Food Preservation Techniques for Rural Ethiopia

Formulation of Complementary Flour (Brief)

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1. Introduction

Diets in low-income countries like Ethiopia are characterized as being monotonous and predominantly cereal-based[1]. Consumption of vegetables, fruits, and animal-source foods remains very low, leading to micronutrient deficiencies and poor health outcomes like increased risk of chronic diseases[2,3]. The perishability of these foods discourages their consumption, particularly in areas of the world where cold chain is not readily available[4]. The limited local demand for the consumption of these foods also discourages the production of these foods, decreasing their supply and availability, increasing their cost, and making them even more unaffordable[5].

Increasing the consumption of nutrient-dense foods like fruits, vegetables, and animal-source foods in settings like rural Ethiopia requires more than educating communities about the nutritional and health benefits. Deliberate efforts are needed to address consumer concerns about perishability and food safety[6].

Supporting caregivers with optimally formulated recipes that consider the availability, accessibility, and affordability of foods in their community is critical to ensure optimal complementary feeding at the critical period of 6-23 months of the child’s age.

Therefore, this series of studies aims to understand the role of household drying techniques on the nutritional value, food safety, and shelf life of vegetable and animal-source foods. This brief presents findings from the study’s focus on formulating a complementary flour by considering the availability and affordability of ingredients.

2. Methodology

2.1 Developing Formulation Using Linear Programming (LP)

Linear programming (LP) is a mathematical technique used to minimize or maximize a linear objective function subject to a set of constraints. Many objective functions can be chosen, for example, meeting nutrient requirements, minimizing cost, or maximizing the proportion of local ingredients used. The objective of the linear programming is to generate an optimal formulation that meet several constraints to formulate the best possible cereal-legume mix flour that can meet nutrient needs from complementary foods.

2.2 Constraints and Decision Variables

2.2.1 Constraints

The constraints considered in setting-up the linear programming (LP) optimization are:

- Nutrient targets
- Available ingredients
- Food prices

2.2.2 Decision Variables

The linear programming will optimize the amount of each ingredient (cereal, legumes, and other available ingredients) to be included in the complementary flour mix.

2.2.3 Objective Function

The objective function of the linear programming is to minimize the cost of the cereal-legume mix, while meeting requirements of as many nutrients as possible.

2.2.4 Nutrient Targets

In this study, a LP tool was configured to choose ingredient weights to minimize the total cost per 50g unit of complementary food mix, while meeting a set of WHO nutrient requirements (Lutter & Dewey)[7]. The ingredients choice was based on a list of available ingredients identified by World Vision. Additional quality considerations (e.g. susceptibility to aflatoxin) of the ingredients were made in deciding about which ingredient should be included. The linear programming first used food composition data to optimize the formulation. Three alternative formulations were developed. In such formulation exercises, it is often the case that not all nutrient requirements can be met, and some nutrients would become 'problem nutrients.' Problem nutrients are nutrients whose targets are difficult to meet and would ultimately require fortification or the inclusion of more expensive ingredients. When faced with such events, the model constraints were relaxed to meet as many nutrients as possible. The nutrient constraints described by Lutter & Dewey[7] were considered but the list was limited to those for which composition data was available.

2.2.5 Testing of Formulated Complementary Flour

The formulated complementary flour mix was prepared at the laboratory of the center for food science and nutrition (Addis Ababa University) and was tested for processing quality, functional properties, and nutritional composition. A sensory test was conducted by semi-trained panelists to identify the most acceptable formulation among the alternatives.

2.2.6 Confirmatory Food Analyses

Proximate Analyses: The proximate analyses were conducted as per the AOAC protocol[10].

Moisture: Moisture content was determined by drying in an oven to constant weight.

Protein: Protein was determined by Kjeldahl method based on nitrogen determination (N*6.25).

Fat: Crude fat was determined using Soxhlet method.

Carbohydrate: Carbohydrate content was analyzed by difference:- Carbohydrate (%) = 100- (% crude protein+% Moisture +% total ash+ % crude fat).

Energy: Total energy in calories was calculated by applying the Atwater conversion factor of 4, 9, and 4 for each gram of protein, lipid and carbohydrate, respectively.

Mineral Composition: Iron, Zinc, Calcium: The minerals (iron, zinc and calcium) were analyzed by flame atomic absorption spectrophotometer after wet digestion using the AOAC11 official method.

Vitamin A and Vitamin C Analyses: Vitamin A (total carotenoids) and vitamin C were measured using spectrophotometric analyses as described in AOAC 974.29 and AOAC 967.21, respectively.

2.2.7 Functional Properties

Water Absorption Capacity: Water absorption or hydration capacity of the complementary flour was determined as described by Onwuka[12].

Water Solubility Index: Water solubility index was determined through the method described in Jin et al.[13].

Bulk Density: The bulk density was determined through the method described by Jinnapong et al.[14]

2.2.8 Recipe Development

A recipe that provides the best consistency was developed. The consistency was measured using observational methods such as spoon cohesiveness and drip test.

2.2.9 Sensory Analyses

The sensory acceptability and preference were measured by employing a 9- point hedonic scale: (1) Dislike extremely, (2) Dislike very much, (3) Dislike moderately, (4) Dislike slightly, (5) neither like or dislike (6) Like slightly, (7) Like moderately, (8) Like very much, (9) Like extremely. Panelists were instructed to rate the three alternative formulations for their taste, odor, texture, appearance, and overall acceptability. The panelists were semi-trained panelists from Addis Ababa.

***Eligibility Criteria:** Willing to participate in the study, no allergies, not having flu or any other condition that could affect taste and smell.

***Panelists Demographics:** Ages 20-40; all panelists (n=20) were experienced in the procedures involved in sensory evaluations; were students in the College of Natural and Computational Sciences.

3. Results

The price and list of available ingredients, assessed by World Vision are annexed to this report. Through an iterative process, a set of formulations was developed. A key finding is that for the complementary food to meet nutritional targets, it needed supplementation with animal-source foods (e.g., milk). Among cereals, the incorporation of teff in the mix help fill nutrient gaps, but teff was also among the most expensive cereal available in the market. Putting a price, nutritional and portion size constraints at a time did not allow the model to provide an optimal solution. Consequently, we run models relaxing price and portion size constraints. The formulations and their composition are presented in the following table.

Figure 1: Picture shows pre-processed ingredients used for formulation.

Table 1: Composition of the formulations obtained using linear programming

Type	Composition
Formulation 1	**Cereal + legume (37 g):** 35% red teff; 27% dehulled wheat; 38% dehulled chickpea+ **Milk (121 g fresh/16 g powder)** Portion= 53 g
Formulation 2	**Cereal + legume (39 g)**: 26% de-hulled maize, 26% de-hulled wheat, 13% de-hulled chickpea, 36% red roasted teff + **Milk (118 g fresh/ 15.3 g powder)** Portion= 52 g
Formulation 3	**Cereal + legume (37 g):** 27% de-hulled white sorghum, 14% de-hulled wheat, 27% de-hulled chickpea, 32 % of roasted teff Milk (100 g fresh/ 13 g powder) Portion= 50 g
Additional ingredients, common for all three (can be added during preparation)	**Iodized salt (**0.6 g**)** **Soyabean** (1.85 g) **and palm** (3.34 g) **oil**
Without milk formulation	Requires $CaCO_3$ (0.23 g) + premix

The three formulations were analyzed to check whether their nutrient content was in line with the calculated values; chickpea can be replaced with roasted, de-hulled field pea.

Table 2: Nutrient composition (/100 g) of the formulations (laboratory results) relative to WHO requirements

Nutrient composition	*Formulation 1*	*Formulation 2*	*Formulation 3*	*WHO requirements*
Moisture (%)	12.4	11.1	10.8	--
Ash (g)	3.6	3.7	3.7	--
Fiber (g)	1.92	1.89	2.03	< 5
Energy (kcal)	479.8	475.4	478.2	440
Protein (g)	21.2	19.6	19.4	6-11
Fat (g)	19.5	19.2	19.4	12.7
Carbohydrate (g)	37.0	37.0	37.0	--
*Iron (mg)**	63.1	8.8	8.5	14
*Zinc (mg)**	3.5	3.3	3.4	8.3
Calcium (gm)	565.8	558.4	563.2	200-400
Vitamin A (µg RA)¥	92	90	84	250
Vitamin C (mg)	2.51	2.50	2.20	140-180

*Below WHO requirement, ¥ with Vitamin A fortified oil

The water absorption capacity indicates how much water a certain amount of complementary food flour can absorb and retain. Higher values suggest a flour that can incorporate more water, which may affect the texture and consistency of the prepared food. Formulations 1 and 3 have almost identical WAC, both slightly higher than Formulation 2, indicating they may yield slightly moister or more cohesive products upon hydration. The small standard deviations indicate relatively consistent performance within each formulation.

The water solubility index measures the fraction of the material that is soluble in water. Higher values indicate greater solubility. The WSI values are quite close across all formulations, suggesting that there are minor differences in solubility among them. This parameter affects the clarity and thickness of solutions made with the flour and could influence the digestibility and bioavailability of nutrients. The relatively low and similar values across formulations suggest that the flours have low solubility in water, which is typical for many types of flour used in complementary food formulations.

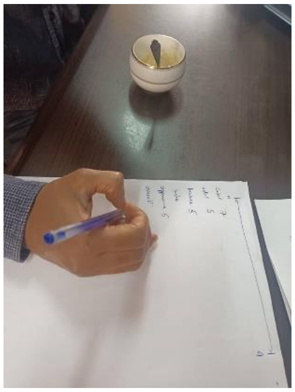
Table 3 Functional property of the complementary flour formulations

Type	Water Absorption Capacity	Water Solubility Index	Bulk Density
Formulation 1	99.17±5.07	1.11±0.48	1.24±0.02
Formulation 2	98.19±5.01	1.10±0.46	1.20±0.02
Formulation 3	99.14±5.06	1.09±0.47	1.21±0.02

Bulk density relates to the weight of the flour per unit volume and can influence packaging, portion size, and texture of the food product. A lower bulk density might be preferable for lighter, more aerated products. Formulation 2 has the lowest bulk density, suggesting it might produce a slightly lighter product than Formulations 1 and 3. However, the differences are minor, as indicated by the close values and small standard deviations.

Table 4: Sensory evaluation of the three formulations

Out of 9	*Formulation 1*	*Formulation 2*	*Formulation 3*
Color	6.5	6.5	6.9
Taste	6.4	6.4	6.9
Odor	6.5	6.3	6.6
Flavor	6.6	6.3	6.5
Appearance	6.5	6.3	6.9
Texture	6.0	5.9	7.0
Overall acceptability	**7.0**	**7.0**	**7.5**



Preparation Conditions

A trial was conducted to determine the right mix of water and flour to have an appropriate dry matter of the prepared complementary food. Cooking 20g of flour in 120 ml of hot water yielded a porridge with a dry matter of 14.4 g dry matter per 100 g. The consistency of the porridge was good as it led to a viscosity of 83 s-1 at 45*C.

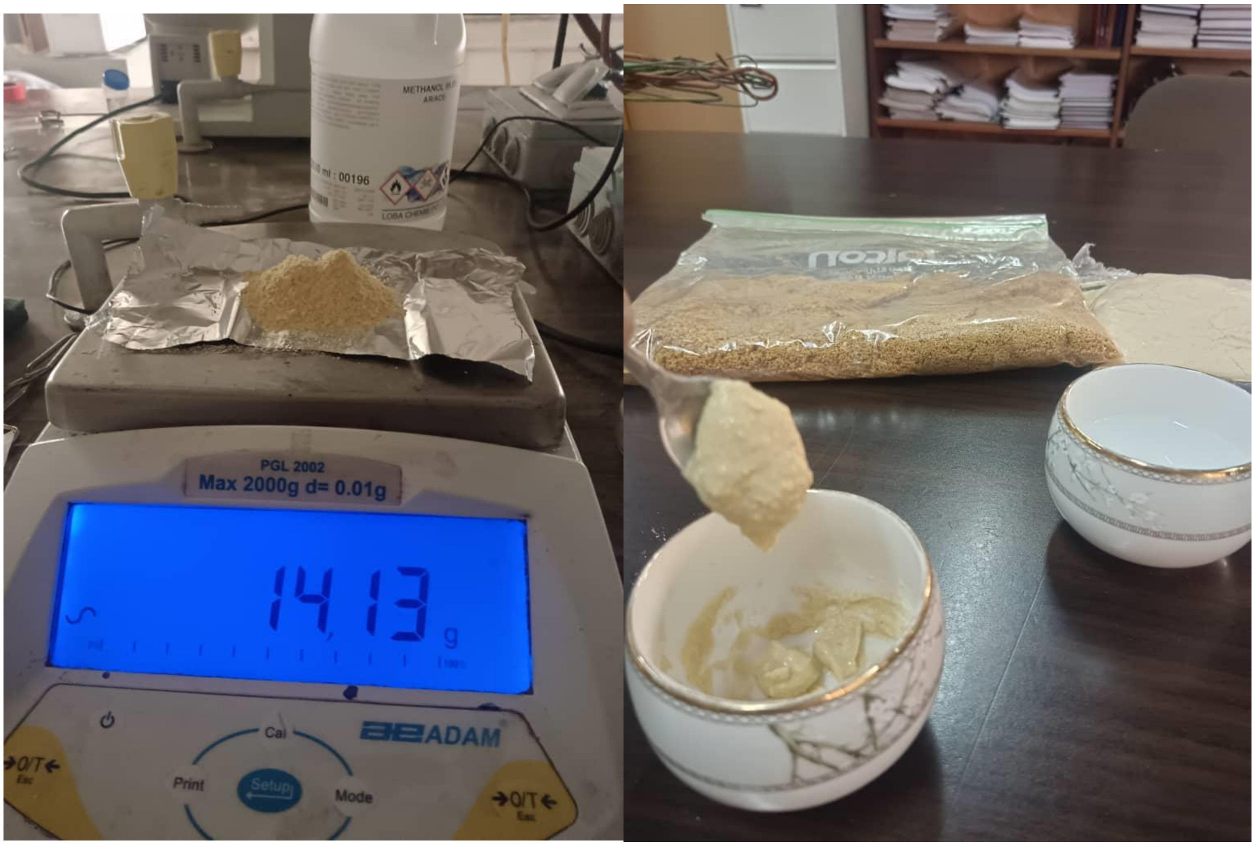


Figure 2: Preparation of complementary food and drip testing

Additional Processes and Ingredients to Fill Nutrient Gaps

Among the three formulations evaluated, milk can be added in powder form, or in liquid form if these complementary flours are prepared in rural settings. Milk can be added in the liquid form during preparation of porridges. When available and accessible, eggs and vegetables can also be added to further enrich the flour. If possible, these formulations should be enriched with vitamin mineral premix and calcium carbonate to fill potential nutrient gaps.

Based on price and availability, pumpkin, sesame, kale, and peanut can significantly contribute to the nutrient density of the complementary flour at a relatively low cost. We recommend to focusing on pumpkin, sesame and kale, while excluding peanuts because of the high aflatoxin contamination of this ingredient. However, for pumpkin, sesame, and kale to be included, they will need to be effectively dried to concentrate the nutrients in as low volume as possible, given gastric-capacity limitations of children in the first two years. Such drying can be informed by the comprehensive review on drying documented in this report. Drying conditions should be carefully selected in a way that minimizes nutrient loss. For sorghum and sesame, low-phytate and tannin variants should be chosen to improve mineral absorption.

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