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Nutrition in Central Uganda

An Estimation of a Minimum Cost Healthy Diet

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Abstract:

This study makes use of linear programming methodology to design a minimum cost diet for the Central Ugandan region. We used a set of constraints on recommended levels of daily nutrient intake, recommended proportions of groups of foods, as well as preferences and food availability in Central Uganda, to design a minimum cost healthy daily diet. Several models were considered, each forcing at least one of the following frequently consumed staple foods: matooke, cassava, and rice. We found that the minimum costs of the optimal diets were lowest in the planting season of March and highest in the harvesting season of December.

Key words:

Central Uganda, minimum cost diet, malnutrition, linear programming.

I. Introduction and Problem Statement

Uganda is a well endowed country with natural resources such as fertile soils and regular rainfall augmented by moderate temperatures. These resources place Uganda strategically for the production of a variety of tropical food crops. Therefore, agriculture is the most important sector of the Ugandan economy. Most of the farming is rain-fed and the sector is dominated by small scale subsistence farmers whose land holdings average 2 hectares (MAAIF 2009, p3.). The total arable land is approximated to be 28.3% of the total land. However, significant variations exist between the southern and the northern parts of the country. The south receives rainfall throughout the year while the north is affected by a long dry spell towards the last months of the year. The country also produces animal products from both poultry and live stock. In addition, the presence of the fresh water resources such as lakes and rivers enables production of large quantities of different kinds of fish (Uganda food and nutrition policy 2003). Generally, Uganda can be categorized as being a food self sufficient country (Kikafunda et al. 2010).

However, being a country of geographical and cultural diversity, Uganda has a multiplicity of food traditions. According to the Constitution of Uganda (1995) there are over 50 ethnic groups that are recognized (p. 186-191). Each of these groups has a special staple food and a special way in as which it is prepared. Generally, this variety of food culture can be identified with four broad regions in the country as Eastern, Western, Northern, and Central Uganda. The diversity in food culture is partly attributable to the differences in the geographical and climatic conditions in the different regions. Indeed, the geographical and cultural diversity pose a major constraint on the kinds of foods available and acceptable to people in the different regions. The geography limits the growth of some food to specific regions, while culture has a direct or indirect impact on the food and nutritional security, through the principles they impose on the way land is used, the

right to use the land, ways of preparing food and what is consumed (Byaruhanga and Opedun 2008, p.55-58). For example, matooke cannot grow in the northern region because of the unimodal rainfall pattern in the region. Culturally, matooke (steamed green banana) is the traditional staple food in the Central region, millet (small seeded grain) in the Western, posho (maize meal) in the Northern and sweet potatoes in the Eastern region (Byaruhanga and Opedun 2008, p.55-58). However, it is not uncommon to find a typical household in any of the mentioned regions having different kinds of foods for a meal although the traditional staple is always included as an important part of the meal.

Because different foodstuffs have different nutrient compositions, the geographical and cultural ties limit the level of nutrients people derive from their diets. Moreover, Uganda faces problems with malnutrition and hunger. The Uganda food and nutrition policy (2003) reports that malnutrition is responsible for 40% of the deaths among children, stunted growth in 38% of children below 5 years old, and underweight of 22.5% of children in the same age range (p.3). This prevalence of malnutrition is attributed to micronutrient deficiencies such as Vitamin A, iron, and iodine. Deficiencies are reported with frequencies of occurrence estimated at 5.4% for vitamin A and 50% for iron (Uganda Food and Nutrition policy 2003, p3).

Potts and Nagujja (2007) report that in 1999, the total goiter rate for children between 6 and 11 years old stood at 58%, with higher rates for highland areas (p.2). In addition, 50% of young women (15-49 years) were reported to have Iron Deficiency Anaemia (IDA) to which 30 % of maternal deaths were attributed (Potts and Nagujja 2007 p.2; WHO prevalence data 1998). According to the WHO (1993-2005), children had severe anaemia with a prevalence rate of 64.1%, pregnant women had moderate anaemia of 41.2%, while non-pregnant women had comparatively low anaemia of 28.8% (p.24, 29, 39). The authors also report that Vitamin A deficiency is

more prevalent in rural areas and that the country is more likely to spend an estimate of 2.5 billion USD due to untreated illnesses resulting from VAD and 382 million USD due to lost productivity of women with anaemia (Potts and Nagujja, p.3).

With the impacts of malnutrition already identified in Uganda such as maternal deaths, child mortality, goiter prevalence and stunted growth, there is enough evidence of the need to develop a solution. In addressing this problem, current literature (Potts et al. 2007; Odongo et al.) focuses on bio-fortification of the food crops with the deficient nutrients. This study on the other hand is an attempt to provide a different kind of response. Thus, we focus on seeking to provide a minimum cost diet for Central Ugandans while considering a number of factors such as nutritional recommendations, cultural and geographical diversity, and food availability. Hence, this study will ideally solve the problem of malnutrition through designing a healthy, well-balanced diet which also considers cultural and food availability constraints.

II. Overview of Uganda

Uganda is among the poorest countries of the world with a GDP per capita PPP estimated at $1,210, lower than the Sub Saharan countries average (IMF 2009). The country has a total population of 33.8 million people of which 35% is below the poverty line (HDR 2010 p.186; World Fact book 2010). Over the last decade, Uganda has seen its GDP increase significantly. The GDP grew on average 5.6% from 2000 to 2005 and 7.18% in 2009 (IMF 2009). Uganda ranked the 143rd out of 179 countries using the Human Development Index (HDR 2010, p.186).

Agriculture is the most important sector of the Ugandan economy and it contributes about 22.5% of GDP and employs about 82% of the population (World Fact book 2010). The country produces a variety of crops which range from main staples, pulses, vegetables, and fruits. The major

traditional food staples are: matooke, cassava, potatoes (*Ipomoea and solanum*), corn, millet, and sorghum (Haggblade 2010, p.2). A report by the World Food Program (2009) reveal the common pulses as being beans, peas, groundnuts, simsim, and sunflower (p.96). In the same way, Aliguma and Nyoro (2004) report that the most commonly available fruits are: passion, citrus, apple bananas, avocadoes, guava, mangoes and papaya (p. 4). Most of the vegetables grown are categorized as indigenous and the common ones include: nakati (*Amaranthus aethiopicum*), tomatoes (*Lycoperscum esculentum*), green doodo (*Amaranthus dubius*), and other *Amaranthus ssp* (Rubaihayo et al. 2003).

III. Methodology

In this study, we made use of Mathematical Linear Programming to solve for the constrained minimization problem. The software used for the purpose of this study was the General Algebraic Modeling System (GAMS). As previously mentioned, the objective of the study is to minimize the cost of a daily diet, under a set of constraints. Three sets of constraints were considered: nutritional level constraints, balanced diet constraints, and preferences constraints. The nutritional level constraints include a set of constraints that force the optimal diet to meet the minimum recommended daily intake of important nutrients. The balanced diet constraints include a set of constraints that force the optimal diet to include a variety of foods, including: grains, vegetables, fruits, meats and beans, as well as dairy products, in a certain recommended proportion. Finally, the preference constraints include a set of constraints that force the optimal diet to reflect the preferences of the Central Ugandan people. Hence the model is as follows:

$$Minimize\ C = \sum_{i=1}^{i=76} p_i x_i,$$

where Cost is denoted by *C*, prices of food items are denoted by p, quantities of food items are denoted by x and the *i*'s represent the number of different food items.

Subject to:

1. Nutritional Level Constraints: $Nutrient_a \leqq \sum_{i=1}^{i=76} a_i x_i$

where a indicates the level of a certain nutrient on a certain food item x.

2. Balanced Diet Constraints: $m * \sum_{i=j}^{i=k} x_i - n * \sum_{i=b}^{i=d} x_i = 0$

where m and n indicate the ratios to which certain foods or groups of foods (such as grains and vegetables) are to be consumed.

3. Preferences Constraints: $\sum_{i=j}^{i=k} x_i \geq y\,; \quad \sum_{i=j}^{i=k} x_i \leq z$

where a certain food item x (or group of food items) is to be consumed to at least a certain level y, or no more than a certain level z.

In order to solve our constrained minimization problem, the next step was to obtain the corresponding numerical values to be replaced for the variables in the objective function as well as equations 1, 2, and 3 described above. The data needed for this model included food prices, nutritional composition of a set of food products for the various forms of preparation, information on the recommendations of the nutritionists on what composes a balanced daily diet, as well as information on food preferences of the Central Ugandan people.

IV. Data Description and Resources

i. Food prices

The currency used in Uganda is called "Ugandan shilling" and is abbreviated as UGX. While the currency is constantly fluctuating with respect to the USD, it is currently exchanged at 1UGX = 0.0004USD. The food prices collected were reported in UGX. The main source of food price information in several markets in Central Uganda is INFOTRADE (also known as, FIT Uganda LTD). The INFOTRADE database collects prices on selected food items for all regions of Uganda from a set of representative markets, on a weekly basis. For Central Uganda those markets include: Kalerwe, Kiboga, Luwero, Masaka, Nakawa, Nakasero, and Owino. Since the prices of certain seasonal crops may vary throughout the year, we collected prices for three different seasons: planting season, harvest season, and lean season. There are two planting seasons in Uganda, one of which generally takes place in the month of March and the second in the month of September. We decided to use the food prices from the month of March to represent the planting season. Thus, the food prices for the planting season are the average food prices in the seven aforementioned markets in Central Uganda across two different dates (March 4, 2009 and March 11, 2009). The first harvest season generally takes place in the month of June whereas the second harvest season takes place in the month of December. Between the first harvest and the second planting season, the lean season is considered to be the month of August. Hence, the food prices for the lean season are the average food prices in the seven Central Ugandan markets across two different dates (August 3, 2009 and August 12, 2009). Finally, we considered the second harvesting season which takes place in the month of December for the purpose of obtaining price information on harvesting season. Thus, the food prices for the harvesting season are the average food

prices in the seven Central Ugandan markets across two different dates (December 4, 2009 and December 12, 2009).

While INFOTRADE database is a valuable source of Ugandan food price information, there are several food items, important for the Ugandan people's daily diet, for which price information is not available on this database. Hence, after considering several different options (such as using the food prices of the neighboring countries) we considered simply gathering the price information through a survey of the retailers in the corresponding markets. The retailers were asked on food price information (only for the food items for which INFOTRADE lacked price information) for all the different seasons described above. We preferred this methodology despite its weaknesses (namely, the survey was not carried out directly by the authors of this study, but by a Master's student in Uganda; further, the retailers were asked for the average prices at a given season rather than at a given date) because in contrary to Uganda, the neighboring countries are food importers (often from Uganda) and hence their prices are possibly much higher than those in Uganda. For a detailed list of the food price information obtained by INFOTRADE versus the food price information obtained by the Retailers' Survey, please refer to Table 6 in Appendix 1.

ii. Nutritional Composition

The next important set of information for the project consists of information on the nutritional composition of food items in the several ways of preparation. Currently, there is no comprehensive database with the nutritional composition of the food items consumed in Uganda specifically (Baingana 2004, p.501). The most comprehensive database in terms of nutrients as well as the variety of food items included that we managed to have access to, was the USDA database called "HealtheTech SR Search." The Diet Organizer is an interactive software which uses this USDA

database. This software's primary purpose is to provide information about the nutrient composition of food items consumed in the United States. However, Central Ugandan average food preferences differ from those in the U.S., and not all the food items consumed in Central Uganda were listed in this database. Hence, for food items for which information on their nutritional composition was not available on the Diet Organizer software, we used alternative sources of information. Specifically, we used three comprehensive studies titled "Tanzania Food Composition Tables" (Lukmanji et al. 2008), "Development of Mechanisms for Sustainable Production and Utilization of Indigenous Vegetables and Management of their Genetic diversity in Uganda" (Rubaihayo et al. 2003), and "Phytoevaluation of the nutritional values of ten green leafy vegetables in South -Western Nigeria" (Olaiya and Adebisi 2010). For a detailed list of the specific source of nutrient composition information for each of the food items please refer to Table 7 in Appendix 1. Finally, it is worth noting that while we gathered information on a wide variety of nutrients, not all nutrients found on food items are part of this model. The nutrients to be included were chosen out of the nutrients that the Diet Organizer reports, for simplicity purposes.

The National Academy of Sciences, Institute of Medicine – Food and Nutrition Board, report the recommended levels of daily nutrient intake by gender and age. In this study, we considered the group of females of the age bracket 19-70 and obtained their corresponding level of recommended daily nutrient intake. This decision was motivated by the general health concerns for Ugandan females that were described in the introductory section. Both lower and higher limits were obtained, although the higher limits were in many cases not defined. In the case that the aforementioned DRI table lacked information about the recommended levels of certain nutrients, alternative sources of information were used, such as: Self Nutrition Data website and Supplement Quality website.

iii. Balanced Diet

An ideal diet is not only healthy and cheap, but also well balanced. The USDA Food and Nutrition Service provides valuable information on what a well-balanced diet composes of. The widely acknowledged pyramid system suggested by nutritionist, recommends that the daily nutrient be taken from all of the following types of food groups: grains, vegetables, fruits, meat and beans, and milk; all in certain proportions. Hence, according to the USDA nutritionists, on a 2200 calorie diet (which is the closest to the level obtained in our models) for each nine servings of grains, a person should consume three servings of fruits, four servings of vegetables, two servings of meats and beans, and two to three servings of milk. Following these suggestions therefore, our model includes the set of balanced diet constraints described in the previous section.

iv. Food preferences

Finally, an optimal diet that is healthy, affordable and well-balanced is worth nothing if people do not prefer it. Hence, our model considers the preferences of the Central Ugandan people at least to some degree. On a WFP, food security analysis for Uganda, certain staple foods were identified to be consumed most frequently in the Central Ugandan region. Those include: cassava, matooke, potatoes, and rice (WFP, 2009, p.54). Thus, we modified our model several times to include at least a certain level, usually 200 – 500g of at least one of the staple foods mentioned. Whenever the diet resulted with a high level of other food items because of these restrictions on staple foods, we added additional constraints based on our best knowledge of what levels are reasonable for consumption of other non-staple food items.

V. Mathematical Programming Model

As previously mentioned, prices for all food items were gathered for three different seasons. However, for the purpose of our study, we chose to work primarily with the prices of the planting seasons (March 2009). The study can easily be replicated for the other two seasons by simply changing the set of prices used. Thus, the cost minimization equation in our model is defined as follows:

$$
\begin{aligned}
Cost = {} & 484.1154 * beef_{100gr} + 565.3846 * goat\ meat_{100\ gr} + 423.6364 * pork_{100gr} + 734.6154 \\
& * chicken_{100gr} + 95.5513 * egg_1 + 1{,}261.5830 * corn_{100gr} + 148.4615 * yellow\ beans_{100\ gr} \\
& + 119.4444 * white\ beans_{100\ gr} + 140.7692 * red\ beans_{100\ gr} + 199.2308 * cowpeas_{100gr} \\
& + 196.1538 * rice_{100\ gr} + 100 * doodo_{100gr} + 100 * bugga_{100\ gr} + 150 * nakati_{100\ gr} + 250 \\
& * cabbage_{100\ gr} + 120 * eggplant_{100gr} + 126.1583 * maize_{100gr} + 1500 * bananas_{1000gr} \\
& + 44.5385 * matooke_{100gr} + 160 * plantain_{100gr} + 60.3846 * cassava_{100gr} + 61.5385 \\
& * sweet\ potatoes_{100gr} + 71.6923 * Irish\ potatoes_{100gr} + 180 * mangoes_{100gr} + 150 \\
& * orange\ juice_{1000ml} + 150 * oranges_{100gr} + 200 * jackfruit_{100gr} + 1{,}000 * avocados_{100gr} \\
& + 1{,}500 * tangerine\ juice_{1000ml} + 1{,}400 * lemon\ juice_{1000ml} + 1{,}400 * lemons_{100gr} + 1{,}200 \\
& * pineapples_{1000gr} + 800 * guavas_{1000gr} + 90 * papaya_{100gr} + 200 * tomatoes_{100gr} + 200 \\
& * green\ peppers_{100gr} + 140 * carrots_{100gr} + 150 * pumpkin_{100gr} + 130 * watermelon_{100gr} \\
& + 120 * eggplants_{100gr} + 120 * onions_{100gr} + 460 * tilapia_{100gr} + 50 * mukene_{100gr} \\
& + 74.6154 * whole\ milk_{100gr}
\end{aligned}
$$

We ran several models in an attempt to find the best optimal diet. For the basic model, which we called the Naïve Model, we constrained the objective function with only the nutritional level constraints. Hence, as we will see, the resulting diet is not that realistic although its cost is the lowest. In the remaining three models, we added the balanced-diet constraints as well as preference constraints. Since cassava, matooke, sweet potatoes and rice are the most frequently con-

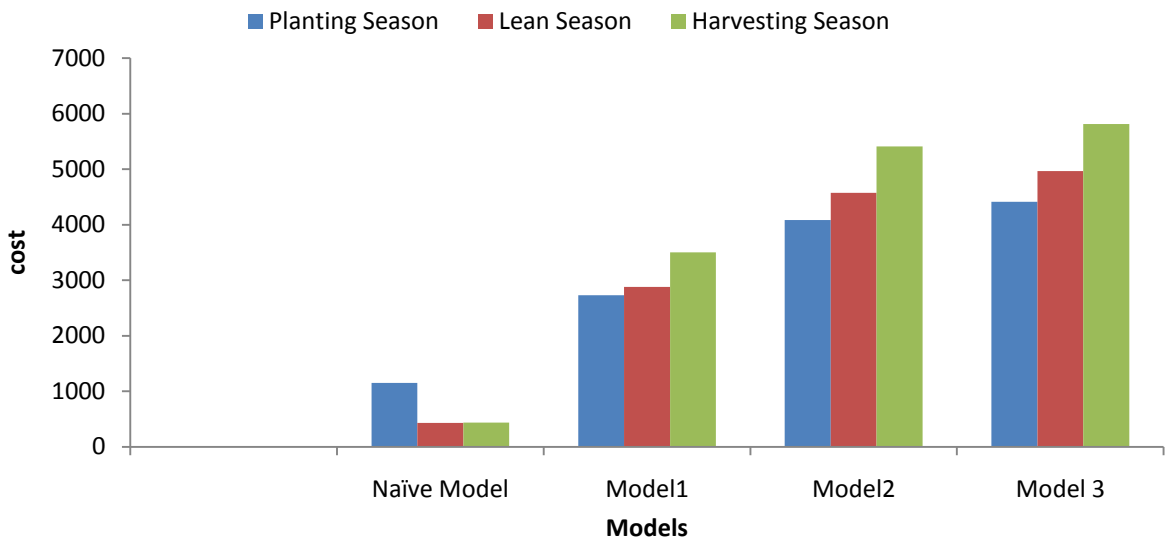
sumed staple foods in Central Uganda, we forced each of them (except for sweet potatoes) in turn in our models. Sweet potato consumption was not forced because they always entered the model, most likely because of their cheap price and high nutrition. Hence, in Model 1, we forced the diet to include at least 200g of matooke; in Model 2 we forced the diet to include at least 400g of cassava; and, in Model 3 we forced the diet to include at least 300g of rice. In all cases, the models picked on sweet potatoes and guavas in high quantities. Hence, we added other constraints to limit sweet potatoes and guavas to at most 500g (or 200g) and 100g respectively. The resulting diets had varying costs across seasons. Table 1 below gives the costs in Ugandan Shilling (UGX) for each of the diets depicted by the aforementioned models, across seasons. All three seasons are included for comparison purposes, however, only the Planting Season prices are considered for the rest of the estimations.

Table 1: Minimum Cost for Diets at Different Seasons in Uganda

Objective function	Naïve Model	Model 1	Model 2	Model 3
Planting Season (March)	1149.729	2730.627	4081.124	4412.611
Lean Season (August)	428.7368	2881.918	4575.691	4967.010
Harvesting Season (December)	435.0823	3504.130	5408.349	5815.406

Thus, in ascending order, the cheapest is the Naïve Model diet, followed by the Model 1 diet containing matooke, Model 2 diet containing cassava, and Model 3 diet containing rice. It is also interesting to note that the cost of each diet is lowest during the planting season (month of March), and highest during the harvesting season (month of December).Figure 1 below gives a graphical representation of the cost results discussed.

Figure 1: Minimum Cost Values for Different Seasons in Uganda



The prices reflect the diversity and amount of food depicted by each model. From here forth we concentrate on the planting season. Table 2 below shows the variety and quantity of foods depicted by each model. The Naïve Model is not realistic because it suggests that a person should consume approximately 1.5 kg of sweet potatoes and approximately 400 g of pork each day. While it also includes some cassava, mukene and milk in small quantities, it is far from reflecting a Central Ugandan daily diet. The remaining three models however, reflect a diversity of foods, including staple foods that are most frequently consumed in the region. For a graphical representation of the differences between the Naïve Model diet (which does not include a variety of foods) and Model 1, 2, and 3 diets (which include a variety of foods following the recommended proportions of grains, vegetables, fruits, meats and beans, and milk) please refer to Appendix 2.

.

Table 2: Food Combinations for all Models

Food Components	Naïve Model	Model 1	Model 2	Model 3
Pan-fried pork (100g)	3.993	0.000484	0.000539	1.87E05
Exotic fried chicken (100g)	-	-	0.074	-
White beans boiled with salt (100g)	-	1.457	1.225	1.273
Super rice cooked (100g)	-			3
Matooke cooked (100g)	-	2		-
Cooked plantain (100g)	-	-	1.722	-
Boiled Cassava (100g)	-	-	4	2.604
Fried Cassava (100g)	0.014	-		-
Sweets potato Steamed without skin (100g)	15.191	5	2	2
Irish potato boiled without skin without salt(100g)	-	3.296	-	-
Deep fried potato chips (100g)	-	0.135	-	-
Raw mangoes (100g)	-	2.71	2.474	2.435
Avocado raw (100g)	-	0.733	2.413	2.611
Guava raw (1,000g)	-	0.1	0.1	0.1
Pumpkin boiled drained without salt (100g)	-	3.014	1.019	0.769
Fresh Mukene (silver fish) (100g)	0.862	0.417	0.417	0.417
Whole milk (100g)	2.289	1.874	1.716	1.69

In addition to including a variety of foods, Models 1, 2, and 3 diets included certain proportions of the different groups of foods. Table 3 shows the proportions of each group of foods consumed in each one of the four diets measured in 100g.

Table 3: Food Group Composition for all Models

Group of Food	Naive model	Model 1	Model 2	Model 3
Grains and starch	15.205	8.431	7.722	7.604
Vegetables	-	3.747	3.432	3.380
Fruit	-	2.810	2.574	2.535
Beans and Meats	0.863	1.874	1.716	1.690
Milk	2.289	1.874	1.716	1.690

Notice that the proportion of the grains, vegetables, fruits, meats and beans, as well as milk in Models 1, 2 and 3, is exactly the same, namely 45% grains, 20% vegetables, 15% fruits, 10% meats and beans, and 10% milk (although there are slight differences in quantities). However, the Naïve Model includes mainly grains, with some meat and milk, but with no fruits and vegetables. For a graphic representation of these results, please refer to Figure 6 in Appendix 2.

Based on our set of nutritional composition constraints, all diets include 2,500 calories or less and at least the minimum recommended level of each nutrient. Please refer to Table 5 for the specific quantities of each nutrient contained in the diets of the Naïve Model, and Models 1, 2 and 3.

Table 4: Diet Nutrient Composition for all Models

Nutrients	Minimum recom-mended level	Naïve model	Model 1	Model 2	Model 3
Sodium	1300	48677.198	24131.363	23956.527	23920.629
potassium	4700	4700	4700	4700	4700
Carbohydrates	130	356.958	407.328	394.211	379.814
Fiber	21	38.024	50.071	47.481	43.38
Protein	46	99.981	94.428	85.94	89.559
Vitamin A	2334	1.14E+07	5.47E+06	5.42E+06	5.41E+06
Vitamin C	75	19877.538	16554.853	15265.4	14981.523
Calcium	1000	43880.6	22097.392	21888.436	21863.838
Iron	8	787.65	389.373	387.752	388.975
Vitamin D	5	10.348	5	5	5
Vitamin E	15	15	15	15	15
Thiamin	1.1	2.255	2.102	1.664	2.021
Riboflavin	1.1	2.844	3.185	2.942	2.699
Niacin	14	14	16.706	14	15.332
Vitamin B6	1.3	3.992	3.707	3.376	2.859
nnFolate	400	400	515.662	525.454	513.103
Vitamin B12	2.4	8.387	6.548	6.415	5.95
Pantothenic Acid	5	14.489	12	10.29	10.798
Phosphorus	700	1.99E+05	97133.133	97048.732	96999.153
Magnesium	320	74612.45	36387.457	36289.846	36259.048
Zinc	8	355.545	242.057	177.291	178.158
Selenium	55	55	55	55	55
Copper	0.9	1.704	2.995	2.617	2.611
Manganese	1.8	4.665	3.73	2.297	3.68
Fats	65	65	65	76.151	76.617
Saturated Fats	20	38.887	36.18	34.976	34.841
Polyunsaturated fats	-	3.654	4.501	7.37	7.513
Monounsaturated fats	-	18.849	19.737	28.179	28.98
Cholesterol	300	28450.73	13745.877	13746.223	13746.282
Sugars	-	174.57	164.32	157.747	131.342
Calories	-	2391.307	2500	2500	2500

Disregarding the Naïve Model, the optimal diets depicted by Models 1, 2 and 3 are equally reasonable. In fact, Models 1, 2 and 3 vary little in terms of food composition and nutrition; al-

though they vary in price to a greater extent. Hence all three can be considered best solutions to our problem. This would offer Central Ugandan people more options to diversity both in terms of day to day consumption variety as well as in terms of cost.

VI. Conclusion

While this study offers a valuable perspective of how Linear Programming can be used in solving dietary and health related issues, it does have a few limitations. There are data limitations as well as limitations to our results. The data limitations come from the usage of a U.S. food database (The Diet Organizer Software) in order to obtain the nutritional composition of the food items. However in some cases the crops grown in the U.S. or for the U.S. market are bio-fortified with certain nutrient, in contrast to Uganda, where the food crops are not bio-fortified. Further, the soil, climate, use of fertilizers - all these factors that influence the nutritional composition of a crop - differ in the U.S. compared to Uganda. Hence, once a database with the nutritional composition of crops grown in Uganda becomes available, that information could be used to replicate our study in order to compare and contrast the results.

In this study, there are also limitations with respect to the nutrients considered. In other words, there are micronutrients that were not considered in our model, because they were not reported in the data sources that we used. This is another area of potential future research. Finally, there are limitations to our results in all four models. While our models meet the minimum recommended daily intakes of all the nutrients considered, in some cases the levels by far exceed the upper limits of recommended nutrient intake. Whenever the higher levels of recommended daily intake of those nutrients where imposed to the models, the solutions would become infeasible. Hence, our

decision to do without those constraints resulted with optimal diets consisting of concerning high levels of the following nutrients: Cholesterol, Sodium, Carbohydrates, Vitamin A, Vitamin C, Calcium, Iron, Phosphorus, Magnesium, and Zinc. Likely, this is related to the fact that we used a U.S. food database to obtain their nutritional composition, as explained above. This is in particular a weakness to our models since as mentioned in the introduction of this study, there is reported deficiency of Vitamin A and Iron in Uganda. Hence, further investigation with regard to these nutrients is needed.

Future research in this area, in addition to addressing the above mentioned limitations, can also focus in extending the application of this model to other nations and regions. Further, investigating the health related issues, diet preferences, religious restrictions, and income levels or a narrower group of people, and applying the same methodology in designing an appropriate diet to meet their specific needs, would be an interesting extension to this study.

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Appendix 1

Table 6: Food Crops Groups According to Source of Price Information

Source 1 (UGX)	Source 2 (UGX)
Beef	Nakati
Cassava	Green paper
Bananas	Doodo
Local Chicken	Bugga
Exotic	Katumkuma
Black eye peas	Tomatoes
Yellow bean	Eggplants
White beans	Pumpkins
Red beans	Mangoes
Exotic eggs/tray of 30	Oranges
Local eggs	Passion fruits
Nile fish	Jackfruit
Tilapia	Lemons
Goat meat	Tangerines
Ground nuts	Guava
Irish potatoes	Onions
maize flour	Carrots
matoke	water melon
Milk cow	Bananas (bogoya)
Pine apple	Plantain (gonja)
Pork	sweet bananas (sukari Ndiizi)
Rice kaiso	Avocadoes
Super rice	Pawpaw
upland rice	Mukene
Simsim	
Sweet potatoes	

Note: Source 1 includes food items whose prices were obtained from the INFOTRADE database (FIT Uganda LTD).

Source 2 includes food items whose prices were obtained from the survey of retailers.

Table 7: Food Items Categorized According to Source of Nutrition Composition

Source 1	Source 2	Source 3
Beef	Corn	Green Doodo
Goat meat	Bananas (bogoya)	Bugga
Pork	Matooke	Nakati
Local Chicken	Plantain (gonja)	
Exotic Chicken	Cassava	
Corn	Irish Potatoes	
Beans	Jackfruit	
Cowpea	Milk	
Cabbage	Tilapia	
Eggplants	Mukene	
Sweet potatoes	Cassava	
Mangoes	Simsim	
Avocadoes		
Tangerines		
Lemon		
Pine apple		
Guava		
Tomatoes		
Onions		
Green peppers		
Papaya		
Bananas		
Carrots		
Pumpkin		
Water melon		

Note: Source 1 includes food Items whose nutrient compositions were obtained from the Data Organizer software, Source 2 include food items from the Tanzania Food Nutrition Table, and Source 3 include food items for which the nutrient composition were obtained from Olaiya and Adebisi (2010) as well as Rubaihayo et al. (2003).

Appendix 2

Figure 2: Naïve Model Plate

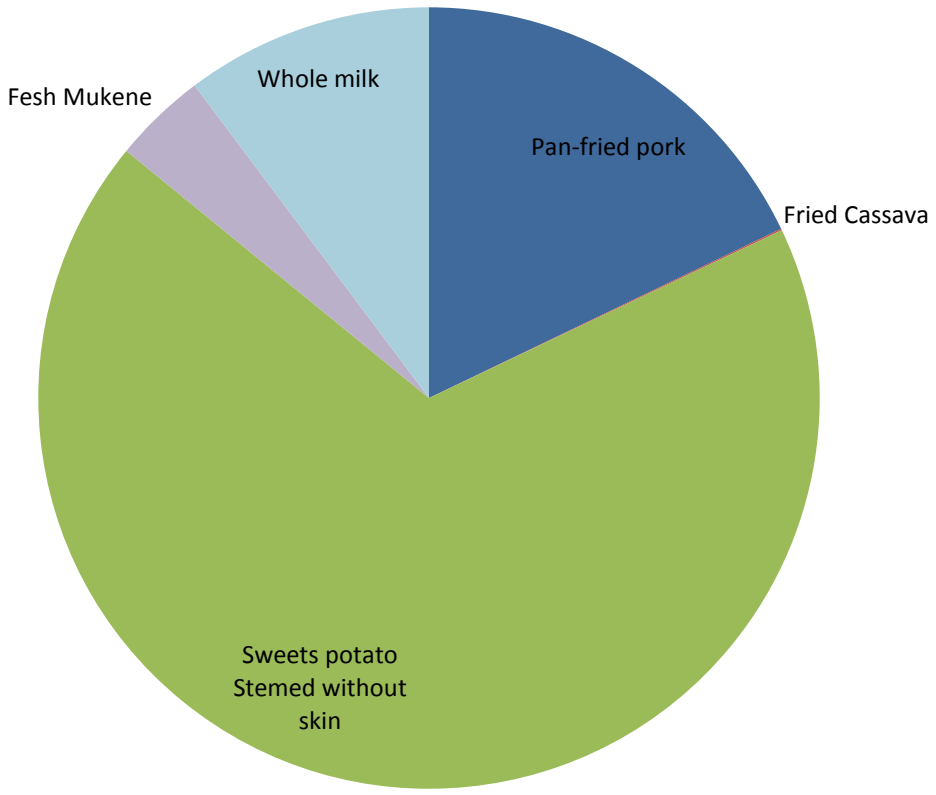


Figure 3: Model 1 Plate

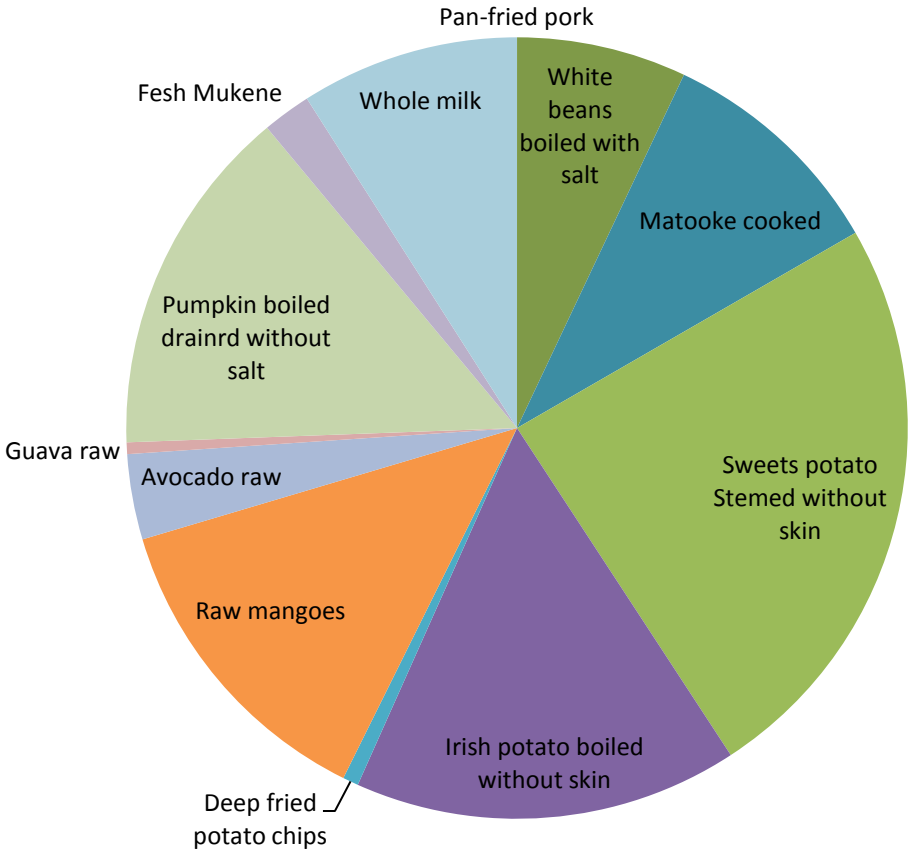


Figure 4: Model 2 Plate

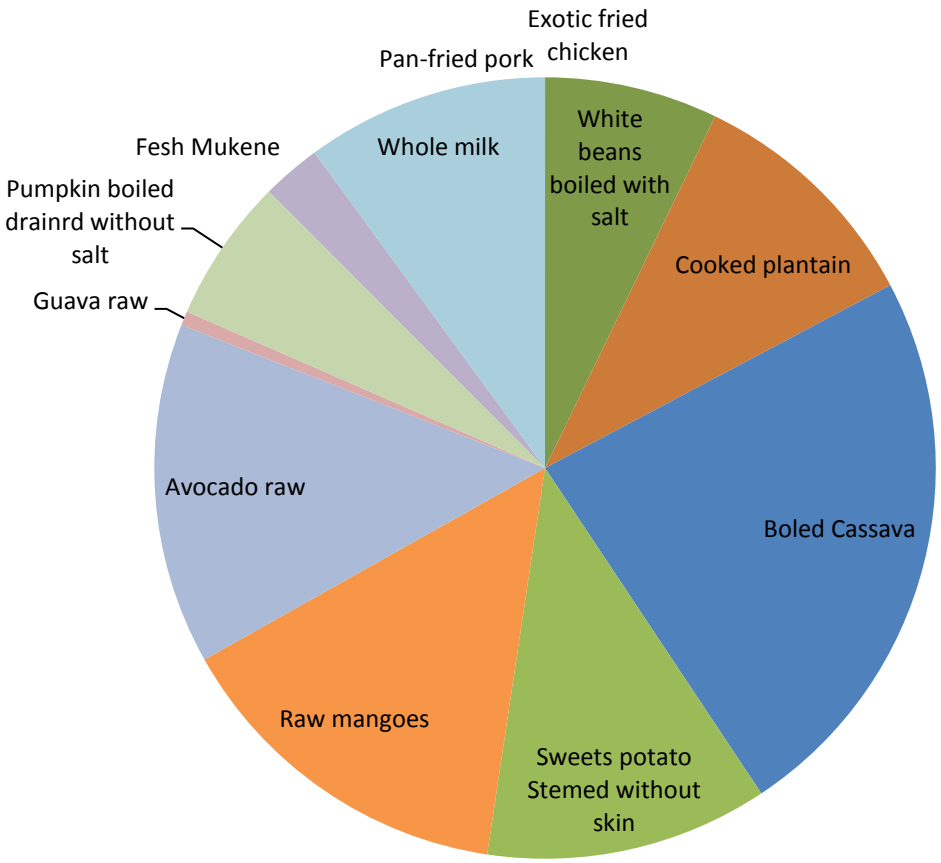


Figure 5: Model 3 Plate

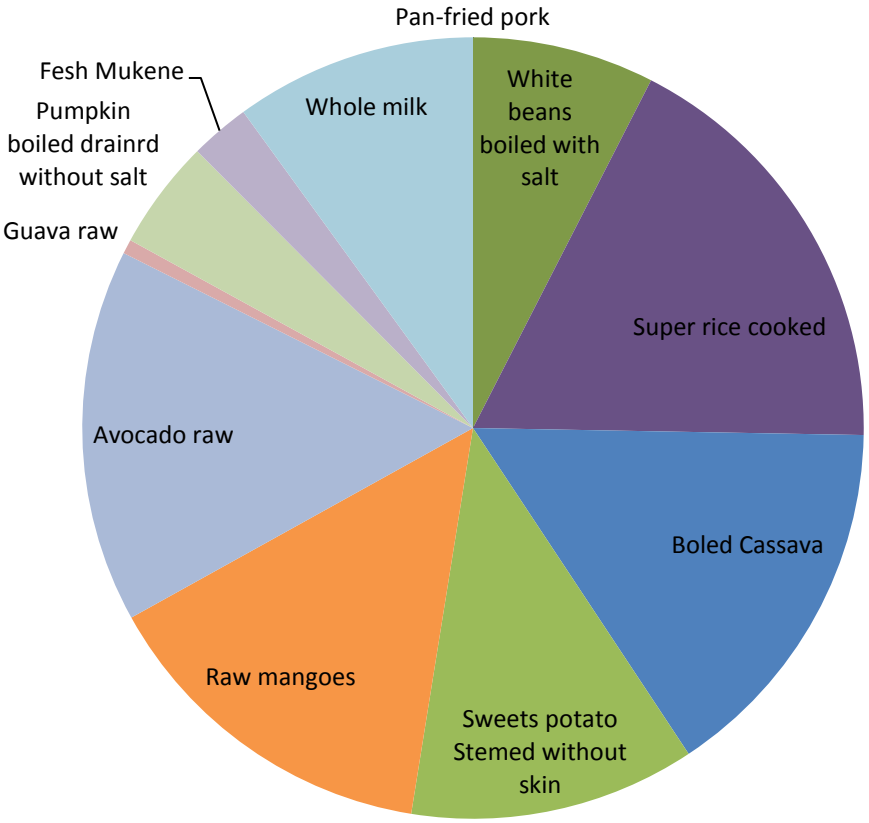
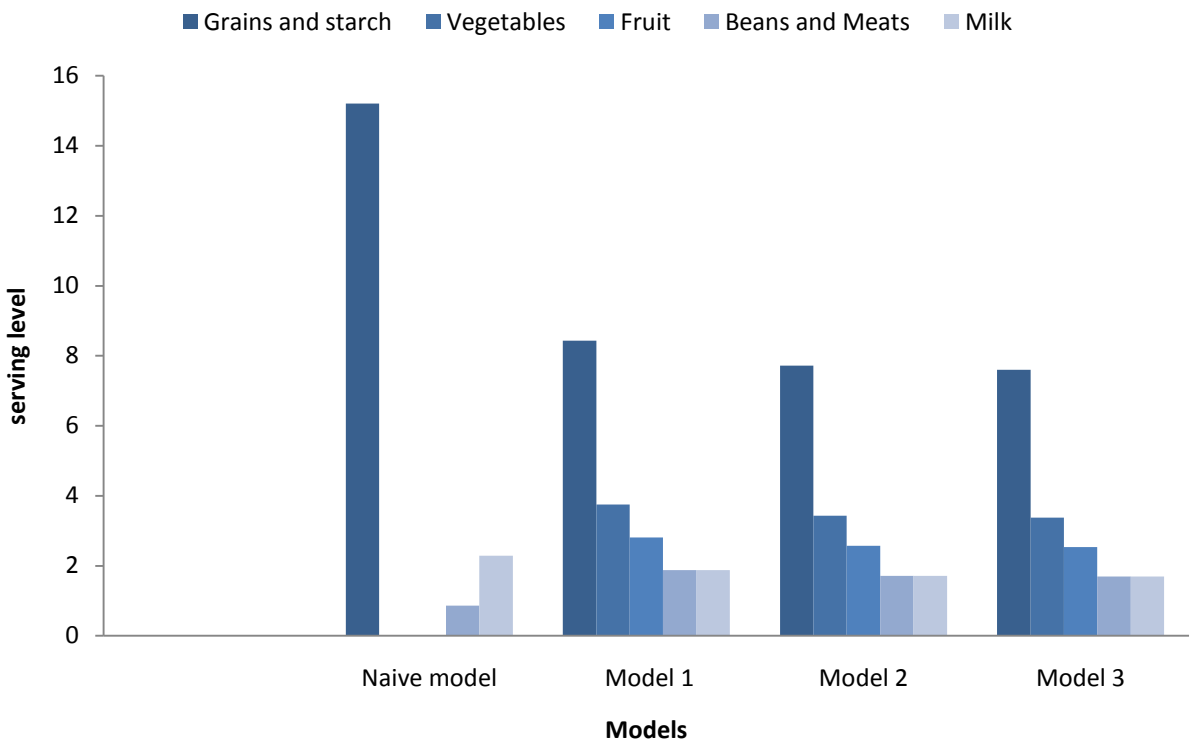


Figure 6: Representation of Food Group Composition by Model



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