A LINEAR PROGRAMMING ANALYSIS OF HUMAN DIETS BASED UPON MAJOR STAPLE CROPS: SENSITIVITY OF LOW COST FORMULATIONS TO CALORIC, PROTEIN AND BULK CONSTRAINTS

by

John G. Chamberlin

B.S., Michigan State University (1968)

Submitted in Partial Fulfillment
of the Requirements of the
Degree of

Master of Science

at the

Massachusetts Institute of
Technology

August 1971

Signature of Author . . . .
Department of Mechanical Engineering, August 1971

Certified by . . . .
Thesis Supervisor

Accepted by . . . .
Chairman, Departmental Committee
on Graduate Students

To my parents

Ich denke dies,
Und, ja, auch das
Und kann nicht wirklich sagen.
Wenn ich war klug,
Oder vielleicht dumm
Ich konnte besser fragen.

Warum die Wolken und die Wellen
Müssen immer weiter fahren.

Ich denke auch
Wenn ich hab' recht
Es gibt noch andere Fragen.
Vielleicht die Regeln
Der Menschen sind,
Die Gleichen die Wolken tragen.

A LINEAR PROGRAMMING ANALYSIS OF HUMAN DIETS BASED UPON MAJOR STAPLE CROPS: SENSITIVITY OF LOW COST FORMULATIONS TO CALORIC, PROTEIN AND BULK CONSTRAINTS

by

John G. Chamberlin

Submitted to the Department of Mechanical Engineering on August 16, 1971, in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

Minimum cost diets, based upon various staples, were formulated to meet the nutritional requirements of selected age groups; the sensitivity of the formulations to nutritional and bulk constraints and to the inclusion of various protein concentrates was examined. Data on food compositions were assembled for countries representing five major dietary regions: maize, rice, wheat, millet and sorghum, and yams and cassava. In addition to the staples other significant calorie and protein sources present in the diet and various protein concentrates were considered. This data, together with information compiled on human calorie and protein requirements and on feasible levels of bulk and weight in human diets, provided a basis for formulation of least cost diets using linear programming. For each diet area basic adult diets, diets considering pregnancy and lactation requirements, and diets for children of ten and twenty kilograms weight were considered. The sensitivity of these low cost formulations to

caloric, protein and bulk constraints was of primary interest. The relative extent to which the constraints were binding and the opportunity costs of protein concentrates and other nonstaple foods have implications for programs of nutritional improvement.

Thesis Supervisor: Robert E. Stickney

Title: Associate Professor in Mech. Eng.

ACKNOWLEDGEMENTS

I am grateful to my thesis advisor, Professor Robert E. Stickney, for his commitment to and enthusiasm for my thesis topic and for the advice and constructive criticism he gave me. I would also like to thank Dr. Benjamin Torun for his helpful comments and suggestions.

My thesis seemed to make the most progress when I was able to talk through ideas associated with it. Philip Abbott showed a lot of patience about this, and everyone in the Thermodynamics and Kinetics Laboratory deserves an acknowledgement for listening to what seemed to them strange ideas and for providing interesting working conditions.

I really appreciate the typing done by Miss Heidrun Bahls. Typing a thesis is really not much fun.

TABLE OF CONTENTS

	Page
TITLE	1
ABSTRACT	2
ACKNOWLEDGEMENTS	4
TABLE OF CONTENTS	5
INTRODUCTION	7
NUTRITIONAL CONSTRAINTS	13
LINEAR PROGRAMMING	17
DISCUSSION OF FORMULATIONS	21
Millet and Sorghum Diet: Northern Nigeria	22
Wheat Diet: Turkey	23
Rice Diet: India and East Pakistan	24
Maize Diet: Mexico	26
Yam and Cassava Diet: Southern Nigeria	28
DISCUSSION OF BINDING CONSTRAINTS	30
OPPORTUNITY COSTS OF PROTEIN CONCENTRATES	32
OPPORTUNITY COSTS OF ANIMAL PRODUCTS	34
CONCLUSIONS	35
REFERENCES	39
TABLES	42
APPENDIX A. DATA ON FOOD COMPOSITIONS AND COSTS	52
Abbreviations and Units	52
Food Compositions and Costs	53
Sources of Food Composition Data	57

Page

Sources of Food Prices 58

References 59

APPENDIX B. ESTIMATION OF COOKED BULK PER UNIT DRY WEIGHT. . . . 60

References 62

APPENDIX C. INPUT BOUNDS ON INGREDIENT USAGE 63

Adult Diets: Adult65, Adult55P, Adult55L 63

Child Diets: Child10, Child20. 64

INTRODUCTION

One of the definitions of the process of economic development might be the provision of a better and fuller life, for individuals and for the community. This process is strongly linked with the problems of food supply and the provision of adequate diets. An individual's physical and mental development, his resistance to disease, and his productivity are all adversely affected if his diet does not contain adequate amounts of essential nutrients (1).

The problem of providing adequate diets is not purely an economic one. A food of exceptional nutritional value and low cost may not be accepted because of its taste, color, texture or other attributes that are of a qualitative nature. For man, food is not only a necessity but also a component of the quality and continuity of life. Thus it is not to be expected that an economic analysis of the nutritional values of foods will in itself provide final answers to questions of how to provide adequate diets that are not prohibitively expensive for many of the groups most in need of nutritional improvement.

However, the economic aspects of many questions involved in developing and executing programs for nutritional improvement can not be ignored. A protein supplement may have been developed and be culturally acceptable and nutritionally valuable yet be unable to compete with inferior products because of its price. An organization may wish information on the relative promise of several protein concentrates in food supplementation programs, from a cost viewpoint, before determining in which to invest resources for development of trial programs. A nation might like to examine the

the economic feasibility of introducing a food supplement as opposed to using extension techniques to encourage the use of better mixtures of already accepted foods. Or a government considering formulating and distributing a high protein food through schools or clinics could be concerned with producing an adequate food with as low a cost as possible.

Given the importance of nutritional improvement programs, it seems worthwhile to utilize the best available analytical techniques to provide answers to the above questions. All involve in some sense the provision of a mixture of possible foods which meets certain nutritional and other constraints at a mimimum cost. Powerful techniques of mathematical analysis exist for solving this type of problem. The mathematical solution in itself may not be a definite solution to the original nutritional problem. The problems of feasibility and acceptability would still exist and would have to be considered by an informed analyst. Any difficulties introduced by uncertainties in food compositions and variations in food prices would also have to be considered. To recognize these limitations is only to be honest. The value of performing an analysis based upon economic and nutritional criteria remains. Such an analysis permits consideration of many factors simultaneously and can provide insights not otherwise perceptible. Often the mere step of formulating the problem in a rigorous manner points out areas of question and clarifies certain aspects of the problem.

Bearing in mind the limitations of the approach we shall attempt to obtain at least approximate answers to some of the questions mentioned above, using linear programming as an analytical tool. The present study should be viewed as a preliminary step which can be corrected and refined by subsequent, more directed studies.

Because the nutrient content of a mixture of foods is the sum of the nutrient contents of its components, a diet problem has the mathematical characteristics that facilitate its formulation as a linear programming problem. In fact, determination of a least cost diet was one of the first problems formulated for solution by linear programming (LP) (2). During the 1950's and 60's the increasing accessibility of computers with the capacity for LP was associated with the development of interest in using this method to formulate animal feeds (3). Such computer formulated feeds are now in common use throughout the United States. Equally direct applications to human diets were not immediately forthcoming, as cultural constraints as well as nutritional and economic ones enter into the planning of human diets.

Work was done by V. Smith in the early 1960's utilizing linear programming as a tool for determining low cost diets that fit American food preference patterns (4, 5). Smith suggested several other applications of LP to human dietary computations, including planning by underdeveloped areas directed toward greater fulfillment of nutritional needs using available resources. More recently Smith has worked with least cost diets fitting Colombian food preference patterns (6). Formulations developed by computer were also the basis of a study by Buffa concerning production in North Africa of protein enriched foods for children (7). Devanney has utilized LP as a tool for analysing the conditions under which Fish Protein Concentrate would be an ingredient in efficient protein supplementation programs (8).

The present analysis is aimed at utilizing the sensitivity data produced through the use of LP rather than at formulating diets for actual use. Data on nutrient compositions were collected for the staple foods and other important sources of calories and protein for five major dietary regions (9, 10, 11, 12, 13). For each staple a representative geographic area was chosen for which data on food prices and actual food consumption patterns was available (14, 15, 16, 17). The staples considered and the representative geographical areas were as follows: wheat-Turkey, millet and sorghum-Northern Nigeria, maize-Mexico, rice-India and East Pakistan, and yams and cassava-Southern Nigeria. In the present preliminary survey only calorie, protein and essential amino acid compositions were utilized. This seemed appropriate as perhaps the most prevalent world nutritional problem is protein deficiency, which is often associated with caloric deficiencies. For work directed at more specific situations and questions, consideration of vitamins and minerals in the diet would certainly be of interest. Consideration of those nutrients in the present analysis would have involved difficulties in dealing with compositions and methods of preparation of locally used fruits and vegetables. While fruits and vegetables would be important sources of vitamins and minerals, their contribution to meeting protein and calorie needs can normally be neglected.

Data were also gathered on the nutritional requirements of the population groups selected for consideration, and on the bulk and weight allowable in human diets.

From the input data on food compositions and nutritional constraints, the LP system determined a mixture of foods that satisfied the nutritional constraints and minimized the cost of the mixture. Often initial solutions were not at all reasonable in view of present eating habits or other practical criteria. For example a "rice diet" containing no rice or a diet composed chiefly of melonseeds were discarded as unreasonable solutions. These faults were corrected by the insertion of bounds (upper or lower limits) on the usages of the ingredients in question. Whenever bounds were used they will be mentioned in discussing the results. This same pattern of critical examination of LP solutions for reasonableness had earlier proven necessary in the formulation of least cost animal feeds (18). Linear programming and similar methods must be seen as tools. Their use makes possible examination of more aspects and alternatives in a problem, but at each stage human judgement is necessary to decide whether and how a solution can be used.

After solutions had been obtained that generally followed existing cultural patterns, closer attention was given to the sensitivity data that is one of the more valuable aspects of LP. In terms of the diet problem, this sensitivity data tells the relative cost of obtaining nutrients which are binding (at the limit of the allowed values). Information on how the cost and other aspects of the solution would change if the amounts of each ingredient contained in the solution were caused to vary or if alternate ingredients were allowed in the solution is also produced. Such information can be of use in considering alternate schemes for diet supplementation or in comparing the feasibility of industrially prepared foods to that of home combinations of already used local foods.

A number of readily available subroutine systems for solution of linear programming problems exist. In this case the system known as MPS/360 was used. Many detailed descriptions of the theory and application of LP exist (5, 19, 20).

NUTRITIONAL CONSTRAINTS

Data were compiled on the calorie, protein, and essential amino acid allowances advisable for various population groups of interest (21, 22, 23, 24, 25). The groups selected for study consisted of a representative adult diet and four groups with intensified calorie and protein requirements: pregnant women, lactating women, and children of 10 and 20 kilograms body weight (approximately 1-2 and 4-5 years of age, respectively). The representative adult diet was included chiefly for comparison with actual food consumption patterns and as a base for determining how the problem of obtaining an adequate, low cost diet was altered for the other four groups by their intensified requirements. Infants were not considered because of the difficulty of dealing with weaning practices and including appropriate amounts of milk in the diet. The compiled dietary constraints are presented in Table 1.

The representative adult diet, abbreviated Adult65, was based upon the requirements of a 65 kilogram adult. A calorie level was required that represents an average calorie level in many developing countries (21). This level, 2400 kilocalories (kcal), was less than would be required by active individuals. Thus formulations for this diet provided conservative estimates of the extent to which calories are a binding constraint. Protein and essential amino acid allowances for all the diets were calculated as in Munro (22), according to guidelines discussed at the 1971 meeting of the Joint WHO/FAO Expert Committee on Protein Requirements. These guidelines were based on the reconciliation of the factorial method of measuring dietary protein needs with the results of experiments on minimum protein requirements for nitrogen equilibrium which took the concept of differing utilizations of various proteins into consideration. For the Adult65 diet total protein was at the level of 0.6 grams per kilogram of body weight per day with essential amino acids constituting 20 per cent of the total protein. As in all diets considered the egg pattern was used to determine the constraints placed on individual amino acids (23).

The constraint set Adult55P involved addition of allowances for pregnancy to the basic allowances for a 55 kg woman of child bearing age. To the basic calorie allowance of 2200 kcal (24) was added a 200 kcal pregnancy allowance (25). The total protein requirement was again figured at the level of 0.6 g/kg-day with the addition of a 6 g/day pregnancy allowance (25). The conservative assumption was made that essential amino acids should compose 50 per cent of this total protein allowance, since the growth of the fetus requires the manufacture of much new protein containing a large proportion of essential amino acids. Because of the body weights selected, the calorie and total protein constraints for the Adult65 and Adult55P diets were identical, 2400 kcal and 39 grams for both. Thus the results of the Adult65 formulation can be viewed as a lower limit on solutions to diets with pregnancy allowances under the assumption that not all the protein intake during pregnancy need be of a high quality. Similarly the solutions to Adult55P provided information on how the formulated diet for the Adult65 constraint set would change if the protein in it was required to contain a higher percentage of the essential amino acids.

The constraint set Adult55L consisted of the allowances for a 55 kg woman during lactation. A lactation allowance of 1000 kcal (25) was added to the basic caloric allowance of 2400 kcal (24) and a lactation protein allowance of 15 grams was added to the base of 0.6 g/kg-day (25). Because of the large additional protein allowance which goes to produce milk, itself a high quality protein, the constraints were set to require 50 per cent of the total protein allowance of 48 g to be essential amino acids.

The diets for the 10 and 20 kg children, abbreviated Child10 and Child20 respectively, were based upon caloric allowances adopted from the FAO tables (24). For the 10 kg child 1.5 g/kg-day and for the 20 kg child 1.0 g/kg-day were used as protein allowances (8). In both cases essential amino acids were constrained to consist of 50 per cent of this protein allowance (22).

Since many least cost mixtures containing the amounts of nutrients needed to satisfy the needs of children and infants may be too bulky to be reasonable, it was necessary to add constraints on the bulk of children's diets (26). Originally a conservative (low) estimate of allowable volumes was made and the children's diets based on millet and sorghum were initially formulated with these bulk constraints of 800 and 1000 milliliters. It was not possible to formulate diets in the other regions based upon products locally consumed without exceeding these bounds. Since the initial choice had been a conservative one, the bulk constraints for the 10 kg child and for the 20 kg child formulations were raised to 900 and 1250 milliliters respectively. These new levels were still within the ranges of bulk of children's diets actually observed, albeit at the upper end of this range (26). Estimates were made of the cooked volumes of various foods per unit dry weight. For these estimates it was assumed that foods would be prepared in the form of a gruel. These factors for volume in a child diet were then included in the food composition data.

For adult diets an upper limit was placed on allowable weight. This figure was also based upon actual consumption patterns, however the weight bounds were never operational (14). The weight bound used was 1400 grams which is the level of intake in Southern Nigeria. This represents an attainable level but perhaps not an attractive one in all cultures. Therefore, whenever formulated diets are discussed which involve intakes of food having dry weights of over 1100 grams, this fact will be mentioned as one of the questionable aspects of that formulation.

LINEAR PROGRAMMING

Linear programming is a mathematical technique for determining how to best use a set of resources when there are constraints on the ways in which the resources may be used. In the case of the diet problem the resources are various foods; each of which has a particular cost associated with it. The objective is to obtain a least cost mixture of the foods subject to the constraints on nutritional value and bulk which the mixture must satisfy. Additional constraints, termed bounds, may be imposed to limit the amounts of certain foods in the mixture.

Given the systematic representation of the system contained in the input data on food compositions and nutritional constraints, the mathematical algorithm that is the basis of linear programming first computes a feasible mixture of foods that satisfies the constraint set. Then, one by one, other foods are examined to determine if their inclusion in the mixture, either in addition to the foods already present or as a replacement for one of them, would result in a reduction in the cost of the mixture. This procedure continues systematically, according to mathematical guidelines, until no possibility for improvement exists. At this point a minimum cost mixture which satisfies all the constraints has been obtained.

The guidelines used by the algorithm to determine which ingredients will enter the mixture and to decide when the optimum has been reached provide a means of examining the effects of changes in the stated problem. One guideline involves calculation of the cost of including a unit of a given food in the mixture. When this cost is zero or negative a food can be included in the mixture without increasing its cost. Using such data a linear programming system calculates the opportunity costs for alternate ingredients. An opportunity cost is the price an ingredient would have to possess to enter into the solution with no net change in the cost of the mixture. The algorithm also calculates the effect on the cost of the mixture if alternate ingredients are forced into the solution at their input prices.

Because the algorithm must always satisfy the given set of constraints, numbers are generated that provide a relative measure of the importance of the binding constraints. For example these numbers may indicate that the cost of increasing the required level of calories by one per cent would be twenty times the cost of increasing the required level of lysine by the same one per cent. This is a manner of saying that the compositions and prices of the foods under consideration make it much more expensive to obtain calories in the amount required by the constraint set than to obtain the required level of lysine.

To illustrate in a qualitative way the methods involved in obtaining a solution to a LP problem and to give examples of some of the types of information produced, consider the solution to the Adult65 constraints depicted in Table 1. Initially the algorithm computes a feasible solution to the problem. Assume that the initial solution is simply 700 g of millet, which satisfies all the constraints for a cost of 4.3¢. At this point the only nutritional constraint exactly at its limit is calories (i.e. the caloric constraint is the only "binding constraint" for this particular diet). As the algorithm considers each alternate ingredient for possible inclusion in the mixture, it determines that oil is a cheaper source of calories than millet. Thus oil may be marginally substituted for millet with a reduction in the cost of the mixture. When millet is reduced to 430 g and oil increased to 104 g lysine reaches its lower limit and both calories and lysine are binding constraints. At this point the cost is 3.9¢. Then cowpeas are calculated to be a cheaper source of lysine than either millet or oil. Thus they are included in the diet. Because cowpeas include fewer calories in proportion to their lysine content than the millet they replaced, oil is added to compensate for the energy lost through the replacement of millet lysine by cowpea lysine. At the ingredient usages depicted in Table 2 (millet-387 g, oil-119 g, and cowpeas-6g) total protein also becomes binding. At this point the algorithm examined all alternate foods and determined that no other food could replace any of those already in the mixture without either increasing cost or violating the constraints. Thus this formulation was the optimum one in terms of least cost.

The means of calculation of the "costs" of the binding constraints can also be seen. To increase the level of calories in the diet by one per cent (24 kcal) by the cheapest caloric source, oil, requires the addition of 2.7 g of oil at a cost of .031 ¢. Dividing this by the cost of the regional staple (millet and sorghum at 6.2 ¢/kg), to facilitate comparisons between regions with widely different price levels, results in the measure of .0050 shown for calories in Table 2. This calculation is more complicated for the other binding constraints. For example increasing the lysine bound would result in the addition of cowpeas. But because cowpeas also contain calories and total protein, adjustments in millet and oil would also be necessary to arrive at the new least cost mixture. However the figure displayed in Table 2 is the net cost of making the change in constraint divided by the price of the regional staple in this case too.

DISCUSSION OF FORMULATIONS

The solutions to the selected sets of dietary constraints for the five regions, together with examples of an actual pattern of consumption for a region using each staple, are presented in Tables 2-6. The objective was not to force the LP formulated diets to resemble in exact detail the actual diets, although this can easily be done by setting upper and lower bounds on ingredient usages. Instead an effort was made to get the solution for the constraint set Adult65 to roughly match the actual diet. This was done initially by assigning artificially high prices to ingredients not used in a region. This served as a means of excluding unreasonable ingredients from a least cost solution. Later upper and lower bounds were assigned, when needed, to adjust the usages of ingredients desiredin a formulation to proportions similar to those of actual consumption patterns. The higher protein adult diets with allowances for pregnancy and lactation and the diets for children were not expected to conform so easily to the national actual or average diet. The analysis figures accompanying the LP solution can be used to make statements about what would be involved in shifting a solution to match more exactly the existing diet pattern or why the existing pattern was not duplicated by the least cost solution. It should be noted that diets within a region of a given staple crop might vary substantially from the example given. For example, although the average intake of chickpeas for all Turkish army bases was 30 g/day, individual bases in different regions of the country varied from 0 g/day to 55 g/day

(27). In the case of the Nigerian diets further caution in using the typical pattern is necessary as it represents estimated food supplies rather than actual food consumption.

Millet and Sorghum Diet: Northern Nigeria

For the Northern Nigerian diet shown in Table 2, the obvious differences between the solution for Adult65 and the actual diet are the absence of sorghum and starchy roots and the inclusion of a large amount of oil. The LP results show that sorghum and millet are virtually interchangeable in the least cost diet. For example, converting to all sorghum would add only 3% to the cost of the diet. At different times and locations in Northern Nigeria the actual diet would probably include various mixes of millet and sorghum. The solution also indicates that yams and cassava or additional grain could replace a large portion of the oil in the diet, at a low cost. The process would be accompanied by an accentuation of the extent to which calories are binding and the loss of total protein, and later of lysine, as binding constraints. The Adult55P and Adult55L solutions are also basically reasonable. Oil and cassava can be traded off, one for the other, and grain and peanuts substituted for cowpeas, again at little cost. Thus, in the case of the adult diets, low cost formulations resembling the actual millet and sorghum diets are easily obtained.

The millet and sorghum diets for children were initially formulated with lower bulk constraints than was possible for the other regions, as was mentioned earlier. The reason for the ease of formulation in the Northern Nigerian case was the inclusion of peanuts. These were allowed to enter in this case because of the normal inclusion of significant amounts of peanuts in the diets of Northern Nigeria. This result shows the importance of even a small amount of low bulk, high protein food in obtaining adequate diets for children. Foods such as peanuts might be fed in small amounts as snacks instead of at meals. Using the less conservative bulk constraints, and excluding peanuts and other protein concentrates, the solutions depicted in Table 2 were obtained. For both the Child10 and Child20 formulations the exclusion of peanuts led to the inclusion of large amounts of cowpeas. To reduce the cowpea usages, without exceeding the bulk constraint, would require the inclusion of a more concentrated source of methionine and cystine than either millet, sorghum or cowpeas provide.

Wheat Diet: Turkey

The wheat diets shown in Table 3 for Adult65 and Adult55P compare well with the actual average of diets consumed on Turkish military posts. Upper bounds were placed on the usages of bread (900 g) and other wheat (100 g) to prevent excessive usages of these ingredients. The bound on wheat was more generally limiting than that on bread because the loss of nutrients involved in processing the wheat into bread resulted in a higher cost per unit of nutrient for bread than for unprocessed wheat. The level of other wheat (mainly bulgar) used in the formulations is within the limits of consumption of bulgar and rice at several of the bases. The use of oil in the lactation formulation results from the higher calorie requirement of this constraint set.

Wheat was assigned no upper bound in the children's diets because of uncertainty as to how to handle the bulk of bread. The assumption that wheat would be prepared in a form other than bread would be a good one in the case of the 10 kg child and more questionable for the older child. The LP solutions to these diets did indicate that alternate low cost formulations exist which include bread and additional cowpeas and involve reduced levels of wheat. The level of oil used in these diets is high but either oil or sugar was necessary to fulfill the calorie constraints without exceeding the limitation on bulk. It is interesting to note how the differences between locally used legumes may be significant. Without the inclusion of chickpeas it was not possible to obtain a diet based on the locally used foods which met the calorie, protein and bulk constraints.

Rice Diet: India and East Pakistan

The rice diets in Table 4 show that in India (the source of the prices used) rice is the cheapest source of calories and, in the case of Adult65, the amount of rice required to meet the caloric constraint also provides more than enough total protein and essential amino acids. However, it was necessary to place an upper bound on the amount of wheat entering the higher protein adult diets to prevent wheat from replacing rice as the main component of the least cost diet. This occurred because wheat provided several of the amino acids more cheaply. The amount of rice in the Adult65 formulation can be reduced to lower levels through the substitution of an alternate source of calories. Inclusion of 430 kilocalories of oil, sugar, vegetables or a combination thereof would reduce the rice to 541 grams. Meeting the caloric constraint without violating the weight constraint would be still more difficult if the formulation had a higher calorie requirement, as would be the case if the physical activity of the target group were at more than a moderate to low level. For the pregnancy and lactation formulations reducing the amount of rice to levels near those of the typical pattern would result in an increase in the amount of dry beans to 150 or 200 grams. This results from the relatively low methionine and cystine contents of both rice and dry beans. A better source of these sulphur amino acids would be necessary to reduce the usage of rice without significantly increasing that of dry beans. Fish meets this need well and the inclusion of the 33 g found in the actual diet would reduce the rice content required to meet the nutritional requirements by around 100 grams. However, cottonseed meal (CSM), peanuts and other vegetable protein concentrates would be even more valuable for producing a low cost diet based on rice. At 75 ¢/kg CSM would still be included in the optimal mixture in the amount of 34 grams. This would reduce the use of rice significantly. The absence of a good methionine-cystine source also made it impossible to reduce the dry weight of the lactation formulation below 1100 grams.

It was impossible to formulate children's diets based solely on rice and other locally used foods which met the nutritional constraints without exceeding the bulk constraint. Large amounts of wheat and cowpeas (a product which is not normally used in India and had thus been given an artificial price of 99 ¢/kg), as well as oil, were needed to compensate for the low nutritional density of rice. Lower bounds on the usage of rice in these diets had to be established to keep it in the formulation at all. Any low cost mixtures, based on locally grown crops, that used a substantial amount of rice required the use of CSM, peanuts or a similar concentrated source of protein alien to the normal diet to meet the nutritional and bulk constraints.

Maize Diet: Mexico

For the maize formulations shown in Table 5, upper bounds were placed on maize and rice to keep usages near the actual consumption pattern. If patterns from another maize consuming nation had been used, the amounts of bread and rice used might have been somewhat different, as there is much variation in secondary staples throughout the maize region. In Mexico wheat is consumed chiefly as bread, thus an upper limit of zero was placed on other forms of wheat in the adult diets.

The Adult65 formulation was quite reasonable. If a reduction in the amount of maize in the diet was forced by reducing the appropriate upper bound, up to 50 g of maize could be replaced by an equivalent amount of sugar. This would effect a 5 % increase in the cost of the formulation.

The Adult55P and Adult55L formulations have excessive amounts of dry beans. This results from the large loss of tryptophan involved in processing maize into tortillas. To reduce the quantity of beans, the bread and/or maize usages would have to increase above those of the actual diet portrayed. To maintain tryptophan in the required amount it would be necessary to add approximately 10 g of tortilla or 2.5 g of bread for each gram of beans removed from the formulation. In addition to resulting in usages of bread and maize well above those of the example diet, the weight constraint on the diet would become binding. In the present lactation formulation the weight is nearly at the limit of 1400 g.

In the children's diets the sugar and oil can be interchanged at very slight cost and a certain amount of adjustment can be made between the wheat included in the diet and maize, rice or sorghum. Sugar was included in the Child10 formulation while oil came into the Child20 formulation because, while oil is a cheaper source of calories than sugar, sugar was assigned a slightly lower bulk per calorie than was oil. This caused the use of sugar in the diet for the younger child where the effect of the bulk constraint is more critical.

Yam and Cassava Diet: Southern Nigeria

The solutions for the yam and cassava diets, shown in Table 6, can not resemble the actual diet of Eastern Nigeria to a very great extent and still meet the nutritional requirements. It was necessary to place lower bounds on the usage of both yams and cassava to have them appear in the diet at all. Upper bounds had to be set on the usage of maize to prevent its becoming the major item in the diet. For the Adult65 formulation it was possible to have a fairly reasonable diet based upon roots and tubers if oil and cowpeas were included in amounts in excess of those actually consumed. For the other diets the amounts of cowpeas used become absurd. It would be possible to add an additional 100 g of yams and cassava to the Adult55P diet before reaching the upper limit of allowable weight, and a maximum of 12 g of yams and cassava could be added to the Adult55L formulation. Cowpea usages would decrease very slightly. These changes would have to be forced by the use of higher values of the lower bounds on usage, since they would further increase the price of the least cost formulations.

It is impossible to meet the nutritional and bulk constraints for the children's diets if any more than token amounts of yams and cassava are forced into the formulation. In no case would yams and cassava have entered into a least cost diet unless forced in by lower bounds on ingredient usage. For all the diets in this region calling for high quality protein, the inclusion of protein concentrates would have been feasible even at costs of 3 to 7 times those of the staples, yams and cassava.

For further discussion of this point, see the section entitled "Opportunity Costs for Protein Concentrates".

DISCUSSION OF BINDING CONSTRAINTS

The extent to which various constraints are binding in the different diets can be seen in the binding constraints sections of Tables 2-6. In general the following picture is apparent. For the Adult65 diets, with the exception of the yam and cassava diet, the predominant binding constraint is that for calories. This statement is based on the fact that, in those cases where total protein or any of the essential amino acids are binding in addition to calories, the cost for a given percentage change of its constrained value is generally at least an order of magnitude less than that for an equal percentage change in calories. For the children's diets the picture is quite different. For these constraint sets there are several constraints binding simultaneously. One or two of the essential amino acids are usually as binding or more binding than calories. It is also apparent that for these formulations the bulk constraint is an important one. Clearly it would have been misleading to use LP as a guide to formulation of least cost infant diets without considering the effect that an upper limit on the consumable volume of food has on the level of nutrient concentration included in the formulated diets. The existence of a constraining volume is responsible for making it advantageous to include protein and calorie concentrates in the children's formulations. The composition data and analysis data for such formulations demonstrates that both concentrated sources of protein, such as legumes and oilseeds, and concentrated sources of calories, such as oils or sugar, are needed to meet the nutritional constraints without exceeding the volume constraint. The Adult55P diet and the Adult55L diet are not so easy to categorize. The constraint that is binding varies from case to case, and there is no definite pattern. These variations occur because the formulated diets are not always in accord with the regional dietary patterns, as discussed in the preceeding section, and because these diets are exceptionally sensitive to the compositions and relative costs of the local foods.

The yam and cassava diets present a special case. Here the difference in importance between calories and the other constraints is small in the Adult65 diet. There is not as abrupt a change in problem as one moves to the diets for children. This is because the low nutrient densities of the staples make all the diets depend chiefly on the nutrient balance of cowpeas.

Table 7 is one way of portraying the general increase in the extent to which other constraints become binding (as compared to the caloric constraint) when one turns from the Adult65 diet to the formulations for children. For the Adult65 formulations the ratios of non-caloric to caloric costs per one per cent change in constraint levels are zero or small. For each region and staple the ratio increases for the 20 kg child formulation and for the 10 kg child formulation.

OPPORTUNITY COSTS OF PROTEIN CONCENTRATES

Table 8 presents the opportunity cost data from the LP solutions in a normalized form. The analysis accompanying the solution included a maximum price at which ingredients not included in the formulation could appear in an alternate optimal solution having exactly the same total cost. For each region these opportunity costs for protein concentrates have been divided by the price of the staple food for that region. This insures that differences in opportunity costs due to different price levels in the different regions are minimized. Since the protein levels in these concentrates are approximately 3 to 4 times those in the staple crops, an opportunity cost of this order would indicate the value assigned the concentrate was due to its protein content. Lower opportunity costs would indicate that the protein content of these concentrates was not a significant aid in meeting the binding constraints of the diet. Higher values would indicate that other attributes, such as high nutrient concentration (low bulk per nutrient), give the protein concentrates more value in a given circumstance than would result from their protein analysis alone.

Several statements can be made about the variation of these opportunity costs with constraint set and with region. In general the value of these products is highest for the 10 kg child, followed by the 20 kg child. The lowest values are found in the formulations for the Adult65 constraint set. The values in the lactation and pregnancy formulations are of an intermediate level.

Available data on actual prices for cottonseed meal and for peanuts indicate that in Nigeria and in India the prices of cottonseed meal are roughly equal to the prices of the respective staples while the prices of peanuts are one to two times those of the staples (16). For both products these actual prices are significantly less than their opportunity costs in formulations for several of the target groups. However, cottonseed meal is shown by the opportunity costs to have a generally higher value in the formulations than peanuts. This would appear to make the use of cottonseed meal based formulations much more favorable economically than the use of peanut based formulations.

The values of opportunity costs for Southern Nigeria are also interesting. This is the only region in which the protein supplements have a high opportunity cost (4 to 6) in the case of the Adult65 diet. Here the staples have so little nutritional value that both the caloric and protein values of the concentrates are important.

The protein supplements are shown as having high values in the 10 kg child formulations and generally a lower but still significant value in the production of low cost formulations for older children. Only in a few cases does the opportunity cost criteria establish a significant usefulness for the supplements in meeting the lactation requirements. These cases, for the rice and yam and cassava diets, may be worth further examination. For the Adult55P formulation several of the concentrates show significantly high opportunity costs for the rice, maize, and yam and cassava regions to suggest examination of possible pregnancy foods.

OPPORTUNITY COSTS OF ANIMAL PRODUCTS

Opportunity costs obtained for several animal products are listed in Table 9. In general the opportunity costs for these products in the children's formulations were the same as those of the better vegetable protein concentrates, such as cottonseed meal (Latin American composition). The animal products generally displayed lower opportunity costs for the adult diets than did the vegetable products. In several cases these products would not enter the least cost formulation for the Adult65 constraint set unless their cost was well below that of the regional staple. This occurs because of the low caloric concentrations of the animal products. Only in the case of the pregnancy diet based upon yams and cassava did the value of any of the animal products rise. This resulted from the fact that calories were not a binding constraint in this formulation.

CONCLUSIONS

The results of this study point out the extreme difficulty of formulating child food mixtures that satisfy both the nutritional and bulk constraints when the staples are rice or yams and cassava. This indicates that success with programs based upon education of mothers to use good mixtures of locally produced foods, such as those conducted in Haiti by the Mothercraft Centers (29), would be more difficult to obtain in regions using these staples than in regions using maize or millet. This indicates at least a bound on the usefulness of this approach to nutritional improvement in certain regions. Better mixtures than those presently used in these regions might be devised, but it would be difficult or impossible to create low cost, low bulk mixtures meeting all nutritional requirements.

The solutions for the wheat region also indicate that the feasibility of the mixture of local products approach is highly dependent on the composition of the local legumes. Feasible solutions for children's formulations did not exist based upon wheat and dry beans. Instead an alternate legume, chickpeas, had to be included. It might prove hard to explain in educational programs that one sort of legume was more worthy of inclusion in foods for children than another that might appear to be very similar.

The appearance of calorie concentrates such as oil or sugar in all the child formulations points out the need for consideration of the caloric base in diets to which protein supplements are to be added. Much of the protein value of a supplement can be wasted as metabolized energy if the caloric content of the supplemented diet is low (30). In cases where the caloric content of the base diet, as well as the protein content, is low, it might be advisable to consider the addition of concentrated sources of low cost calories to the formulated supplements.

Opportunity cost data can serve as a screen for determining which supplements are worthy of consideration within a given region. If the local prices of products under consideration are much below the level of their opportunity costs in the diet formulations being considered, they could then be advantageously used in low cost industrially processed formulations. The cost advantages of various proposed or available products can then be compared. This would be useful as a very low cost is necessary for a manufactured supplement if it is to be successfully introduced in a region where many people grow food for their own use rather than purchasing it in markets. It might also prove advantageous to cut product development costs by borrowing already developed and tested formulations from other regions. The opportunity costs would help indicate if it could be worthwhile to explore new formulations with attendant research and time costs, or if borrowed formulations would be only marginally more costly than the best potential but untried ones. For instance, the high opportunity cost of cottonseed meal shown for children's formulations for the rice region suggests that the Institute of Nutrition of Central America and Panama formulations (31) based upon this protein concentrate might be used in rice regions. This would look especially attractive as alternate products included in the runs did not

PAGES (S) MISSING FROM ORIGINAL

Page 37 Missing

have comparable opportunity costs. The cost of peanuts, for example, would have to be a factor of 3 or 4 less than that of CSM before a protein supplement based on peanuts could become significantly cheaper than one based upon CSM.

This study has been a preliminary effort designed primarily to demonstrate the analytical approach and to present some general results. The details of the results are tentative and future work should be more directly tied to specific questions and programs of interest to organizations involved in nutritional improvement. After an LP study had been made of a selected problem the next steps would be tests for acceptibility and effectiveness of the formulations selected. If the objective was to introduce a product commercially, marketing tests would also have to be conducted. If the formulations initially considered failed to meet standards of effectiveness or acceptibility, the results of the tests could be included as bounds or constraints in new LP formulations. By this means the most economically attractive formulation meeting all nutritional, cultural and practical criteria could be achieved and implemented as a method of nutritional improvement.

REFERENCES

1. Cravioto, J. and DeLicardie, E. R., Nutrition Reviews, Vol. 29, No. 5, pp. 107-111, 1971.

2. Dantzig, G., (see reference 20).

3. Potter, L. M., et al., Linear Programming and Its Use in the Feed Manufacturing Industry, The University of Connecticut, College of Agriculture Experiment Station, Bulletin 371, Jan. 1962.

4. Smith, Victor E., "Linear Programming Models for the Determination of Palatable Human Diets", Journal of Farm Economics, 41:272-83 (1959).

5. Smith, Victor E., Electronic Computation of Human Diets, MSU Business Studies, 1963.

6. Florencio, Cecilia A. and Smith, Victor E., "Toward More Efficient Expenditure for Food Among Colombian Families", Nutrition Reports International, Vol. 1 No. 4, pp. 207-230, 1970.

7. Buffa, Aldo, La Production Industrille d'Aliments Enrichis en Proteines dans les Pays en Cours de Developpment, Industries Alimentairs et Agricoles, May 1967, Number 5.

8. Devanney, J. W., III, The Economics of Fish Protein Concentrate, Report No. MITSG 71-3, November 20, 1970.

9. Food Composition Tables for Use in Africa, FAO, Rome, 1968.

10. Block, R. J., and Weiss, K. W., Amino Acid Handbook, Charles C. Thomas, Springfield, Illinois, 1956.

11. Bowes, H. N. and Church, Charles F., Bowes and Church's Food Values of Portions Commonly Used, 10th Ed., Lippincott, 1968.

12. Food Composition Table for Use in Latin America, INCAP-ICNND, Bethesda, Maryland, 1961.

13. Maize and Maize Diets: A Nutritional Survey, FAO, Rome 1954.

14. Agricultural Development in Nigeria, 1965-1980, FAO, Rome, 1966.

15. Projections of Supply of and Demand for Agricultural Products in Mexico to 1965, 1970, and 1975, USDA, Economic Research Service, S. Monson,Jerusalem, 1966.

16. Production Yearbook for 1969, FAO, Rome, 1970.

17. Glinsukon, T., et al., A Complete Weaning Food for India, unpublished paper prepared for course 20:38, May 1970.

18. Hutton, Robert F. and Allison, J. R., "An LP Model for Development of Feed Formulas under Mill-Operating Conditions", Journal of Farm Economics, 39:94-111 (1957).

19. Wagner, H., Principles of Operations Research, Prentice-Hall, 1969.

20. Hadley, G. Linear Programming, Addison-Wesley, 1962.

21. Provisional Indicative World Plan for Agricultural Development, FAO, Rome, 1958.

22. Munro, H. N., "Amino Acid Requirements and Metabolism and Their Relevance to Parenteral Nutrition", to be included in Parenteral Nutrition, Wilkenson, A., ed.

23. Protein Requirements, WHO Technical Report Series #301, WHO, Geneva 1965.

24. Caloric Requirements: Report of the Second Committee on Calorie Requirements, FAO, Rome, 1958.

25. Recommended Dietary Allowances, 7th Rev. Ed., NAS-NRC, Food and Nutrition Board, Pub. No. 1694, NAS, Washington, 1968.

26. Nicol, B. M., Nutrition Reviews, Vol. 29, No. 4, pp. 83-88, 1971.

27. Turkey, Nutrition Survey of the Armed Forces, Interdepartmental Committee on Nutrition for National Defense, NIH, Bethesda, Maryland, April 1958.

28. Pakistan, Nutrition Survey of East Pakistan, Nutrition Section, Office of International Research, NIH, May 1966.

29. King, Kendall, "Development of All-plant Food Mixture Using Crops Indigenous to Haiti: Amino Acid Composition and Protein Quality", Economic Botany, Vol. 18, No. 4, Oct.-Dec. 1964, 311-322.

30. Sukhatme, P. V., "Size and Nature of the Protein Gap", Nutrition Reviews, Vol. 28, No. 9, Sept. 1970, 223-226.

31. Incaparina, INCAP, 1962

Table 1

NUTRITIONAL CONSTRAINTS FOR SELECTED POPULATION GROUPS

Nutrient	Units	Adult65	Adult55P	Adult55L	Child10	Child20
Calories	kcal/day	2400	2400	3400	1150	1700
Total Protein	g/day	39	39	48	15	20
Isoleucine	mg/day	1030	2575	3170	990	1320
Leucine	mg/day	1370	3430	4230	1320	1760
Lysine	mg/day	1000	2500	3070	960	1320
Phenylalinine plus Tyrosine	mg/day	1560	3900	4800	1500	2000
Phenylalinine	mg/day	900	2250	2780	870	1160
Methionine plus Cystine	mg/day	860	2150	2640	825	1110
Methionine	mg/day	370	935	1150	360	480
Threonine	mg/day	790	1975	2450	765	1020
Tryptophan	mg/day	250	625	770	240	320
Valine	mg/day	1140	2850	3500	1095	1460
Volume in child diet	liters/day	-	-	-	.9	1.25
Weight	kg/day	1.4	1.4	1.4	-	-

Table 2

FORMULATED LEAST COST DIETS

Staple: Millet and Sorghum   Example: Northern Nigeria

Foods	Typical Pattern[a]	Adult65	Adult55P	Adult55L	Child10	Child20
		(all amounts dry weight in g/day)				
Millet[b,c]	230	387	506	621	98	223
Sorghum[b,c]	245					
Other Grains	36					
Cassava[b]	180					
Yams[b]	289					
Oil[b]	14	119	43	104	45	75
Cowpeas[b]	40	6	86	105	121	70
Nuts	12					
Peanuts[b]	19				0[u]	0[u]
Dairy	53					
Meat	35					
Binding Constraints ("cost"/per cent)[d]						
Calories		.0050	.0050	.0071	.0066	.0066
Total Protein		.0005	-	-	-	-
Sulfur Amino Acids[e]		-	.0072	.0270	.0380	.0380
Lysine		.0006	.0021	.0003	-	-
Volume		-	-	-	.0390	.0390
Cost per Day (¢)		3.87	4.72	6.39	2.68	3.21

[a]From estimated per capita food supplies in Northern Nigeria, Agricultural Development in Nigeria

[b]Foods considered by LP for inclusion in least cost diet.

[c]Alternate formulations in which arbitrary amounts of the millet in the present formulation have been replaced by sorghum are possible at small incremental cost.

[d]Cost in cents to effect a one per cent change in the level of the given binding constraint, divided by the price per kilogram of the regional staple for purposes of normalization between regions.

[e]Methionine plus cystine

[u]Food usage at upper bound

Table 3

FORMULATED LEAST COST DIETS

Staple: Wheat   Example: Turkey

Foods	Typical Pattern[a]	Adult65	Adult55P	Adult55L	Child10	Child20
		(all amounts dry weight in g/day)				
Bread[b]	852	756	730	900[u]		
Rice	34					
Other Wheat[b]	65	100[u]	100[u]	100[u]	163	265
Oil[b]	36			57	46	79
Sugar[b]	32					
Chickpeas[b]	30				57	12
Dry Beans[b]	38		21	31		26
Lentils	7					
Vegetables	158					
Fruits	32					
Dairy	16					
Meat	134					
Binding Constraints ("cost"/per cent)[c]						
Calories		.0087	.0070	.0151	.0065	.0083
Methionine		-	-	-	.0160	.0070
Lysine		-	.0020	.0083	-	.0014
Volume		-	-	-	.0176	.0098
Cost per Day (¢)		8.73	8.89	13.09	4.80	6.64

[a]Averaged values from Nutrition Survey of the Armed Forces, Turkey (27)

[b]Foods considered by LP for inclusion in least cost diet.

[c]Cost in cents to effect a one per cent change in the level of the given binding constraint, divided by the price per kilogram of the regional staple for purposes of normalization between regions.

[u]Food usage at upper bound

Table 4

FORMULATED LEAST COST DIETS

Staple: Rice   Example: India and East Pakistan

Foods	Typical Pattern[a]	Adult65	Adult55P	Adult55L	Child10	Child20
		(all amounts dry weight in g/day)				
Rice[b]	505	659	856	1080	80[l]	80[l]
Wheat[b]	18		40[u]	40[u]	71	86
Other Cereals	6					
Starchy Roots	56					
Oil[b]	6				43	73
Sugar[b]	7					
Dry Beans[b]	25		13	13	19	96
Cowpeas[b]					50	41
Vegetables	134					
Fruit	10					
Dairy	17					
Meat	6					
Fish	33					
Binding Constraints ("cost"/per cent)[c]						
Calories		.0066	–	–	.0063	.0093
Sulfur Amino Acids[d]		–	.0100	.0120	.0226	.0301
Methionine		–	–	–	.0159	.0213
Lysine		–	.0001	–	–	–
Volume		–	–	–	.0353	.0093
Cost per Day (¢)		9.23	12.98	16.11	11.94	15.32

[a]Food intake by rural groups in East Pakistan, Nutritional Survey of East Pakistan (28)

[b]Foods considered by LP for inclusion in least cost diet.

[c]Cost in cents to effect a one per cent change in the level of the given binding constraint, divided by the price per kilogram of the regional staple for purposes of normalization between regions.

[d]Methionine plus cystine

[u]Food usage at upper bound

[l]Food usage at lower bound

Table 5

FORMULATED LEAST COST DIETS

Staple: Maize   Example: Mexico

Foods	Typical Pattern[a]	Adult65	Adult55P	Adult55L	Child10	Child20
		(all amounts dry weight in g/day)				
Maize[b,c]	623	630[u]	400	630[u]	134	194
Bread[b]	150		124	174		
Rice[b]	20	40[u]	40[u]	40[u]		
Wheat[b]		0[u]	0[u]	0[u]	49	58
Starchy Tubers	30					
Oil[b]	16	1				73
Sugar[b]	99				100	
Dry Beans[b]	69		145	158	36	51
Vegetables	35					
Fruits	136					
Milk	285					
Meat	45					
Binding Constraints ("cost"/per cent)[d]						
Calories		.0103	.0051	.0115	.0062	.0076
Sulfur Amino Acids[e]		-	.0010	-	.0017	.0010
Methionine		-	-	-	.0132	-
Lysine		-	-	-	.0001	.0012
Trypthophan		-	.0028	.0024	-	-
Volume		-	-	-	.0182	.0034
Cost per Day (¢)		3.92	5.15	6.80	2.53	3.68

[a]Annual per capita consumption of foodstuffs, Projections of Supply of and Demand for Agricultural Products in Mexico to 1965, 1970, and 1975 (15)

[b]Foods considered by LP for inclusion in least cost diet.

[c]Tortillas were concerted to their maize equivalent. The upper bound on tortillas of 900 g (converted to a equivalent of 530 g maize) plus the upper bound on other maize of 100 g produce the total maize upper bound of 630 g.

[d]Cost in cents to effect a one per cent change in the level of the given binding constraint, divided by the price per kilogram of the regional staple for purposes of normalization between regions.

[e]Methionine plus cystine

[u]Food usage at upper bound

Table 6

FORMULATED LEAST COST DIETS

Staple: Yams and Cassava   Example: Southern Nigeria

Foods	Typical Pattern[a]	Adult65	Adult55P	Adult55L	Child10	Child20
		(all amounts dry weight in g/day)				
Yams[b]	761	700[1]	400[1]	350[1]	20[1]	20[1]
Cassava[b]	401	400[1]	400[1]	350[1]	5[1]	5[1]
Cocoyams	103					
Maize[b]	31	27	100[u]	100[u]	8	60[u]
Other Grains	14					
Oil[b]	31	110		61	46	75
Cowpeas[b]	11	78	393	529	202	233
Vegetables	50					
Fruit	15					
Meat	19					
Fish	23					
Binding Constraints ("cost"/per cent)[c]						
Calories		.0074	-	.0105	.0038	.0052
Total Protein		.0014	-	-	-	-
Sulfur Amino Acids[d]		.0026	.0169	.0133	.0080	.0055
Volume		-	-	-	.0043	-
Cost per Day (¢)		7.67	9.44	11.44	3.32	4.58

[a]From estimated per capita food supplies in Eastern Nigeria, Agricultural Development in Nigeria (14)

[b]Foods considered by LP for inclusion in least cost diet.

[c]Cost in cents to effect a one per cent change in the level of the given binding constraint, divided by the price per kilogram of the regional staple for purposes of normalization between regions.

[d]Methionine plus cystine

[u]Food usage at upper bound

[1]Food usage at lower bound

Table 7

COMPARISON OF THE EXTENT TO WHICH CALORIC AND

NON-CALORIC CONSTRAINTS ARE BINDING IN SELECTED FORMULATIONS

	C_{ncal}*/C_{cal}†		
Staples	Adult65	Child20	Child10
Millet and Sorghum	0.2	5.9	5.9
Wheat	0.0	2.2	5.2
Rice	0.0	10.8	11.7
Maize	0.0	0.7	5.4
Yam and Cassava	0.5	1.1	3.2

*C_{ncal}: Cost to change the most binding non-caloric constraint 1 % .

†C_{cal} : Cost to change caloric constraint 1 %.

Table 8

NORMALIZED OPPORTUNITY COSTS* OF PROTEIN CONCENTRATES

Protein Concentrate	Turkey	N. Nigeria	India	Mexico	S. Nigeria
Cottonseed Meal (LA)†					
Child10	19	29	33	19	10
Child20	8	29	33	3	7
Adult55P	3	3	5	6	9
Adult55L	2	3	5	3	7
Adult65	1	2	1	2	6
Cottonseed Meal (Africa)					
Child10	15	22	17	15	9
Child20	6	22	17	3	6
Adult55P	2	2	2	5	7
Adult55L	2	2	2	3	6
Adult65	1	2	2	2	5
Sesame Seed Meal					
Child10	21	17	33	19	8
Child20	8	17	33	3	7
Adult55P	2	2	4	4	6
Adult55L	3	2	4	3	6
Adult65	2	2	2	2	5
Soybean Meal					
Child10	12	18	17	14	7
Child20	7	18	17	4	5
Adult55P	3	3	4	5	6
Adult55L	3	3	4	3	5
Adult65	1	3	1	2	5
Sunflower Seed Meal					
Child10	11	12	10	10	6
Child20	5	12	10	3	6
Adult55P	2	2	3	3	5
Adult55L	3	2	3	3	5
Adult65	2	2	2	2	4
Peanuts (LA)					
Child10	6	23	9	14	9
Child20	4	23	9	4	7
Adult55P	2	2	4	5	7
Adult55L	3	2	4	3	7
Adult65	2	2	2	2	5
Peanuts (Africa)					
Child10	5	10	7	5	6
Child20	4	10	7	3	5
Adult55P	2	2	3	3	4
Adult55L	3	2	3	3	5
Adult65	2	2	2	2	4

(Continued on succeeding page)

Table 8 (cont.)

Staple	Wheat	Millet	Rice	Maize	Roots[§]
Staple Price (¢/kg)	10.2	6.2	14.0	5.8	4.3

*The normalized opportunity cost is defined as the opportunity cost of the protein concentrate divided by the cost of an equal weight of the predominant staple of the region in question.

[†]Latin American composition

[§]Average of Yams and Cassava

Table 9

NORMALIZED OPPORTUNITY COSTS*OF BEEF, GOAT, AND FISH

Animal Product	Turkey	N. Nigeria	India	Mexico	S. Nigeria
Beef					
Child10	19	10	32	9	5
Child20	7	10	32	2	3
Adult55P	2	2	2	2	4
Adult55L	2	2	2	1	3
Adult65	1	2	1	1	3
Goat					
Child10	13	7	19	12	3
Child20	6	7	19	2	2
Adult55P	1	1	2	1	3
Adult55L	1	1	2	1	2
Adult65	1	1	0	1	2
Fish					
Child10	22	14	34	21	5
Child20	9	14	34	2	3
Adult55P	2	2	3	1	5
Adult55L	1	2	3	1	3
Adult65	0	2	0	0	2
Staple	Wheat	Millet	Rice	Maize	Roots†
Staple Price (¢/kg)	10.2	6.2	14.0	5.8	4.3

*The normalized opportunity cost is defined as the opportunity cost of the product divided by the cost of an equal weight of the predominant staple of the region in question.

†Average of Yams and Cassava

APPENDIX A

DATA ON FOOD COMPOSITION AND COSTS

1. - Abbreviations and Units

Abbreviations	Explanation	Units
KCAL	Kilocalories	kcal/kg
PROTEIN	Total Protein	g/kg
TRP	Tryptophan	mg/kg
PHA	Phenylalinine	mg/kg
LEU	Leucine	mg/kg
ISL	Isoleucine	mg/kg
LYS	Lysine	mg/kg
VAL	Valine	mg/kg
MET	Methionine	mg/kg
THR	Threonine	mg/kg
METCYS	Methionine plus Cystine	mg/kg
PHATYR	Phenylalinine plus Tyrosine	mg/kg
WT	Weight of dry food	kg/kg
VOLUMECD	Volume of food as cooked in child diets	liters/kg
COSTN	Cost in N. Nigerian prices	¢/kg
COSTS	Cost in S. Nigerian prices	¢/kg
COSTM	Cost in Mexican prices	¢/kg
COSTT	Cost in Turkish prices	¢/kg
COSTI	Cost in Indian prices	¢/kg

2. - Food Compositions and Costs (per kg)

	Barley	Bread	Maize	Millet	Rice(LA)
COSTN	99.0	99.0	99.0	6.2	99.0
COSTS	99.0	99.0	10.0	99.0	99.0
COSTM	99.0	7.0	5.8	99.0	6.6
COSTT	99.0	10.2	99.0	99.0	99.0
COSTI	99.0	99.0	99.0	99.0	14.0
KCAL	3370.0	2738.0	3560.0	3420.0	3640.0
PROTEIN	100.0	84.0	93.0	97.0	72.0
TRP	1000.0	890.0	650.0	1650.0	910.0
PHA	4900.0	4580.0	4180.0	3880.0	3560.0
LEU	6800.0	6740.0	11800.0	12000.0	6360.0
ISL	3300.0	4190.0	3720.0	5140.0	3560.0
LYS	3400.0	2610.0	2510.0	2330.0	2570.0
VAL	4800.0	4250.0	4930.0	6120.0	4750.0
MET	1600.0	1380.0	1670.0	2230.0	1370.0
THR	3700.0	2750.0	3810.0	3690.0	2720.0
METCYS	4100.0	5180.0	3160.0	3590.0	2190.0
PHATYR	8000.0	8450.0	9090.0	6790.0	7940.0
WT	1.0	1.0	1.0	1.0	1.0
VOLUMECD	4.0	4.0	4.0	4.0	4.0

	Rice(Africa)	Rye	Sorghum (LA)	Sorghum (Af)	Tortilla
COSTN	99.0	99.0	99.0	6.2	99.0
COSTS	99.0	99.0	99.0	99.0	99.0
COSTM	99.0	99.0	99.0	99.0	3.4
COSTT	99.0	99.0	99.0	99.0	99.0
COSTI	99.0	99.0	99.0	99.0	99.0
KCAL	3610.0	3360.0	3420.0	3430.0	2100.0
PROTEIN	67.0	105.0	88.0	101.0	46.0
TRP	845.0	840.0	990.0	1110.0	185.0
PHA	3310.0	4720.0	4300.0	4850.0	1980.0
LEU	5920.0	7050.0	14400.0	16250.0	8700.0
ISL	3310.0	4300.0	4660.0	5250.0	1800.0
LYS	2390.0	3460.0	1790.0	2020.0	1010.0
VAL	4430.0	5250.0	4970.0	5660.0	2480.0
MET	1270.0	1160.0	1440.0	1620.0	780.0
THR	2540.0	4200.0	3040.0	3430.0	1620.0
METCYS	2040.0	1160.0	2890.0	3240.0	1290.0
PHATYR	7390.0	4720.0	9670.0	10900.0	3700.0
WT	1.0	1.0	1.0	1.0	1.0
VOLUMECD	4.0	4.0	4.0	4.0	8.0

Food Composition and Costs (per kg) cont.

	Wheat(LA)	Wheat(Af)	Cassava	Cocoyams	Potatoes
COSTN	99.0	99.0	2.7	99.0	99.0
COSTS	99.0	99.0	2.7	99.0	99.0
COSTM	7.0	99.0	99.0	99.0	99.0
COSTT	10.2	99.0	99.0	99.0	99.0
COSTI	18.0	99.0	99.0	99.0	99.0
KCAL	3300.0	3620.0	1090.0	865.0	836.0
PROTEIN	123.0	110.0	9.0	16.0	20.0
TRP	1580.0	1410.0	50.0	290.0	320.0
PHA	5800.0	5180.0	260.0	860.0	1120.0
LEU	9100.0	8130.0	430.0	910.0	1920.0
ISL	5800.0	5180.0	290.0	640.0	1000.0
LYS	3290.0	2940.0	470.0	660.0	1340.0
VAL	5830.0	5300.0	420.0	850.0	1080.0
MET	1580.0	1410.0	130.0	180.0	420.0
THR	5140.0	4590.0	340.0	540.0	1060.0
METCYS	5830.0	5300.0	180.0	440.0	680.0
PHATYR	10520.0	9420.0	430.0	1580.0	1120.0
WT	1.0	1.0	1.0	1.0	1.0
VOLUMECD	4.0	4.0	1.5	1.5	1.5

	Yams	Oil	Sugar	Chickpeas	Cowpeas
COSTN	5.8	11.5	99.0	99.0	12.8
COSTS	5.8	11.5	22.0	99.0	12.8
COSTM	99.0	22.0	9.7	99.0	99.0
COSTT	99.0	40.0	25.0	23.0	99.0
COSTI	99.0	40.0	26.0	99.0	99.0
KCAL	900.0	8840.0	3850.0	3640.0	3420.0
PROTEIN	21.0	0.0	0.0	182.0	233.0
TRP	380.0	0.0	0.0	2740.0	2100.0
PHA	1130.0	0.0	0.0	9100.0	12100.0
LEU	1200.0	0.0	0.0	26900.0	18400.0
ISL	840.0	0.0	0.0	11300.0	11400.0
LYS	860.0	0.0	0.0	10400.0	15400.0
VAL	1120.0	0.0	0.0	8200.0	12600.0
MET	230.0	0.0	0.0	1820.0	2300.0
THR	710.0	0.0	0.0	5840.0	9700.0
METCYS	570.0	0.0	0.0	1820.0	3900.0
PHATYR	2080.0	0.0	0.0	9100.0	23100.0
WT	1.0	1.0	1.0	1.0	1.0
VOLUMECD	1.5	.5	.2	4.0	4.0

Food Compositions and Costs (per kg) cont.

	Broad Beans	Dry Beans	Peanuts(LA)	Peanuts(Af)	Soybeans
COSTN	99.0	99.0	99.0	15.3	99.0
COSTS	99.0	99.0	99.0	99.0	99.0
COSTM	99.0	10.6	99.0	99.0	99.0
COSTT	99.0	20.0	99.0	99.0	99.0
COSTI	99.0	20.0	99.0	99.0	99.0
KCAL	3390.0	3370.0	5600.0	5490.0	3980.0
PROTEIN	240.0	220.0	267.0	232.0	337.0
TRP	2160.0	2200.0	3700.0	3220.0	4430.0
PHA	8160.0	11600.0	15800.0	13700.0	17570.0
LEU	18200.0	25900.0	18900.0	16400.0	28000.0
ISL	13200.0	12500.0	12300.0	10700.0	21400.0
LYS	13200.0	12500.0	10800.0	9400.0	24300.0
VAL	13400.0	11200.0	15200.0	13200.0	19200.0
MET	1200.0	1540.0	2480.0	2150.0	4060.0
THR	6250.0	10550.0	16600.0	7250.0	14400.0
METCYS	4080.0	3080.0	9770.0	5930.0	8490.0
PHATYR	15610.0	11600.0	33800.0	23650.0	29370.0
WT	1.0	1.0	1.0	1.0	1.0
VOLUMECD	4.0	4.0	4.0	4.0	4.0

	Cottonseed Meal(LA)	Cottonseed Meal(Af)	Sesame Seed Meal	Sunflower Seed Meal	Beef
COSTN	99.0	99.0	99.0	99.0	99.0
COSTS	99.0	99.0	99.0	99.0	33.0
COSTM	99.0	99.0	99.0	99.0	99.0
COSTT	99.0	99.0	99.0	99.0	99.0
COSTI	99.0	99.0	99.0	99.0	99.0
KCAL	3980.0	3690.0	5840.0	5750.0	2370.0
PROTEIN	329.0	277.0	176.0	224.0	183.0
TRP	5050.0	4250.0	3520.0	2240.0	7470.0
PHA	21100.0	17700.0	13000.0	9620.0	4500.0
LEU	22100.0	18600.0	14200.0	16600.0	7470.0
ISL	13900.0	11700.0	8450.0	8720.0	2130.0
LYS	17200.0	14400.0	4760.0	6280.0	14900.0
VAL	17900.0	15100.0	8970.0	17500.0	9520.0
MET	5450.0	4570.0	5820.0	3580.0	15900.0
THR	13200.0	11100.0	5460.0	7150.0	10090.0
METCYS	11700.0	9800.0	8070.0	6480.0	8030.0
PHATYR	29800.0	24900.0	19170.0	9620.0	4500.0
WT	1.0	1.0	1.0	1.0	1.0
VOLUMECD	4.0	4.0	4.0	4.0	2.0

Food Compositions and Costs (per kg) cont.

	Goat	Fish
COSTN	99.0	99.0
COSTS	29.1	28.0
COSTM	99.0	99.0
COSTT	99.0	99.0
COSTI	99.0	99.0
KCAL	1650.0	1540.0
PROTEIN	187.0	205.0
PHATYR	6130.0	7870.0
MET	3630.0	5800.0
PHA	6130.0	7870.0
TRP	1960.0	1870.0
LEU	11700.0	16350.0
ISL	7840.0	10770.0
LYS	12200.0	20920.0
VAL	7470.0	11300.0
THR	7180.0	9320.0
METCYS	3630.0	5800.0
WT	1.0	1.0
VOLUMECD	2.0	2.0

3. - Sources of Food Composition Data

Foods	Calories and Protein	Amino Acids
Barley	1	2,a (Dustin 53a)
Bread	3	3
Maize	4	2,a (Meal, Table XI)
Millet	1	2,a (Table XI)
Rice (LA)	4	2,c (Table XI)
Rice (Af)	1	2,c (Table XI)
Rye	1	2,a (Meal)
Sorghum (LA)	4	2,a (Table XI)
Sorghum (Af)	1	2,a (Table XI)
Tortilla	4	5,a
Wheat (LA)	4	2,b (Table XI)
Wheat (Af)	1	2,b (Table XI)
Cassava	1	2,a (Bigwood, '53b)
Cocoyams	1	2,a (Yam pattern)
Potatoes	3	2,a (white, average)
Yams	1	2,a (Edwards, '55)
Oil	4	Not Applicable
Sugar	1	Not Applicable
Chickpea	4	2,a (Massieu '50)
Cowpeas	1	2,a (Horn '50)
Broad Beans	4	2,a (Massieu '49)
Dry Beans	4	2,a (Mexican bean, cooked)
Peanuts (LA)	4	2,e (Meal, average)
Peanuts (Af)	1	2,e (Meal, average)
Soybeans	1	2,f (Block)
Cottonseed Meal (LA)	4	2,d (Average)
Cottonseed Meal (Af)	1	2,d (Average)
Sesame Seed Meal	4	2,a (Average)
Sunflower Seed Meal	4	2,a (Commercial Process)
Beef	1	3
Goat	1	3
Fish	3	3

Notes

a	6.25 g protein/g N,	Assumed
b	5.83 g protein/g N,	4
c	5.95 g protein/g N,	4
d	5.30 g protein/g N,	4
e	5.46 g protein/g N,	4
f	5.71 g protein/g N,	4

4. - Sources of Food Prices

All prices listed at 99.0 ¢/kg are fictitious and were assigned to exclude foods from formulations while obtaining opportunity costs. The remaining values of prices came from several sources. For Northern and Southern Nigeria prices were calculated from data contained in an FAO study of Nigerian agricultural development (6). For Mexico all prices except those of rice and bread were obtained from a 1966 report on agricultural supply and demand in Mexico (7). The rice price was estimated to be between the prices of maize and wheat, while bread was assigned the price of wheat. The Indian price for rice is an average of the FAO Production Yearbook figures (8). Other Indian cost data was modified from price data included in A Complete Weaning Food for India, an unpublished paper (9). The Turkish wheat price is also from the Production Yearbook (8). Bread was assigned the same price as wheat and other foods were estimated by analogy to Indian prices.

References

1. Food Composition Tables for Use in Africa, FAO, Rome, 1968

2. Block, R. J. and Weiss. K. W.; Amino Acid Handbook, Charles C. Thomas, Springfield, Illinois, 1956

3. Bowes, H. N. and Church, Charles F.; Bowes and Church's Food Values of Portions Commonly Used, 10th Ed., Lippincott, 1968

4. Food Composition Table for Use in Latin America, INCAP-ICNND, Bethesda, Maryland, 1961

5. Maize and Maize Diets: A Nutritional Survey, FAO, Rome, 1954

6. Agricultural Development in Nigeria, 1965-1980, FAO, Rome, 1966

7. Projections of Supply of and Demand for Agricultural Products in Mexico to 1965,1970, and 1975, USDA, Economic Research Service, S. Monson, Jerusalem, 1966

8. Production Yearbook for 1969, FAO, Rome, 1970

9. Glinsukon, T. , et. al.,"A Complete Weaning Food for India", Unpublished paper prepared for Course 20:38 , May, 1970

APPENDIX B

Estimation of Cooked Bulk per Unit Dry Weight

Since exact figures on the density of prepared infant diets were not available, estimates were made.

Common recipes for cereals prepared as gruels (oatmeal, wheat cereals, and corn meal mush) call for 29 to 43 grams of raw cereal (1 to 1.5 ounces) to make approximately 170 milliliters of cooked gruel (1). This is a volume per gram of dry cereal of 5.8 to 4.0. This range should be somewhat high as the cereals prepared for these uses have a lower moisture content than have the whole grains listed in the food composition tables.

A moisture content of 80 per cent is usual in infant foods and 10 per cent is a normal level in grains and dried beans as stored (2). Since infant foods prepared as gruels would have a specific gravity of approximately one, 1000 ml of gruel would contain 200 grams of dry matter (20% of 1000 grams). Two hundred grams of dry matter would be the equivalent of 220 grams of the basic food at a moisture content of 10 per cent. This is equivalent to a cooked bulk per unit dry weight of 4.5 ml/g.

For dry peas and beans values of 1.2 to 1.6 milliliters per gram dry weight are usual. In preparation for cooking, these legumes increase in the neighborhood of three times in bulk (3). This leads to bulks per unit dry weight of 3.6 to 4.8.

The consistency of gruels would vary in practice and the amount a child could consume would also vary with this consistency. Based upon the above figures an estimate of cooked bulk per unit dry weight of 4 ml/g was used for all grains, beans, and meals. This was hopefully within an interesting range.

For meats and for roots and tubers other figures were used. Assuming a specific gravity of approximately 1 for fresh meat, and noting that the nutrient densities in meat-based infant foods are roughly half those of whole meat, a cooked bulk per unit weight of 2 ml/g was used for meat products (4).

For root and tuber adult diets figures on bulk (5) and dry weight (6) indicated bulk as eaten of under 1.5 milliliters per gram of dry weight. Since yam fufu and similar products would be in the diets of all age groups this figure is probably a reasonable one to use. Since raw roots and tubers are approximately 80 per cent water, it may well be conservative.

Oils have a bulk per gram of approximately .5, and the value for sugar is slightly less than 1 ml/g (7). Since dissolved sugar would not add to bulk, it was assumed that only one fifth of the sugar would appear as an increment to the bulk.

References

1. Oat meal boxes, et. al.

2. Fomon, Samuel J., Infant Nutrition, W. B. Saunders Co., Philadelphia, 1967

3. Rietz, Carl A. and Wanderstock, Jeremiah, A Guide to the Selection and Cooking of Foods, Vol. 2, AVI, Westport, Connecticut, 1965

4. Bowes, H. N. and Church, Charles F., Bowes and Church's Food Values of Portions Commonly Used, 10th Ed., Lippincott, 1966

5. Nicol, B. M., Nutrition Reviews, Vol. 29, No. 4, April, 1971, pp.83-88

6. Agricultural Development in Nigeria 1965-1980, FAO, Rome, 1966

7. The World Almanac, 1970 Edition, Newspaper Enterprise Association, New York, 1969

APPENDIX C

Input Bounds on Ingredient Usage

1. - Adult Diets: Adult 65, Adult55P, Adult55L

Dietary Staple	Ingredient	Bound(g)	Type
Wheat	Bread	900	UP
	Wheat	100	UP
Rice	Wheat	40	UP
Maize	Wheat	0	EQ
	Tortilla	900	UP
	Maize	100	UP
	Rice	40	UP
Yams and Cassava	Maize	100	UP
	Yams	700*	LO
	Cassava	400**	LO

UP Upper bound set on usage of this ingredient.

LO Lower bound set on usage of this ingredient.

EQ Ingredient usage set equal to value of bound.

*Lowered to 400 g in the case of the Adult55P diet, and set at 350 g in the case of the Adult55L formulation.

**Lowered to 350 g in the case of the Adult55L diet.

2. - Child Diets: Child10, Child20

Dietary Staple	Ingredient	Bound	Type
Wheat	CSM (LA)	0	EQ
	CSM (Af)	0	EQ
	Sesame Seed Meal	0	EQ
	Sunflower Seed Meal	0	EQ
	Soybeans	0	EQ
	Peanuts (LA)	0	EQ
	Peanuts (Af)	0	EQ
	Goat	0	EQ
	Fish	0	EQ
	Beef	0	EQ
Rice	Same bounds as wheat plus		
	Rice	80	LO
Maize	Same bounds as wheat plus		
	Bread	0	EQ
	Wheat	60	UP
	Rice	40	UP
Yams and Cassava	Maize	60	UP
	Yams	20	LO
	Cassava	5	LO

UP Upper bound set on usage of this ingredient.

LO Lower bound set on usage of this ingredient.

EQ Ingredient usage set equal to value of bound.