2	0.1	0.1	0.3	0.2	0.2	0.2	0.1	0.2	0.1	0.3	0.3	0.2	0.2	0.2
Folate (µg)	29.0	43.1	29.0	20.4	30.6	25.3	45.5	45.9	16.0	32.2	16.0	30.9	32.0	25.3	71.0	71.0
Choline (mg)	278.8	409.9	278.8	1.3	2.5	0.0	426.6	427.2	32.6	236.1	32.6	0.8	2.5	0.0	230.4	230.3
Vit B12 (µg)	2.0	1.0	2.0	1.2	0.0	1.3	1.0	1.0	2.8	0.5	2.8	1.1	0.0	1.3	0.5	0.5
Vit C (mg)	0.1	0.3	0.1	2.0	0.9	2.2	0.6	0.6	0.0	0.0	0.0	2.2	0.9	2.2	0.4	0.4
Vit K (µg)	0.1	0.7	0.1	0.2	0.7	0.0	0.1	0.0	0.3	0.5	0.3	0.5	0.7	0.0	0.1	0.1
Caffeine (mg)	6.7	0.0	6.7	20.2	0.4	0.0	0.0	0.0	26.0	24.0	26.0	0.0	1.1	0.0	0.0	0.0

Figures in **red** do not meet the model constraints.

5 Discussion

Ingredients to formulate RUTF in Sierra Leone and that have been used in previous studies to treat SAM and MAM have been successfully identified. The possible combinations of local ingredients were tested and compared based on cost, nutritional content, and aflatoxin content. LP results show that all feasible combinations contained animal products (fish, eggs or both). Those that did not contain animal products did not achieve the constraints on omega 3 and 6, protein quality and quantity. Dairy products (powdered milk and whey protein) were not selected by the model, presumably because of their high cost *i.e.*, other ingredients could provide the nutrients at a lower cost.

5.1 Nutritional quality of PUFAs

A major constraint that caused unfeasible model results was the minimum level for n-3 PUFAs in the model. Omega 3 (n-3) and Omega 6 (n-6) are important nutrients for RUTF formulation [56]. In particular long chain PUFAs: docosahexaenoic acid (DHA, 22:6(n-3)), eicosapentaenoic acid (EPA) (20:5, n-3), and arachidonic acid (AA, 20:4(n-6)) have key roles in the development of the eye and brain and therefore are critical for child development and treatment of malnutrition. Those long chain-PUFAs can be synthesised from short chain-PUFAS, linoleic acid (LA, 18:2(n-6)) and alpha linoleic acid (ALA, 18:3(n-3)) [56] but not efficiently [57]. RUTF nutritional specifications do not include a differentiation between short and long chain n-3/n-6. Long chain-PUFAs are in only in low amounts in vegetables and therefore in RUTFs prepared only from plant foods according to Jones [56]. There are discussions about the composition of peanut fat that is mainly omega 6 and can help weight recovery but long chain-n-3 PUFAs - EPA and DHA are important for neurocognitive restauration [57,58] On the other hand, fish and fish oil are a good source of long chain PUFAs.

Fish is a major commodity in Sierra Leone and therefore an inexpensive RUTF from fish may work if fish could be sourced at an affordable price. Fish had been used as an ingredient in RUSF formulated for children in Cambodia[50] where fish is inexpensive. Fish powder could also be a possibility as it has been used in Sierra Leone in recipes for young children and pregnant and lactating women [12]. Fish oil that is high in long chain n-3 PUFAs has been used as been used in supplement to RUTF to treat severely malnourished children in rural Kenya [56].

5.2 Protein quality

Dried milk and whey protein were not selected by linear programming and this must be because of their cost relative to other sources of high-quality protein. Dried eggs were selected by linear programming in the 4 formulations that met the model's constraints. Dried eggs are a rich source of n-3/n-6 PUFAs as well as of high quality protein. Manary [59] described the importance of protein quality in the recovery of children from SAM and MAM. Children with SAM who were given egg protein recovered better than those who were fed with milk protein and children with MAM who were fed whey protein recovered better than those who were fed soya protein. Receiving sufficient amounts of aromatic amino-acids seems to be also critical for SAM recovery[59]. Quality of protein as well as quantity is important for recovery [58-61].

There are still debates on whether vegetable proteins would be sufficient to treat SAM. Dibari et al.[37], and Owino et al.[20] have developed milk-free RUTF formulas that contain soybean that has high quality protein plus n-3/n-6 PUFAs and met the WHO specifications. Bahwere et al.[62] demonstrated the "non-inferiority" of milk-free RUTFs enriched with crystalline amino acids compared to a standard formula with milk. One aspect is clear is that combining proteins from various foods is advantageous because it increases the overall protein quality of the mixture. [54]

5.3 Phytates

Anti-nutritional factors present in legumes and whole-grains (i.e. phytate, phenolic compounds, tannins, lectin, enzyme inhibitors, saponins, and oxalates) can reduce the bioavailability of minerals and amino-acids[39]. Phytate determination is important according to Dibari et al. 2012 [37] but was not included in Ryan et al.[11] however in the latter, phosphorus bioavailability was adjusted for plant foods by multiplying by 0.3. Brixi 2018 [47] introduced a constraint on phytate content in their model but the value is not given. Brixi stated that phytates are heat resistant but this statement is not correct. Studies have shown that phytates are reduced during typical processing such as soaking, fermentation, and cooking[63]. In addition, extrusion can reduce antinutrients with favourable effects on liberation of amino-acids and compounds of nutritional interest as shown in a review by Nikmaram et al. (2017) [39] and Boye et al[54]. The quantity of phytates in our formulations was less than that measured in a RUTF formulation by Owino et al. [20]. However, in both studies the phytate content of the RUTF formulations were within the acceptable limit [20] .

It should be noted that I quantified phytates in raw products, at their maximum phytate content, that would be further reduced during processing.

More research is needed to understand the effect of extrusion and other processes such as roasting specifically used in the formulation of RUTF, on decreasing anti-nutrients such as phytate and on improving the bioavailability of nutrients of interest such as amino-acids and minerals.

5.4 Prices

Literature reports that local RUTF formulations range between $US 0.04 [47] - 0.07 [37] (vegan formulations) and $US 0.104-0.145 [8,11] (formulations containing whey protein/milk and one at $US 0.119 containing dried fish). Our cheapest formulation was MP_0/ MP_2 –method 2 that contained dried fish ($US 0.125) and that is within this range. The other formulations were more expensive and this may be partially because of dried eggs.

The formulation from the market price (MP) was cheaper than the same formulation from producer's prices (PP). The difference may be due to calculation of dried eggs: the cost was estimated per unit for MP and then translated per 100g (because I did not know if the partners weighed the full product or only its edible part) but for PP, the cost had to be estimated per 100g (Appendices 5 & 6).

Dried eggs were a necessary ingredient in our formulations that do not contain soybean (flour or oil) or groundnuts (because of the aflatoxin limit). If the constraint on aflatoxin was removed and soybean was included, eggs may no longer be a necessary ingredient. Fresh eggs are an excellent source of source of protein, fatty acids, vitamins (i.e. vitamin A) and minerals however they are highly perishable. According to USAID-Feed the Future[64] powdered eggs could help enrich diets in sub-Saharan Africa. Making powdered eggs instead of fresh eggs could increase shelf life and facilitate transport, and hence make eggs more accessible to nutritionally-vulnerable populations. Because of the water content constraint (≤2.5%), eggs to be used in RUTF formulations would have to be dehydrated. Eggs are sprayed-dried using a similar technique to the one used for milk made into powder. The technology also is getting cheaper, partly because of the rise of Asian suppliers of spray dryers[65]. Sierra Leone is currently developing its poultry and egg sector[15,16] making powdered eggs a promising ingredient for a RUTF product. Understanding the cost of spray drying and market accessibility will therefore be an important step if powdered eggs were used in a local RUTF developed in Sierra Leone.

Some of the ingredients selected in this study were not initially dry (sweet potato, banana, eggs, coconut). The prices of those ingredients were calculated based on the estimated weight of the dried products from their initial water content in the fresh products (Appendices 5 and 6). Non-dried ingredients are not commonly selected for RUTF formulations and therefore I did not find clear guidance with regards to how to adjust food prices to account for the cost of drying the ingredients. In a real-case scenario, the cost of the dried ingredient would have to include the cost of processing.

5.5 Food safety: a major challenge for the development of locally-produced RUTFs

Food safety is a major challenge for the local production of RUTF in Sierra Leone. Aside the microbiological risks (that were not mentioned in this work but are indicated in the requirements for RUTF[19]), the risk of aflatoxin contamination, in particular in groundnuts, is a major concern [30] in Sierra Leone and other low-middle income countries[24-26,66] that face similar issues. Developing a product that contains little or no groundnut may be a way forward as shown in our results, however the 'vegan' formulation did not meet the nutritional requirements and alternative sources are animal sourced foods such as dairy, fish, and eggs that may be expensive. In addition, there are also safety concerns with the use of animal foods; for example early publications from the 50s and 70s showed that salmonella survived after spray drying of milk[67] and eggs[64] and those risks should be carefully considered if selecting these foods. Food safety is also a problem with fish, including contaminants such as mercury [52,68].

5.6 Limitations of the study

Our study has shown some limitations.

Ingredient costing: Obtaining accurate ingredient prices is a critical component of the linear programming analyses because the model is based on prices. The prices I obtained were mostly market prices that may be higher than prices obtained when buying ingredients in bulk. Moreover, the cost of processing was not included in the ingredient costs; processing may represent a significant proportion of the price. Understanding commodity value chain including transport, accessibility, fluctuations in prices due to seasonal variation, cost of processing, markets, will give a more accurate picture of the prices[69]. This will be proposed as a future study.

Moisture adjustment: The model required a moisture content of the mixture below 2.5%. Ingredients were sensitive to this moisture constraint. For example, I selected the lowest moisture content for dried fish found in literature (3.5%[52]) and this increased the use of fish in possible formulations. However, in reality, fish may vary in its moisture content and this will influence the selection of possible formulations.

Processing influence: In addition, processing (roasting, extrusion of ingredients) will have an influence on an ingredient's content of moisture and nutrients. Some nutrients such as vitamins are sensitive to heat, air oxidation etc [70]. A limitation of our model is that it did not account for such changes. Nonetheless a mineral and vitamin fortificant (premix) is added at the end of the processing stage and it will provide the majority of vitamins and minerals needed to meet RUTF specifications, since the unfortified RUTF cannot meet such requirements[45].

Nutritional composition: Another limitation of linear programming is that it is relying on food composition tables that may not reflect the actual nutrient content of local foods in the country[69]. Foods vary in their nutritional composition, which can be affected by the type of soil, climate conditions, storage etc. In our study, some of the food composition tables were from USDA (USA) in particular for n-3/n-6 PUFAs and amino-acids, and translating commodity unit size to 100g (Appendix 5) may induce some errors.

Aflatoxin: Furthermore, a limit to this study is that I accounted for the aflatoxin level in groundnuts but did not include other mycotoxins in other products including cassava and millet. Mycotoxins and aflatoxins can also be present in secondary products such as eggs and farmed fish[26,27]but the levels are lower and may be easier to control than with groundnuts.

Sensory acceptability: Finally, a limitation of this study is that linear programming is theoretical and there will be a need to conduct consumer hedonic testing to find out which formulations are acceptable in terms of their sensory properties in the local context. For example, the mixture of dried fish with cocoa and egg may not be very sensorially appealing.

6 Conclusions

A formulation using locally available ingredients in Sierra Leone was tested using linear programming to meet nutritional requirements for RUTF and also the aflatoxin limit.

The options proposed by linear programming include the use of dried eggs and fish. The formula with the cheapest ingredient cost was composed of cocoa, fish, millet, groundnut, palm oil, pigeon peas, rice and sugar (MP_0/ MP_2 –method 2) and this formula had a similar price to another formulation with fish[11] but a limit may be its sensory acceptability. Other formulations that had dried eggs were more expensive.

Limitations were that soybeans - that have high levels of n-3/n-6 PUFAs - are not produced locally, and the amount of groundnuts - that are rich in n-6 PUFAs - was restrained because of the aflatoxin limit set in the model.

Selected formulations will have to be adapted to the local context, and include considerations about availability, accessibility, and affordability of ingredients and processing technologies.

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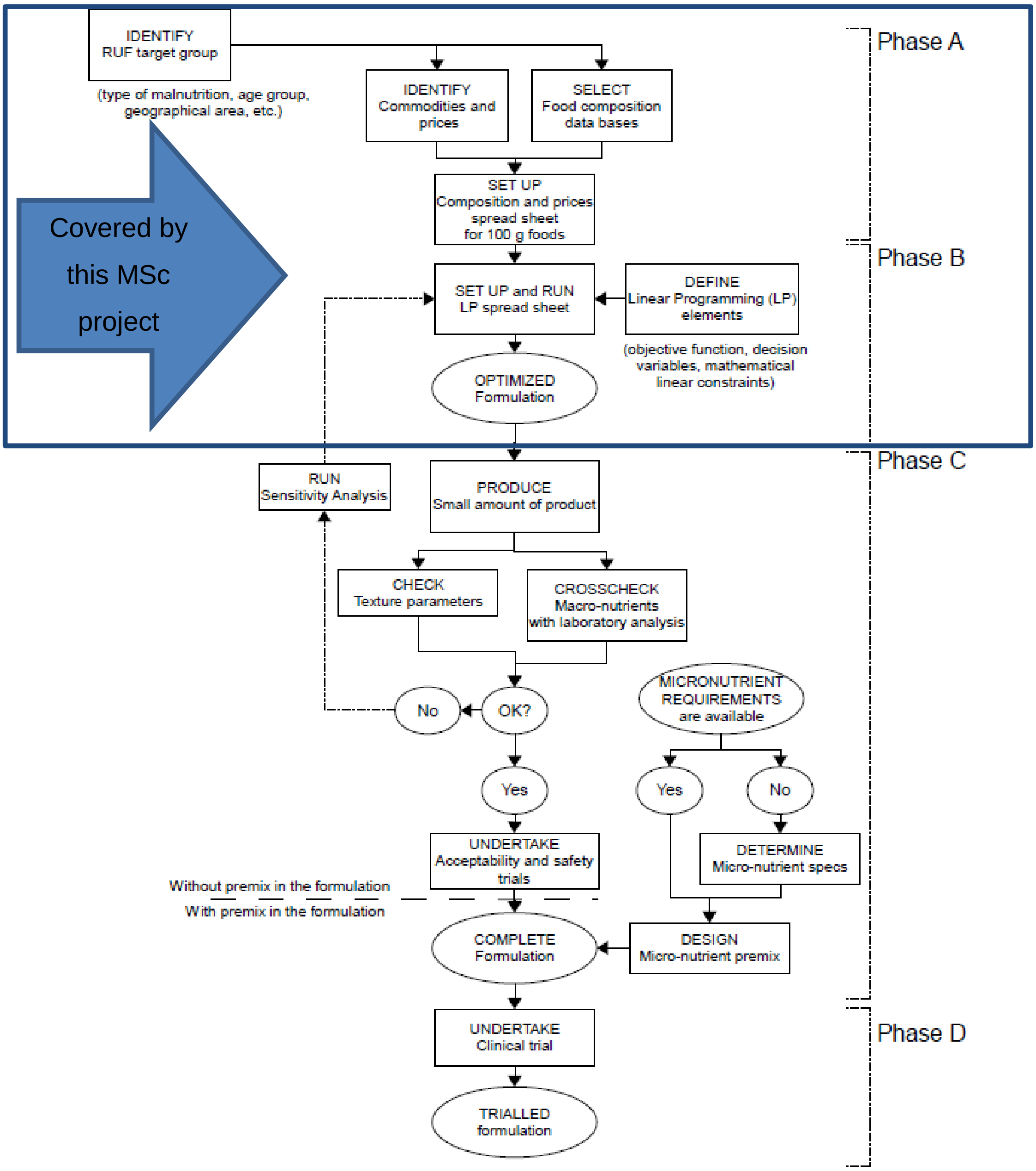
8 Appendices

Appendix 1. Initial list of ingredients based on Sierra Leone crop country production

Locally available Item	**Reference**	**Quantity (tonnes) (FAOStat)**
Cassava (for gari and flour)	FAOStat 2016/Hendrixson et al. 2018	4778393
Rice, paddy	FAOStat 2016/Hendrixson et al. 2018	1560363
~~Vegetables, fresh nes~~	~~FAOStat 2016~~	~~332172~~
Sweet potatoes	FAOStat 2016	311422
Oil palm fruit	FAOStat 2016	210537
~~Fruit, citrus nes~~	~~FAOStat 2016~~	~~107609~~
~~Fruit, fresh nes~~	~~FAOStat 2016~~	~~99064~~
Sugar cane	FAOStat 2016	77269
Groundnuts, with shell	FAOStat 2016	66083
Plantains and others	FAOStat 2016	46020
Millet	FAOStat 2016/Hendrixson et al. 2018	37633
Sorghum	FAOStat 2016/Hendrixson et al. 2018	29487
~~Coffee, green~~	~~FAOStat 2016~~	~~26824~~
~~Mangoes, mangosteens, guavas~~	~~FAOStat 2016~~	~~21731~~
~~Tomatoes~~	~~FAOStat 2016~~	~~20352~~
Cocoa, beans	FAOStat 2016	14714
Maize	FAOStat 2016/Hendrixson et al. 2018	12554
~~Fibre crops~~	~~FAOStat 2016~~	~~9543~~
~~Kola nuts~~	~~FAOStat 2016~~	~~8128~~
Coconuts	FAOStat 2016	4483
~~Chillies and peppers, dry~~	~~FAOStat 2016~~	~~3792~~
Peas, dry	FAOStat 2016	3511
Sesame seed	FAOStat 2016	3260
Taro (cocoyam)	FAOStat 2016	2414
~~Spices~~	~~FAOStat 2016~~	~~2017~~
Broad beans, horse beans, dry	FAOStat 2016/Hendrixson et al. 2018	1422
Bambara groundnut	Hendrixson et al. 2018	>500
Bulgur	Hendrixson et al. 2018	>500
Chickpea flour	Hendrixson et al. 2018	>500
Cous	Hendrixson et al. 2018	>500
Cowpeas	Hendrixson et al. 2018	>500
Melon seed	Hendrixson et al. 2018	>500
Oil, Soybean	Hendrixson et al. 2018	>500
Pigeon peas	Hendrixson et al. 2018	>500
Sugar brown	Hendrixson et al. 2018	>500
Sugar white	Hendrixson et al. 2018	>500
Wheat flour	Hendrixson et al. 2018	>500



Appendix 2. Design and validation method for novel RUF. Source: Dibari 2015 [38]

Appendix 3. List of ingredients communicated to the Sierra Leone prices and returned with market prices calculated per 100g (using a scale). Conversion rate: 1US$ = 9,082.30 SLL

Commodity	Local	Price in SLL/available measurement	Price in SLL/100g
Bambara groundnut	Not readily available	Not readily available	
Broad beans, horse beans, dry	yes	Le 4,000 per cup	Le 2,000
Bulgur	yes	Le 5,000 per cup	Le 3,500
Cassava flour, dried	yes	Le 2,000 per cup	Le 1,500
Cassava gari	yes	Le 5,000 per packet	Le1,000
Chickpea	imported	Le 25,000 per packet 453g (Imported)	Le 5,519
Cocoa, beans	yes	Le 15,000/ kg	Le 1,500
Coconuts	yes	Le 5,000 unit cost	Le 1,000
Cous	yes	Le 3,000 per cup	Le 1,500
Cowpeas	yes	Le 2,500 per cup	Le 1,25
Dried fish	yes	Le 10,000	Le 2,500
Dried milk (imported)	imported	Le 48,000(Imported)	Le 24,000
egg	yes	12 eggs(1 dozen)	Le 17,000
Groundnuts, with shell	yes	Le 3,500 per cup	Le 2,000
Kola nuts	yes	Le 1,000 unit cost/Le 35,000 for 50 pcs	Le 5,000
Maize, dried	yes	Le 2,000 per cup	Le 1,900
Melon seed	yes	Le 5,000 per cup	Le 3,500
Millet	yes	Le 3,000 per cup	Le 1,500
Oil, coconut	yes	Le 15,000 per pint	Le 4500
Oil, groundnut	Not readily available	Not readily available	
Oil, palm	yes	Le 3,500 per Pint	Le,1,000
Oil, palm kernel	yes	Le 2,000 per Pint/ Le 30,000 per Gallon	Le,1,000
Oil, Soybean	imported	(Imported)	
Palm kernels	yes	Le 5.000 per cup	Le 1,000
Peas, dry	To be check later	To be check later	
Pigeon peas	yes	Le 2,000 per cup	Le 1,000
Plantains and others	yes	Le 10,000 unit cost	Le 2,500
Rice, paddy	yes	Le 2,500 per cup (Local rice)	Le 1,000
Sesame seed	yes	Le 5,000 per cup	Le 1,750
Sorghum(flour)	imported	Le 32,000 for 1kg(Imported)	Le 3,200
Soybean flour	Not readily available	Not readily available	
Sugar brown	imported	Le 55,000 for 2kg(Imported)	Le 2,750
Sugar cane	yes	Le 2,000 unit cost	Le 600
Sugar white	imported	Le 2,500 per cup (Imported)	Le 1,000
Sunflower oil	imported	Le 95,000 (5L) Imported	Le 1,900
Sweet potatoes	yes	Le 5,000 per pile	Le 1,000
Taro (cocoyam)	yes	Le 5,000 per pile	Le 1,500
Wheat flour	yes	Le 2,000 per cup	Le 833
Whey protein (concentrate)	imported	Le 1,050,000 (Imported)	Le 47,727
Whole Wheat flour	yes	Le 35,000 per packet(1000g)	Le 3,500

Appendix 4. List of selected ingredients (n=22 *+ 2 additional*) and corresponding food composition databases

Ingredient	Locally produced in Sierra Leone	type of commo-dity	Myco-toxin risk	Source (Choice of ingredients)	Food composition databases	Complete wording on food composition databases (code) (Food Composition databases) *(nutrients)*
Broad beans, horse beans, dry	yes	pulse	yes	FAOStat [14]/Hendrixson et al.[35]	2. WA + UPulses1.0 + PhyFoodComp1.0 (INFOODS) + USDA	• Broad beans, dried, raw (item code 03-024) (WA database) *(macronutrients, minerals and vitamins)* • Broadbeans (fava beans), mature seeds, raw (code 16052) (USDA) *(n-3/n-6 fatty acids, sugar)* • Broad bean, mature, whole, dried, raw (code VIF001) (UPulses1.0) (*amino-acids*) • Broad bean, whole, raw (Ethiopia) (code 03010133) (PhyFoodComp1.0) *(phytates)*
Bulgur	yes	cereal	yes	Hendrixson et al.[35]	USDA + PhyFoodComp1.0 (INFOODS)	• Bulgur, dry (code 20012) (USDA) *(all nutrients)* • Bulgur, raw (code 01030089) (PhyFoodComp1.0) *(phytates)*
Cassava flour, dried	yes	root	yes	Hendrixson et al.[35]	3. WA + PhyFoodComp1.0 (INFOODS)	• Cassava flour (code 02_004) (WA database) *(macronutrients, minerals and vitamins)* • Cassava, raw*****(code 11134) (USDA database) *(n-3/n-6 fatty acids, sugar)* • Cassava flour, Kello, dried (code 02020001) (PhyFoodComp1.0) *(phytates)*
Cocoa, beans	yes	seed/nut	yes	FAOStat [14]	4. USDA + PhyFoodComp1.0 (INFOODS)	• Cocoa, dry powder, unsweetened (code 19165) (USDA) *(all nutrients)* • Cocoa powder, industrial (Nigeria, brand 3#) (code 13030004) (PhyFoodComp1.0) *(phytates)*
Coconuts	yes	seed/nut	yes	FAOStat [14]	5. WA + PhyFoodComp1.0 (INFOODS) + USDA	• Coconut, kernel, dried, raw (code 06_005) (WA) *(macronutrients, minerals and vitamins)* • Nuts, coconut meat, dried (desiccated), not sweetened (code 12108) (USDA) *(n-3/n-6 fatty acids, sugar)*
Cowpeas (also called black eyed pea)	yes	pulse	yes	Hendrixson et al.[35]	WA + UPulses1.0 + PhyFoodComp1.0 (INFOODS) + USDA	• Cowpea, dried, raw (code 03_004) (WA) (macronutrients, minerals and vitamins) • Cowpeas, common (blackeyes, crowder, southern), mature seeds, raw (code 16062)(USDA) *(n-3/n-6 fatty acids, sugar)* • Cowpea, mature, whole, dried, raw (code VUN001) (UPulses1.0) (*amino-acids*) • Cowpea, 12 AK, raw (Nigeria) (code 03010283) (PhyFoodComp1.0) *(phytates)*
Dried egg	yes	animal food	yes	Newspaper articles [15,16]	USDA	• Egg, whole, dried (code 01133) (USDA) *(all nutrients)*
Dried fish	yes	animal food	yes	World Fish Sierra Leone 2016[12]	USDA	• Fish, whitefish, dried (Alaska Native) ** (code 35165) (USDA) *(all nutrients)*

Ingredient	Locally produced in Sierra Leone	type of commo-dity	Myco-toxin risk	Source (Choice of ingredients)	Food composition databases	Complete wording on food composition databases (code) (Food Composition databases) *(nutrients)*
Dried milk, skimmed	no (imported)	dairy	limited	Hendrixson et al.[35]	WA + PhyFoodComp1.0 (INFOODS)	• Milk, cow powder, skimmed (code 10_017) (WA) *(macronutrients, minerals and vitamins)* • Milk, dry, nonfat, calcium reduced (code 01093) (USDA) *(amino-acids, n-3/n-6 fatty acids, sugar***)*
Groundnuts	yes	pulse	yes	FAOStat [14]	WA + PhyFoodComp1.0 (INFOODS) + USDA	• Groundnut flour, with fat (code 06_027) (WA) *(macronutrients, minerals and vitamins)* • Peanuts, all types, dry-roasted, without salt (USDA) (code 16390) *(all nutrients) (n-3/n-6 fatty acids, sugar)* • Groundnut flour (Malawi) (code 06010070) (PhyFoodComp1.0) *(phytates)*
Maize, dried - whole grain	yes	cereal	yes	Hendrixson et al.[35]	USDA database	• Corn flour, whole-grain, yellow (code 20016) (USDA) *(all nutrients)* • Maize, yellow, seed, milled, raw (Nigeria) (01020142) (PhyFoodComp1.0) *(phytates)*
Millet	yes	cereal	yes	FAOStat [14]/Hendrixson et al.[35]	WA + PhyFoodComp1.0 (INFOODS) + USDA	• Pearl millet, flour (without bran) (code 01_063) (WA) *(macronutrients, minerals and vitamins)* • Millet flour (code 20647) (USDA) • Pearl millet flour, Ashana, whole seed (Sudan) (code 01050135) (PhyFoodComp1.0) *(phytates)*
Oil, Coconut	yes	seed/nut	yes	FBDGs Sierra Leone[17]	WA + USDA	• Oil, coconut (code 11_002) (WA) (macronutrients, minerals and vitamins) • Oil, coconut (code 04047) (USDA) *(n-3/n-6 fatty acids)*
Oil, palm	yes	oil	yes	FAOStat [14]	WA + PhyFoodComp1.0 (INFOODS) + USDA	• Palm oil, refined (WA) (code 11_007) (macronutrients, minerals and vitamins) • Oil, palm (USDA) (code 04055) (n-3/n-6 fatty acids) • Palm kernel oil, edible (code 12020001) (PhyFoodComp1.0) *(phytates)*
Pigeon peas	yes	pulse	yes	Hendrixson et al.[35]	WA + PhyFoodComp1.0 (INFOODS) + USDA	• Pigeon pea, dried, raw (code 03_032) (WA) *(macronutrients, minerals and vitamins)* • Pigeon peas (red gram), mature seeds, raw (USDA) (code 16101)*(n-3/n-6 fatty acids),* , Jack Rabbit, pigeon peas (code 45029574) *(sugar)* • Pigeon pea, raw (Malawi) (code 03010627) (PhyFoodComp1.0) *(phytates)*
Plantains and others	yes	root	yes	FAOStat [14]	USDA + PhyFoodComp1.0	• Bananas, dehydrated, or banana powder (code 09041) (USDA) *(all nutrients)* • Banana, raw* (PhyFoodComp1.0) *(phytates)*
Rice	yes	cereal	yes	FAOStat [14]/Hendrixson et al.[35]	WA + PhyFoodComp1.0 (INFOODS) + USDA	• Rice, red native, hulled, raw (code 01_065) (WA) (*macronutrients, minerals and vitamins*) • Wild rice, raw (code 20088) (USDA) (*n-3/n-6 fatty acids, sugar*) • Rice, brown, raw (India) (code 01010097) (PhyFoodComp1.0) (*phytates*)
Sesame seed	yes	seed/nut	yes	FAOStat [14]	WA + PhyFoodComp1.0	• Sesame seeds, whole, dried, raw (code 06_015) (WA) (*macronutrients, minerals and vitamins*)

Ingredient	Locally produced in Sierra Leone	type of commo-dity	Myco-toxin risk	Source (Choice of ingredients)	Food composition databases	Complete wording on food composition databases (code) (Food Composition databases) *(nutrients)*
					(INFOODS) + USDA	• Seeds, sesame seeds, whole, dried (code 12023) (USDA) (*n-3/n-6 fatty acids, sugar*) • Sesame seed, grown inorganic, raw (India) (code 06010161)(PhyFoodComp1.0) (*phytates*)
Sorghum - whole	yes but flour was imported	cereal	yes	FAOStat [14]/Hendrixson et al.[35]	USDA + PhyFoodComp1.0 (INFOODS)	• Sorghum flour, whole-grain (code 20648) (USDA) • Sorghum flour, Karamaka, whole grain, dried (Sudan) (code 01040013)(PhyFoodComp1.0) (*phytates*)
Sugar white	yes	sugar	no	FAOStat [14]/Hendrixson et al.[35]	WA + PhyFoodComp1.0 (INFOODS) + USDA	• Sugar (code 13_002) (WA) • Sugars, powdered (code 19336) USDA) *(all nutrients)* • Refined cane sugar (code 14050002) (PhyFoodComp1.0) (*phytates*)
Sweet potatoes	yes	root	yes	FAOStat [14]	USDA + PhyFoodComp1.0 databases	• Sweet potato, raw, unprepared (Includes foods for USDA's Food Distribution Program) (code 11507) (USDA) *(all nutrients)* Dried-matter adjusted for flour ***** • Sweet potato, brown skin, raw (code 02010044) (PhyFoodComp1.0) (*phytates*)
Whey protein	no (imported)	dairy	limited	Hendrixson et al.[35]	USDA database	• Whey, acid, dried (code 01113) (USDA) *(all nutrients)*
Groundnuts	yes	pulse	yes	FAOStat [14]	WA + PhyFoodComp1.0 (INFOODS) + USDA	• Groundnut paste (code 06_026) (WA) *(macronutrients, minerals and vitamins)* • Peanut butter reduced sodium (USDA) (code 42291) *(all nutrients) (n-3/n-6 fatty acids, sugar)* • Peanut butter (code 06010128) (PhyFoodComp1.0) *(phytates)*
Soybean oil	yes	oil	limited	Hendrixson et al.[35]	WA + PhyFoodComp1.0 (INFOODS) + USDA	• Soya oil (WA) (code 11_009) (*macronutrients, minerals and vitamins*) • Oil, soybean, salad or cooking (USDA) (code 04044) (*n-3/n-6 fatty acids*) • *Not included* (PhyFoodComp1.0) *(phytates)* •

I intended to obtain equivalent ingredients for the various databases but this was not always achievable. For banana, sweet potato flour, the raw foods equivalents were selected because there were no values for flour. For some of the ingredients (e.g. whey protein, dried egg, dried fish), the nutritional composition was entirely from USDA. For 'plantains and others', there was no food composition of plantain flour, and I therefore selected banana flour. Also some complete nutritional compositions of ingredients were difficult to find (e.g. sweet potato flour) and a compromise was to adjust the nutritional composition of sweet potato flour based on fresh sweet potato composition. This was based on the assumption that macronutrients would not vary in the dried sweet potato as well as minerals [71,72]. I checked that the values of sugar and fibre were comprised into the range for sweet potato flour [73]. In practice, during drying, sugars would increase and linoleic acid (n-6 fatty acid) and linolenic acids would tend to decrease as well as provitamin A [74]. The majority of sweet potato cultivars found in sub-Saharan Africa are white-fleshed (containing very low content of provitamin A) [75] therefore I did not include the retinol equivalent. For cassava flour, amino-acids, sugar, and n-3/n-6 PUFAs were obtained from raw cassava and this was also a compromise because fatty acids would decrease during drying. However n-3/n-6 PUFAs were not present or in undetectable quantities in raw cassava. Sierra Leone is an important fish producer according to the World Fish report [12]. Although there were many types of fish described in the WA database, dried fish was not included. I could not extrapolate the food composition of dried fish based on fresh fish because of the complex changes in nutrients (i.e. amino-acids, sugar, and n-3/n-6 PUFAs) that would occur during the drying of fish. I therefore selected a whitefish because whitefish (i.e. cat fish) is common in Sierra Leone [12].

Appendix 5. Calculation of prices for dried edible quantities for banana, eggs, coconut, and groundnuts with shell. Conversion rate: 1US$ = 9,082.30 SLL. Prices are market prices.

Fresh Commodity	USDA reference	Size of the unit	Edible weight per unit (g)	Water /100g	Dry weight (g)	Unit cost (SLL)	Unit cost ($US)	Cost ($US)/100 g dried product
Coconuts	code 12104, Nuts, coconut meat, raw	-	45	47.0	23.9	5000	0.5505	2.3078
Eggs	code 01123, Egg, whole, raw, fresh	large	50	76.2	11.9	17000/12*	0.1560	1.3080
Bananas (for plantains & others)	code 09040, Bananas, raw	medium	118	74.9	29.6	2500	0.2753	0.9297
Sweet potatoes	code 11507, Sweet potato, raw, unprepared	-	130	77.2	29.6	1000	0.1101	0.3715
Groundnuts, with shell **	NA	NA	80	NA	NA	2000	0.2202	0.2753

*sold by packs of 12 eggs.** shell weight is about 20%.

Appendix 6. Calculation of prices for dried edible quantities for banana, eggs, coconut, and groundnuts with shell. Prices are producers' prices from FAOStat

Fresh Commodity	USDA reference	Edible conversion factor (WA database*)	water /100g	Dry weight (g /100g of fresh product)	Cost per 100g of fresh	Cost ($US)/100g dried product
Coconuts	code 12104, Nuts, coconut meat, raw	0.3	47.0	15.9	0.075	0.4729
Eggs	code 01123, Egg, whole, raw, fresh	0.81	76.2	19.3	0.450	2.3313
Bananas (for plantains & others)	code 09040, Bananas, raw	0.64	74.9	16.1	0.121	0.7513
Sweet potatoes	code 11507, Sweet potato, raw, unprepared	0.84	77.2	19.2	0.080	0.4154

*West Africa Database (INFOODS)

Appendix 7. List of producers' prices for ingredients available in FAOStat

Locally available Item	Has to be made into:	2016 Quantity (t) (FAOStat)	2013 Productor's Price ($US/t) FAOStat)	2014 Productor's Price ($US/t) FAOStat)	2015 Productor's Price ($US/t) FAOStat)	average price (2013-15) ($US/t)	average price (2013-2015) ($US/100g FAOStat)
Broad beans, horse beans, dry	Broad bean flour	1422	1814.6	2252.1	2835.4	2301	0.230
Cassava	Cassava flour	4778393	426.8	521.1	545.1	498	0.050
Coconuts	Coconut powder	4483	695.7	759.1	801.5	752	0.075
Eggs, hen, in shell	Dried egg flour	NA	4743.8	4637.6	4129.5	4504	0.450
Maize	Maize flour	12554	1321.4	1208.9	1108.9	1213	0.121
Oil, palm	Oil, palm	61000	936.5	912.9	860.1	903	0.090
Plantains and others	Banana flour	46020	1302.3	1222.3	1094.7	1206	0.121
Rice, paddy	Rice flour	1560363	738.6	707.3	629.8	692	0.069
Sesame seed	Sesame seed flour	3260	2332.3	2554.6	2603.7	2497	0.250
Sugar cane*	Sugar cane	77269	23.3	23.3		23	0.002
Sweet potatoes	Sweet potato flour	311422	805.5	822.7	758.4	796	0.080

***There were no prices for Sierra Leone. I used the price from the neighbouring country Mali**