# Linear Programming Formulation and Biological Evaluation of Chickpea-Based Infant Foods[1]

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ABSTRACT

Three chickpea-based infant food formulations were designed using a linear programming model to minimize total cost while meeting the FAO/WHO requirements for lysine and sulfur amino acids. Each formulation was prepared by cooking and blending the ingredients into a viscous paste that was later drum-dried and analyzed for chemical composition. Biological evaluation of protein quality by means of protein efficiency ratio, net protein ratio, and apparent protein digestibility was also performed. Results showed no significant protein efficiency ratio or net protein ratio differences between the casein control and any of the experimental formulations tested. Although they were produced at minimum cost, all products complied with the infant food specifications established by the Codex Alimentarius Commission.

Low-cost, high-protein food product development for infants is a constant challenge. This is particularly important in developing countries where malnutrition problems are still common, particularly during weaning (Schmidt 1983).

Many efforts have been made to develop low-cost infant foods in Mexico and Latin America. Del Valle et al (1981) formulated "Soyaven," a highly nutritive infant formula already in commercial production. Bressani et al (1963) reported the development of cereal-based foods supplemented with amino acids. Del Angel and Sotelo (1982) and Yepiz et al (1983) also reported the use of cereal and legume combinations to improve the nutritive value of food proteins for human consumption.

The Codex Alimentarius Commission (FAO/WHO 1976) prepared the official guidelines "Recommendations for International Standards of Infant Foods." Dried products described in this section are based on cereals and legumes of low water content processed under conditions that allow their reconstitution with milk or water. Recommended ingredients are wheat, rice, barley, oatmeal, rye, millet, corn, sorghum, and legumes, including soybeans.

If the product is to be mixed with water, it is required that the protein content be no less than 15% (dry basis) and protein quality at least 70% of casein value. The addition of protein concentrates, isolates, and essential amino acids is allowed only in concentrations needed to meet these criteria. Sugar and fruit addition is also allowed.

Low-cost food formulation using graphic models has also been described (Traver et al 1981). However, the widely used optimization methodologies for the formulation of balanced animal feeds have not been thoroughly applied to human foods (Cavins 1972).

Recent research in our laboratories has concentrated on the application of linear programming for the formulation of bakery products using combinations of cereals and legumes, where a bread was obtained using wheat, soybean flour, garbanzo flour, and sorghum flour (Ballesteros et al 1984). These formulations meet the FAO/WHO standards for amino acids while minimizing cost.

This study was undertaken in order to examine the application of linear programming techniques to design low-cost formulations of high nutritive value based on non-export quality chickpea (an under utilized legume in Northern Mexico), rice, soybean meal, and methionine combinations. The objective was to test the information obtained by linear programming for the production of stable dried flakes to be used as instant infant cereal and to assess the nutritive value of the products by standard biological evaluation methods in comparison to what could be considered ideal commercial products present in the market.

## MATERIALS AND METHODS

### Formulation Development

A linear programming model was developed in order to formulate mixtures based on rice, chickpea, commercially defatted soybean meal, and methionine at the lowest possible cost and in such a way as to fulfill the amino acid profile established by FAO/WHO (1976). These formulations were designed with varying quantities of the ingredients shown in Table I. Banana and sugar were included in two formulations for flavor improvement, but not as variables in the equation because they do not contribute with protein or amino acids. Three types of restrictions were set upon the variables: 1) minimum and maximum quantities of ingredients to be included, 2) amino acid supply of each ingredient, and 3) material balance. The objective function established was:

$$\text{Min } Z = \Sigma_{i=1}^{n} C_i X_i$$

where $Z$ is the cost per kilogram of each formulation, excluding the cost of banana and sugar, $C_i$ is the cost of ingredient $i$ in Mexican pesos and $X_i$ is the proportion in which ingredient $i$ is introduced in the formulation.

Table I presents the list of variables, ingredients, and costs at the time of formulation.

For formulations 1 and 2, the only restriction imposed on the linear programming model was $X_2 \geqslant 0.7$, and the latter included banana and soybean meal. Restrictions on formulation 3 were a maximim of 50% chickpea ($X_2 \leqslant 0.5$) and a minimum of 10%

**TABLE I**
**List of Ingredients and Cost**

| Variable | Ingredient | Cost[a] (pesos/kg) | Quantity Supplied | | |
|---|---|---|---|---|---|
| | | | % Protein | Lysine[b] | Methionine + Cysteine[b] |
| $X_1$ | Rice | 34.5 | 8.6 | 0.59 | 0.52 |
| $X_2$ | Chickpea[c] | 40.0 | 24.0 | 1.46 | 0.46 |
| $X_3$ | Methionine | 1,140.0 | ··· | ··· | 95.0 |
| $X_4$ | Soybean meal | 56.0 | 48.0 | 3.19 | 1.46 |
| | Banana[d] | 79.0 | ··· | ··· | ··· |
| | Sugar[d] | 60.0 | ··· | ··· | ··· |

[a]Prices as of July 1985.
[b]Expressed as g/100 of sample (%).
[c]Non-export quality average chickpea price.
[d]These ingredients are not decision variables in the model.

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soybean meal ($X_3 \geqslant 0.1$).

A second group of restrictions was established to meet lysine and methioninine-cysteine requirements according to the FAO/WHO (1973) and NAS/NRC (1980) pattern recommended for humans, 5.5 and 3.5 g/16 g of nitrogen, respectively. This was determined as a function of protein content in each formulation. Each group of equations was also subjected to the overall material balance equation $\Sigma X_i = 1$.

**Processing**

Rice, chickpea, and soybean meal were cooled in boiling water 0.25, 1.0, and 1.5 hr, respectively. When cooled to room temperature, chickpea hulls were manually removed. Predetermined amounts of each ingredient were blended together for 1–2 min in a one-gallon Waring Blendor (Eberback Corp., Ann Arbor, MI) until a thick homogeneous paste was formed. The paste was stored 1 hr at 3–5°C until ready to be dried in an atmospheric, twin drum dryer model ALC-5 (Bufflovack, Blaw Knox Co., Buffalo, NY). The total heat transfer area was 2 $ft^2$, and the mixtures were fed at 15°C, pouring them between the two drums with a clearance of 0.008 in. Steam pressure inside the drums was 20–40 psi, which corresponded to 110-115°C drum surface temperature. Mean residence time was 5.2 sec, final product temperature was 38°C, and final moisture content was 4–5%. Protein, fat, moisture, and ash were determined by AOAC methods (1984) and crude fiber by AACC method 32-10 (1976).

**Biological Evaluation of Protein Quality**

Protein quality was assayed in vivo by means of the protein efficiency ratio (PER) according to AOAC (1984) procedures. Seventy weanling male Sprague Dawley rats were randomly assigned into seven groups of 10 rats each and fed diets containing three commercial products, three experimental formulations, and the reference protein (American Nutritional Research Council [ANRC] casein) for 28 days. The basal diet is presented in Table II. All diets contained 10% protein and were of equal caloric densities. The experimental animals were housed individually in stainless steel cages held under controlled environmental conditions, at 23 ± 1°C, 55–65% relative humidity under a 12-hr light-dark cycle. Water and food were provided ad libitum.

Under the same experimental conditions, net protein ratio (NPR) was determined according to the collaborative study reported by Happich (1984). Apparent protein digestibility was determined according to Valencia et al (1979) utilizing a $Cr_2O_3$ marker, to avoid total collection and feed throughout the 28 days and collecting fecal samples during the last 10 experimental days.

The experimental arrangement for PER and NPR was a randomized design with 10 rats per treatment and a total of seven treatments. Homogeneity of variance was determined by the Bartlet's test (Zar 1984). After analysis of variance, Tukey's test was applied as a multiple range test (Zar 1984).

The developed products were compared with commercial cereal products used in Mexico. These were Cerelac (Nestlê), Gerber's High Protein Cereal, and Gerber's Mixed Cereal.

**TABLE II**
**Composition[a] of the Basal Diet Used for In Vivo Evaluation of Experimental Formulations**

| Ingredient[b] | % |
|---|---|
| Corn oil | 8.0 |
| Vitamin premix[c] | 1.0 |
| Mineral premix[d] | 5.0 |
| $Cr_2O_3$ | 0.2 |
| Cellulose | 1.0 |
| Water | 5.0 |
| Protein source | 10.0 |
| Starch and dextrose to make 100% of diet | ··· |

[a]Corn oil, minerals premix, cellulose, and water were adjusted after proximate analysis of ingredients. Sample was calculated to contain 1.6% N in diet (10% protein), according to AOAC method 43.253, which is applicable to materials with %N above 1.8.

[b]All the ingredients except corn oil were from Bioserv, Inc., NJ, 1982.

[c]The vitamin premix supplied the following g/kg of diet: ascorbic acid 0.45, biotin 0.0002, calcium pantothenate 0.03, choline 0.633, folic acid 0.0009, inositol 0.05, menadione 0.02, niacin 0.04, PABA 0.05, piridoxine 0.01, riboflavin 0.01, thiamine 0.01, vitamin A 9,000 IU, vitamin B 120.01 mg, vitamin D 1,000 IU, vitamin E 25 IU.

[d]Mineral premix supplied the following g/kg of diet: aluminium 0.0005, calcium 11,0865, chlorine 4.7935, copper 0.0175, fluorine 0.0027, iodine 0.0030, iron 0.385, magnesium 0.3812, manganese 0.0055, phosphorus 2.5305, potassium 5.8820, sodium 1,3690, sulfur 0.1162, zinc 0.0637.

## RESULTS AND DISCUSSION

Objective functions and constraint equations for each formulation are presented in Table III. Each model was solved mathematically using a linear programming computer program (LP 88—version 3.12, Eastern Software Products, Inc.) and an IBM PC computer.

Final composition and product cost is given in Table IV. Formulation 1 gave the lowest cost per kilogram (40.8 pesos), and a very small difference, less than one peso, was found between the other two experimental formulations.

Chemical composition of finished products is shown in Table V. Moisture varied from a low of 3.9 to 5.4%, whereas commercial products had higher values (5.5–9.1%).

Protein content for formulations 1 and 3 was 17.9 and 17.3%, respectively. This was in agreement with the standards recommended by the FAO/WHO guidelines (1976). However, the incorporation of banana and sugar in formulation 2 offset its protein content slightly below such recommendation. Essential amino acid balance, however, did meet the minimum recommended by FAO/WHO (1973) and by NAS/NRC (1980) in all three cases.

Carbohydrate content, as determined by difference, was very

**TABLE III**
**Objective Functions for Each Experimental Formulation[a]**

| | Formulation 1 | Formulation 2 | Formulation 3 |
|---|---|---|---|
| Formulation for minimum cost per kilogram | 34.5 rice + 40 chickpea + 1,140 methionine | 34.5 rice + 40 chickpea + 1,140 methionine | 34.5 rice + 40 chickpea + 1,140 methionine + 56 soybean meal |
| Subject to: | | | |
| Ingredient limits | chickpea $\geqslant$0.7 | chickpea $\geqslant$0.7 | chickpea $\geqslant$0.5, methionine $\geqslant$0.10 |
| Sulfur amino acid requirements | 0.52 rice + 0.46 chickpea + 95.0 methionine $\geqslant$0.68 | 0.52 rice + 0.46 chickpea + 95.0 methionine $\geqslant$0.48 | 0.52 rice + 0.46 chickpea + 95.0 methionine + 1.46 soybean meal $\geqslant$0.54 |
| Lysine requirements | 0.59 rice + 1.46 chickpea $\geqslant$1.06 | 0.59 rice + 1.46 chickpea $\geqslant$1.75 | 0.59 rice + 1.46 chickpea + 3.19 methionine $\geqslant$0.85 |
| Overall limits | rice + chickpea + methionine = 1 | rice + chickpea + methionine = 1 | rice + chickpea + methionine + soybean meal = 1 |

[a]Formulations expressed in percentage, except the one pertaining to cost.

TABLE IV
Final Formulation Composition and Costs of Products

| Ingredients in Mixture | % of Total | % Protein | Lysine | Methionine + Cysteine | Cost[a] (pesos/kg) |
|---|---|---|---|---|---|
| Formulation 1 | | | | | 40.77 |
| Chickpea | 70.00 | 16.80 | 1.02 | 0.32 | |
| Rice | 29.78 | 2.58 | 0.17 | 0.16 | |
| Methionine (95%) | 0.22 | | | 0.21 | |
| Formulation 2 | | | | | 50.06 |
| Chickpea | 49.00 | 11.76 | 0.71 | 0.23 | |
| Rice | 20.82 | 1.81 | 0.12 | 0.11 | |
| Methionine (95%) | 0.18 | | | 0.17 | |
| Banana | 18.00 | | | | |
| Sugar | 12.0 | | | | |
| Formulation 3 | | | | | 51.05 |
| Chickpea | 35.0 | 8.40 | 0.51 | 0.16 | |
| Rice | 24.50 | 2.11 | 0.14 | 0.13 | |
| Soybean meal | 10.50 | 5.04 | 0.34 | 0.15 | |
| Methionine | 0.12 | | | 0.11 | |
| Banana | 18.00 | | | | |
| Sugar | 11.88 | | | | |

[a]Costs as of July 1985. Cost includes bananas and sugar used for flavoring.

similar in all the products studied except for Gerber's High Protein Cereal, which gave the lowest, 36.8%. This product was also higher in ash and fiber.

Bartlet's test (1937) for all treatments in the biological evaluation studies was positive thus showing common variance. Analysis of variance with parametric tests was carried out.

Results from PER and apparent digestibility studies are shown in Table VI. PER results show no significant difference for any of the formulations designed by linear programming. Additionally, all met the FAO/WHO requirement of having at least 85% casein value.

Statistical analysis confirms the protein quality of formulated products. Cerelac (a commercial product) had a significantly higher value than casein. However, this product includes powdered milk, a more costly ingredient, which makes it the most expensive infant food in the market. The product with the lowest nutritive value was Gerber's Mixed Cereal. This product did not meet FAO/WHO standards for either quantity or quality of protein.

Because of the shortcomings of the PER assay as an index of protein quality, net protein ratio (NPR) was also determined and net protein utilization was estimated. Table VII gives the results for these indexes.

Bartlet's test (Zar 1984) also showed positive homogeneity of variance for NPR, therefore, analysis of variance was carried out in the same manner as for PER.

NPR results showed no significant difference for any of the formulated products in relation to ANRC casein. According to this test, formulation 3 showed no significant difference from Cerelac or Gerber's High Protein Cereal.

Gerber's Mixed Cereal gave the same results as for PER. Protein apparent digestibility was higher for the ANRC casein diet at 86%, and nearly the same for formulations 1, 2, and 3. They are close to those of Gerber's High Protein Cereal, which is manufactured in the same manner as the experimental formulations. Results from this experiment confirm the similarity in nutritive value of the formulated products.

Formulation 3 showed a higher nutritive value with respect to

TABLE V
Chemical Composition of Chickpea-Based Formulations and Commercial Products[a]

| Ingredients | Formulation F-1 | Formulation F-2 | Formulation F-3 | Gerber's Mixed Cereal | Gerber's High Protein Cereal | Cerelac |
|---|---|---|---|---|---|---|
| Moisture | 5.43 | 3.92 | 4.41 | 7.02 | 9.07 | 5.52 |
| Protein | 17.98 | 14.51 | 17.25 | 12.45 | 36.98 | 12.78 |
| Fat | 4.05 | 2.17 | 1.61 | 1.08 | 8.72 | 1.81 |
| Fiber | 0.74 | 0.68 | 0.84 | 0.36 | 2.69 | 0.28 |
| Carbohydrates | 69.39 | 76.74 | 73.53 | 76.51 | 36.86 | 77.56 |
| Ash | 2.42 | 1.98 | 2.35 | 2.59 | 5.68 | 2.06 |

[a]Formulations expressed in percentages.

TABLE VI
Protein Efficiency Ratios (PER) and Apparent Protein Digestibility of Formulated Mixtures and Commerical Products

| Source of Protein | PER Mean[a] | Corrected PER Mean[a] | Apparent Protein Digestibility[b] |
|---|---|---|---|
| Cerelac | 3.25 a | 2.85 a | ND[c] |
| Gerber's High Protein Cereal | 3.03 ab | 2.65 ab | 81.85 |
| Casein ANRC | 2.85 bc | 2.50 bc | 85.95 |
| Formulation 3 (chickpea, rice, soy, methionine, banana, sugar) | 2.81 bc | 2.47 bc | 81.70 |
| Formulation 1 (chickpea, rice, methionine) | 2.65 c | 2.32 c | 80.75 |
| Formulation 2 (chickpea, rice, methionine banana, sugar) | 2.55 c | 2.24 c | 80.60 |
| Gerber's Mixed Cereal | 1.98 d | 1.74 d | ND |

[a]Means followed by a different letter are significantly different ($P < 0.01$) according to Tukey's test (Zar 1984).
[b]Apparent digestibility of protein in the diets with $Cr_2O_3$ (Valencia et al 1979). The value corresponds to the whole diet.
[c]Not determined.

TABLE VII
Net Protein Ratio (NPR) of Formulated Mixtures and Commercial Products (14 days)

| Source of Protein | Mean[a] NPR | Relative NPR[b] | Estimated[c] Net Protein Utilization |
|---|---|---|---|
| Cerelac | 4.38 a | 100 a | 71.2 a |
| Casein ANRC | 4.19 ab | 100 ab | 68.2 ab |
| Formulation 3 (chickpea, rice, soy, methionine, banana, sugar) | 4.14 ab | 98.8 ab | 67.5 ab |
| Gerber's High Protein Cereal | 3.86 ab | 92.1 ab | 63.1 ab |
| Formulation 1 (chickpea, rice, methionine) | 3.73 b | 89.0 b | 61.1 b |
| Formulation 2 (chickpea, rice, methionine, banana, sugar) | 3.73 b | 89.0 b | 61.1 b |
| Gerber's Mixed Cereal | 2.91 c | 69.0 c | 48.4 c |

[a]Means followed by a different letter are significantly different ($P < 0.05$) according to Tukey's test (Zar 1984).
[b]Relative NPR is relative to casein ANRC according to the collaborative study of Happich et al (1984).
[c]Estimated value according to the equation reported by Bender and Doell (1957).

one of the commercial products because of improved essential amino acid complementation and supplementation. In all three cases, the FAO/WHO standard was met and the NAS/NRC (1980) standard for methionine-cysteine was improved.

## CONCLUSIONS

Chemical analysis and biological evaluation of the linear programming model formulated products confirmed their highly nutritive value in agreement with infant food specifications outlined by FAO/WHO (1976). It was also established that the application of optimization methodologies, such as linear programming, offer a special versatility as far as formulation of low-cost, highly nutritive food products. In particular, underutilized chickpea resources available in many parts of the world have been successfully used as the main ingredient to formulate infant cereals to improve nutrition.

One problem yet to be solved is that the finished product must be carefully controlled, because the nature of the formulation method can cause variations in the content of ingredients as prices change. Nevertheless, certain ranges of ingredients can be established to allow greater flexibility in the formulation.


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