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9. ABSTRACT
The purpose of this study was to design and illustrate an analytic framework for assessing the feasibility of fortification interventions. Over half of the developing world's population suffers from nutritional deficiency. Global malnutrition is clearly one of the most pressing problems facing the international community. In the 1960s, the problem was oversimplified as a "protein gap," and technocrats seized on cereal-grain fortification as the ideal solution. However, field research in the 1970s has revealed that the effects of fortification are far less automatic or dramatic than was presumed. Fortification is only one of several intervention options, many of which can be used together. The real question for planners, then, is the desirability and feasibility of fortification intervention for their nations. That issue is the focus of this study, and it examines fortification of three cereals: rice, wheat, and maize. The barriers to fortification lie in five categories: nutritional need (whether improved nutrient quality will alleviate certain deficiencies), structure of the commodity system (which block access to target groups), technology (which may be excessively complicated), consumer acceptability, and intervention economics (costs vs. benefits of fortification). Each of these barriers is examined in a separate chapter. The last three chapters apply the methodology for examining fortification barriers in Guatemala, Tunisia, and Thailand.

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TABLE OF CONTENTS

	Page
Chapter One: Cereal Fortification: An Overview	1
The Nutrition Problem	1
Fortification as a Solution	4
Purpose and Scope	5
Organization	6
Chapter Two: Nutritional Need	11
Overview	11
Nutritional Importance of Grains: Role in Country/Region	12
Limitations of Cereals as Protein Sources	14
Nutritional Impact Rationale for Fortification	20
Impact Limitations	25
Feasibility Questions	28
Chapter Three: Commodity System Structure	35
Interventions and Commodity Systems	35
Target-Group Coverage	36
Organizational Implications	38
Feasibility Questions	42
Chapter Four: Fortification Technology	45
Introduction	45
Fortificants: Their Properties and Cost	45
Vitamins	45
Minerals	50
Amino Acids and Proteins	53
Fortification Technologies	67
Wheat	70
Rice	77
Corn	80

	Page
Chapter Four: (Continued)	
Stability of Added Nutrients	83
Chemical Reactions	84
Leaching	86
Microbial Actions	86
Stability of Added Nutrients under Specific Processing and Storage Conditions	87
Feasibility Questions	87
Chapter Five: Consumer Acceptability	101
Introduction	101
Some Myths About Cultural Change	101
Data Requisites for Planning Change	103
About the Innovation	103
About the Socio-Cultural Context	105
Role of the Staple Cereal in the Culture	107
Characteristics of the Decision Makers	109
Characteristics of Participants	110
Process and Communication Variables	111
Consumer Acceptability Research Strategy	113
Culturally Relevant Data: Etics and Emics	114
The Need for Holistic Approach	117
The Need for On-Going Evaluation	117
Feasibility Questions	118
Chapter Six: Economic Aspects	123
Introduction	123
Nature of the Economic Barrier	123
Purposes and Organization of the Chapter	124
Intervention Costs	125
Introduction	125
The Methodology of Costing	125
Nature and Magnitude of Component Costs	130
Fortificant Costs	130
Converting to Social Cost	143
Conclusion	144

	Page
Chapter Six: (Continued)	
Intervention Impact	144
Introduction	144
Cost-Effective Analysis	145
Coverage and Delivery	146
Biological Development Measures	151
Conclusion	155
Cost/Benefit Analysis	156
Benefits	156
Comparing Benefits and Costs	158
Intervention Financing	160
A Concluding Note	165
Feasibility Questions	165
Chapter Seven: Case Study: Guatemala	169
Introduction	169
Nutritional Need	169
Consumer Acceptability	170
Other Barriers	170
Barrier I: Nutritional Need	171
Results	172
Barrier II: Commodity System Structure	196
Introduction	196
Channels of Distribution	199
The Tortilla Commodity System in Guatemala	200
Target Group Coverage	201
In-Home Milling Survey	201
Role of the Miller in the Commodity System Structure	210
Barrier III: Technology	219
Barrier IV: Consumer Acceptability	220
Result: Taste Distinction	221
Taste Preferences	221

	Page
Chapter Seven: (Continued)	
Barrier V: Intervention Economics	245
Fortificant Cost	245
Program Logistics	251
Control Costs	251
Cooperation Costs	253
Summary	253
Recommendations	255
Chapter Eight: Case Study: Tunisia	269
Introduction	269
The Tunisian Economy	269
The Agricultural Sector	271
Land Use and the Main Agricultural Regions	271
Land Ownership and Farm Sizes	272
Agricultural Labor Force	272
Agricultural Production	273
Trade in Agricultural Products	273
The Tunisian Government's Role in the Agricultural Sector	273
The Control of Agricultural Prices	274
Food Processing	274
The Office of Cereals	275
Cereal Production	276
Types and Major Uses of Cereals	276
Area Planted in Cereals and Cereal Farm Sizes	277
The Reliability of Cereal Production Data	279
Cereal Production	280
Cereal Yields	281
The Cereal Production Process	282
Foreign Trade in Cereals	283
The Total Availability of Cereals	285
The Uses of Cereals: Seed Use, Feed Use, and Human Consumption	287

	Page
Chapter Eight: (Continued)	
On-Farm Cereal Use	293
The Controlled Grain Marketing System	296
The Functioning of the Controlled System	296
The Size of the Controlled System	299
The Participants in the Controlled System	300
Controlled System Prices	303
Controlled System Purchasing Prices to Cereal Producers	303
Controlled System Cereals Selling Prices to Individual Purchasers	305
Controlled System Cereals Selling Prices to Mills	305
The Controlled System for Processing Wheat: The Large Mills	307
Large Mill Output Estimates	308
Estimates of Wheat Inputs into the Large Mills	309
The Distribution of Wheat to the Large Mills	312
The Extraction Rates Used in the Large Mills	313
The Products of the Large Mills	314
Large Mill Margins and Selling Prices for Processed Products	314
The Controlled System Distribution of Processed Wheat Products	315
Wholesale and Retail Distribution	315
Distribution through Government Food Programs	320
The Production and Consumption of Bakery Products, Pasta, and other Manufactured Wheat Products	321
Controlled System Distributors' Margins and Retail Prices for Processed Wheat Products	324
The Participants in the Controlled System	325
The Noncontrolled Wheat Distribution System	327
Definition of the Noncontrolled System	327
The Reasons for the Existence of the Noncontrolled System: Farmer and Consumer Attitudes Towards the Controlled and Noncontrolled Systems	329
Why Farmers Sell Their Grain to the Noncontrolled System Instead of the Controlled System	330

Page

Chapter Eight: (Continued)

Why Individuals Consume Locally Milled Wheat Products Instead of Centrally Milled Products 334

The Participants in the Noncontrolled System 341

The Tunisian Government's Policy Towards the Noncontrolled System 344

The Noncontrolled Distribution and Retail Systems 347

Noncontrolled System Prices: Farm Prices, Retail Prices, and Wholesale/Retail Margins 349

Wholesale and Retail Margins 353

The Small Mill System for the Processing of Noncontrolled Cereals and Cereals Consumed on the Farm 354

The Quantity of Cereals Processed by the Small Mills 354

The Number of Small Mills and Their Locations 356

The Facilities and Operations of the Small Mills 364

The Home Grinding of Wheat 374

Barriers to the Implementation of a Fortification Program in Tunisia: Centralized Program 376

Barrier I: Nutritional Need 376

Barrier II: Commodity System Structure 382

Barrier III: Technology 384

Barrier IV: Consumer Acceptability 385

Barrier V: Intervention Economics 387

Barriers to a Decentralized Fortification Program 394

Barrier I: Nutritional Need 395

Barrier II: Commodity System Structure 395

Barrier III: Technology 397

Barrier IV: Consumer Acceptability 398

Barrier V: Intervention Economics 398

Chapter Nine: Case Study: Thailand 409

Introduction 409

Barrier I: Nutritional Need 409

	Page
Chapter Nine: (Continued)	
Barrier II: Commodity System Structure	413
Production	413
Milling System	414
Coverage	418
Miller Surveys	419
Size	420
Fee	423
Paddy Procurement	425
Seasonality	426
Storage and Transportation	431
Cost	435
Miller's Attitudes	437
Summary	441
Wholesale/Retail	441
Barrier III: Technology	442
Barrier IV: Consumer Acceptability	445
Consumer Attitudes Towards the Characteristics of the Fortificant Granules	446
Consumer Participation in the Fortification Program	502
Barrier V: Intervention Economics	507
The Millers Appraisal of Consumer Willingness to Pay for Fortification	508
Consumer Evaluation of their own Willingness to Pay for Fortification	509
Comparison of Fortificant Costs with Consumer Expenditures on Rice and Rice Milling	511
Summary of Intervention Economics	515
Summary	516

APPENDICES

Appendix A: Annotated Bibliography	
Studies - Adult Human	A-1
Studies - Children	A-6
General	A-11

		Page
Appendix B:	Chemical Structures of Commercially Produced Vitamins	B-1
Appendix C:	Chemical Structures of Commercially Produced Amino Acids	C-1
Appendix D:	Progress for the Industrial Production of L lysine• HCL	D-1
Appendix E:	Outline of Industrial Processes for the Production of Soy Proteins (Wolf and Cowan, 1971)	E-1
Appendix F:	Process for Production of Fish Protein Concentrate	F-1
Appendix G:	Diagrammatic Representation of Flour Milling (Jones, 1958) and Premix Addition in Centralized Mills	G-1
Appendix H:	Tunisian Village Wheat Mill	H-1
Appendix I:	Manual Procedure for Fortifying Semolina and Flour at the Village Mill	I-1
Appendix J:	Production of Amino Acid and Vitamin Enriched Rice Kernels by Infusion (Mitsuda and Yasumoto, 1974)	J-1
Appendix K:	A Schematic Outline of the Simulated Kernel Process	K-1
Appendix L:	Estimates	L-1
Appendix M:	Maillard Browning Reaction	M-1
Appendix N:	Strecker Degradation	N-1
	Destruction of Amino Acids Under Oxidizing Conditions	N-2
Appendix O:	Schematic Representation of Reactions Leading to Vitamin Degradation	O-1
Appendix P:	Moisture Content of Cereals at Different Atmospheric Humidities and Temperatures	P-1
Appendix Q:	Social Costing and the Shadow Pricing of Foreign Exchange	Q-1
	Exclusion	Q-2
	Inclusion	Q-3
	Revaluation	Q-3
Appendix R:	Regions	R-1
Appendix S:	Basic Elements in Fortification Feasibility Analysis	S-1
	Introduction	S-1
	Nutritional Needs	S-2
	Commodity System Structure	S-3
	Technology	S-4
	Consumer Acceptability	S-6
	Intervention Economics	S-7
	Program Costing	S-9

		Page
Appendix T:	Estimates of the Size of the Noncontrolled System Derived from Records of Grain Purchases to the Controlled System	T-1
Appendix U:	Outline of Groups which Participate in the Controlled System, Noncontrolled Systems and Autoconsumption	U-1
Appendix V:	First Estimate of Number of Mills and Grinders	V-1

CHAPTER 1

CEREAL FORTIFICATION: AN OVERVIEW

James E. Austin

The Nutrition Problem

Over half the developing world's population suffers from nutritional deficiency. Table 1.1 shows that over 1.3 billion of its people do not consume enough calories; of this number, 932 million suffer a daily caloric deficit of more than 250 calories (Table 1.2). And where there are caloric shortages, Table 1.3's data suggest, other severe nutrient deficiencies are also likely among people of all income levels.

Protein-calorie malnutrition's toll is particularly heavy for young children; it contributes directly or indirectly to 57 percent of the deaths of one-to-four year olds in Latin America (Berg, 1973). Anemia and vitamin deficiencies are less threatening to life, but they can lead to the severe functional impairment of broad segments of the population. In Guatemala, for example, 78 percent of the population is estimated to suffer some degree of vitamin A deficiency, which can impair vision and, in extreme cases of xeropthalmia, lead to blindness (Austin and Ickis, 1974).

Malnutrition pervades both urban and rural areas. Its etiology most frequently, though not always, involves poverty; poor city dwellers and their rural cousins are its principal victims. Although the rural malnourished are more numerous, Table 1.4's data on West Pakistan suggest that urbanites suffer the most severe nutritional deficiencies.

These statistics reveal awesome human suffering. They also suggest a serious erosion in human capital that impedes economic development and socioeconomic progress. Clearly, global malnutrition is one of the most pressing problems facing the international community.

Table 1.1

Population with Calorie Intake Below Requirements, 1975

Region	Millions of People	Percentage of Total Population
Asia and Far East	924	82
Africa	243	77
Near East	112	51
Latin America	94	36
	1,373	71

Source: Shlomo Reutlinger, Marcelo Selowsky, I.B.R.D. Working Paper No. 202, December 1975.

Table 1.2

Population with Daily Deficits in Excess of 250 Calories

Region	Millions of People	Percentage of Total Population
Asia and Far East	707	63
Africa	93	61
Near East	61	33
Latin America	71	23
	932	48

Source: Shlomo Reulinger, Marcelo Selowsky, I.B.R.D. Working Paper No. 202, December 1975.

Table 1.3

Caloric and Nutritional Intakes as a Percentage of Requirements According to Income: Rio de Janeiro, 1973

Calories and Nutrients	Monthly per Capita Income, in Cruzeiros									
	Total	Less than 49.99	From 50.00 to 99.99	From 100.00 to 149.99	From 150.00 to 199.99	From 200.00 to 249.99	From 250.00 to 299.99	From 300.00 to 399.99	From 400.00 to 499.99	Above 500.00
Calories (cal)										
Consumed	1707	1208	1462	1892	1835	1954	1680	2158	1945	2441
Required	2019	1834	1881	2291	1985	2057	1711	2145	2189	2171
Percentage of coverage	84.6	65.9	77.7	82.6	92.4	95.0	98.2	100.6	88.9	112.4
Total Protein (g)										
Consumed	52.3	36.0	43.9	56.3	56.5	61.2	54.0	72.7	55.7	84.8
Required	46.9	42.1	43.1	53.3	46.8	47.9	40.6	50.1	53.4	51.9
Percentage of coverage	111.5	85.5	101.9	105.6	120.7	127.8	113.0	145.1	104.3	163.4
Lipid (g)										
Total	45.5	21.7	36.7	50.9	56.7	55.6	41.8	62.1	58.0	80.1
Calcium (mg)										
Consumed	370.5	247.8	456.2	345.5	386.7	359.6	500.9	541.4	354.6	419.0
Required	496.9	515.2	469.1	478.6	492.1	500.6	554.3	570.0	534.3	546.6
Percentage of coverage	74.6	48.1	97.3	72.2	78.6	71.8	90.4	95.0	66.4	76.7
Iron (mg)										
Consumed	11.9	8.7	10.1	12.5	13.3	13.7	12.0	17.8	14.2	16.6
Required	18.5	13.3	18.0	17.1	20.6	19.6	15.9	25.7	19.9	43.0
Percentage of coverage	64.3	65.4	56.1	73.1	64.6	69.9	75.5	69.3	71.4	38.6
Phosphorus (mg)	729.1	496.8	619.0	800.2	811.7	829.8	656.6	1016.0	797.0	1248.0
Thiamin (mg)										
Consumed	0.47	0.36	0.40	0.50	0.53	0.53	0.47	0.62	0.46	0.72
Required	0.80	0.73	0.75	0.91	0.79	0.82	0.68	0.86	0.88	0.87
Percentage of coverage	58.8	49.3	53.3	54.9	67.1	64.6	69.1	72.1	52.3	82.8
Riboflavin (mg)										
Consumed	0.59	0.34	0.50	0.64	0.71	0.68	0.64	0.77	0.67	0.90
Required	1.10	1.00	1.03	1.26	1.08	1.13	0.94	1.18	1.20	1.18
Percentage of coverage	53.0	34.0	48.5	50.8	65.7	60.2	68.1	65.3	55.8	76.3
Niacin (mg)										
Consumed	9.5	6.6	8.1	9.9	11.2	11.3	9.3	13.5	9.7	14.0
Required	13.3	12.0	12.4	15.0	13.0	13.5	11.3	14.1	14.4	14.3
Percentage of coverage	71.4	55.0	65.3	66.0	86.2	83.7	82.3	95.7	69.8	97.9
Ascorbic Acid (mg)										
Consumed	33.0	21.9	26.2	29.5	42.9	43.9	40.7	42.3	48.5	53.5
Required	26.0	24.0	25.2	28.5	26.2	26.1	21.3	28.2	27.1	27.0
Percentage of coverage	126.9	91.3	104.0	103.5	163.7	168.2	191.1	150.0	179.0	198.1

Source: Fundacas Getulio Vargos, Instituto Brasilero de Economia, Diui Saode E Statistical Econometrica, Pesquisa Sobre Consumo Aligmentar, Rio de Janeiro, 1975

Table 1.4

Per Capita Nutrient in Urban and Rural West Pakistan

Nutrient	Urban	Rural	Recommended
Calories (cal)	1806	2126	2067-2088
Protein (g)	58.4	69.8	58.5-59.5
Fat (g)	41.3	40.8	*
Carbohydrate (g)	300.2	369.9	*
Calcium (mg)	356.6	369.9	465
Iron (mg)	16.1	20.5	106.6-11.9
Vitamin A (I.U.)	1610	1731	2985-3042
Thiamine (mg)	1.59	2.05	0.83
Riboflavin (mg)	0.64	0.79	0.83
Niacin (mg)	17.9	21.7	13.7
Vitamin C (mg)	22.5	28.0	28.2

Source: S. M. Naseem. "Mass Poverty in Pakistan: Some Preliminary Findings," Pakistan Development Review 12: 4 (Winter 1973). Pp. 317-360.

*No recommended allowances.

Fortification as a Solution

During the past two decades, national governments and international agencies have increased their efforts to combat malnutrition. Protein fortification of cereal grains is one of the many different forms of "nutrition intervention" they have pursued. Others include supplemental feeding, nutrition education, agricultural production technology, new nutrient-dense processed foods, price subsidies, and programs combining improved health care with better nutrition.

The relative emphasis placed on these interventions has varied by country and over time. In the 1960s the belief that the nutritional problem could be solved with the right technological solution was dominant. The tendency to settle on a single solution was exacerbated by the oversimplification of the world nutrition problem as a "protein gap." In this climate, technocrats seized on cereal-grain fortification as the ideal approach. They heralded it, touted

it -- and oversold it. Field research in the seventies has revealed that fortification's effect is far less dramatic or automatic than they presumed.

Because of these negligible results, the seesaw of opinion may veer from excessive optimism to excessive pessimism. Yet neither extreme is conducive to effective nutrition planning, for there is no one solution to the nutrition problem. When the teeter-totter comes plummeting down in the other direction, the landing is still likely to be unsettling for the riders. Fortification is only one of a number of intervention options, many of which can be used together. A planner should view his or her task as designing a portfolio of nutrition programs that best fits a particular environment and its nutritional problems. Fortification may or may not play a role in any one nation's nutrition strategy.

The widespread belief that some form of fortification may help solve global malnutrition is evidenced by the World Food Conference's recommendation that countries seriously consider it as part of their nutrition programs. The real question for planners, then, is the desirability and feasibility of fortification intervention for their nations. That issue is the focus of this study.

Purpose and Scope

The basic purpose of our research has been to design and illustrate an analytical framework for assessing the feasibility of fortification interventions. The study is not normative; it does not conclude that fortification is good or bad. It starts from the premise that it could be either, depending on the situation.

We have not addressed the strategic question of whether a country should invest in nutrition, nor do we deal with the relative attractiveness of fortification compared to other nutrition interventions, we presume the desire to allocate resources toward nutrition programming. The focal point of the analysis is fortification intervention's feasibility. It is this feasibility -- or lack of it -- that will be a crucial consideration in the planner's comparison of alternative nutrition interventions.

Throughout this work we use the Joint FAO/WHO Expert Committee on Nutrition's definition of fortification: "the process whereby nutrients are added to foods to maintain or improve the quality of the diet of a group, a community, or a population (1971)." However, our examination is basically

restricted to the fortification of cereal grains: rice, wheat, and maize. The cereal grains are the basic foods of most of the world. They supply the majority of the world's calories and proteins, yet they are deficient in nutrient quality and so lend themselves to improvement by fortification. Our methodological approach is, however, largely applicable to carriers other than cereal grains. We will examine both macro-fortificants (proteins and calories) and micro-fortificants (vitamins and minerals).

This study began with a literature review. A selective annotated bibliography is included in Appendix A for the benefit of other researchers. Harvard researchers and their colleagues from sister institutions in Guatemala, Thailand, and Tunisia then carried out joint field studies. They used various types of surveys and tests in this research. These particular three countries became the objects of our research because they rely on the three basic staples and because they were the locations of previous longitudinal studies on the biological effect of protein fortification of cereal grains. Those studies, like this one, were financed by the U.S. Agency for International Development.

The research methodology of this study was multifaceted. The complex nature of malnutrition and the battle against it dictate such an approach. Accordingly, the research team included economists, nutrition scientists, dieticians, medical doctors, sociologists, anthropologists, food technologists, and management specialists. The resultant analytical framework therefore incorporates a variety of perspectives. The bond holding these disciplines together -- the concept of implementation barriers -- here also serves as this book's organizing principle.

Organization

As with all nutrition interventions, there are barriers to the effective implementation of cereal fortification. Identifying, understanding, and evaluating each of these obstacles is essential to determining the feasibility of a fortification program.

The implementation barriers to fortification fall into the following five general categories:

(1) Nutritional need - improved nutrient quality may not alleviate certain deficiencies or their causes

(2) Commodity system structure - the system may limit access to the target groups or create excessive administrative problems

(3) Technology - making and handling the fortificant, or adding it to the grain, may be excessively complicated

(4) Consumer acceptability - fortification may adversely alter the cereal's organoleptic characteristics, cooking properties, or cultural meaning, thereby generating consumer resistance

(5) Intervention economics - the cost of fortification may outweigh its benefits or may be excessively burdensome to affected groups

These are the hurdles that must be overcome to achieve feasibility. Each potential barrier has various aspects which determine how seriously it threatens implementation. We must examine each to assess its significance. The following five chapters explore, in turn, the above categories. They present an approach and illustrate its relevance with examples from the literature and from the field research in the three countries. The last three chapters of the book apply the general feasibility methodology in more detail in examining fortification barriers in Guatemala, Tunisia, and Thailand. Different dimensions of the methodology are emphasized in each country analysis because the scope of our study did not permit complete definitive feasibility studies. Barriers received varying attention so we might test our approach across countries and commodities. Even though the country studies are limited to prefeasibility analyses, we make tentative estimates of the feasibility of cereal grain fortification in each.

A concluding note on presentation is in order. Our methodology and analyses inevitably involve technical discussion. We have attempted to preserve the essence and detail of our studies while presenting them in generally understandable language. We hope this effort results in a treatment that is of maximum utility for specialists and generalists alike. To enahnce the applicability of our methodology, we have ended the five "barrier" chapters with feasibility questions which summarize the key elements of the methodology.

In addition, in Appendix (Appendix S) we have combined these check lists as well as presented the basic steps in costing out a fortification program so that readers can get a quick overview of the study as well as the basic elements needed for a feasibility analysis.

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CHAPTER 2

NUTRITIONAL NEED

Eileen T. Kennedy
Mohammed el Lozy
Stanley Gershoff

Overview

Fortification interventions are undertaken with the belief that, in a given population, a nutritional need exists and this need can be met by a fortification project. Poor nutritional status can be diagnosed through a combination of biochemical, clinical, dietary, and anthropometric measures. Nutrient deficiency states can take many forms. "Micronutrient inadequacies" often present a very clear-cut disease state; for example, an insufficient intake of ascorbic acid may result in scurvy. "Macronutrient inadequacies" like low intakes of calories or protein generally show up in a nonspecific symptom like general growth retardation. Nevertheless, any nutrient deficiency will eventually affect the health of the individual.

Some segments of the population have historically been more prone to nutrient deficiencies than others. Poverty and malnutrition have been closely related. It is not surprising, then, that lower-income groups have exhibited the most severe signs of undernutrition (Austin, 1976). Even within the low-income strata, certain groups are more "at-risk" of poor nutritional status because of their increased nutrient needs. As a general rule, nutrient requirements increase during periods of growth. Infants, preschoolers, adolescents, and pregnant and lactating women all have relatively greater nutrient needs than the general population -- and it is in these individuals that the detrimental effects of malnutrition are most prevalent. The high incidence of perinatal mortality, second- and third-degree malnutrition, and low birth weight in these groups reflects their particular vulnerability to nutritional insult. They are the primary targets for fortification interventions (Austin, 1976).

Once the nutrient deficiency has been identified, it can be eliminated by adding needed substances into a common food. Cereals, as the dietary mainstay of a large portion of the malnourished poor, are a logical candidate for the fortificants.

Nutritional Importance of Grains: Role in Country/Region

Grains are the major calorie source for the world, accounting for 52 percent of the average per capita intake of calories. In the developing countries, 95 percent of the population consumes cereals as its dietary staple (Abbott, 1969). There, rice is the predominant cereal grain, followed by wheat, maize, millet, and sorghum (Abbott, 1969).

The preference of dietary staple varies from area to area. Asians and Africans derive 60 to 75 percent of their caloric intake from cereals, whereas Latin American consumption is at approximately 50 percent of total calories (Milner, 1974). Table 2.1 lists grain consumption patterns in major regions of the world. Rice, it shows, is the predominant staple in Asia.

Wheat represents a high proportion of the diet of the Near and Middle East. Bread and other wheat products provide 70 percent of the calories for inhabitants of these areas. In some of the rural regions of Iran, wheat products provide as much as 85-95 percent of total daily calories (Sen Gupta, 1962-67).

Corn is the least globally-significant of the three major grains. Although fifty countries average an intake of less than 100 grams per person per day, fourteen countries consume 350 grams per capita. Corn is the primary cereal consumed in Latin America (Bressani et al., 1972). In Mexico, for example, corn provides 43 percent, wheat 8 percent, and rice 2 percent of the total calories.

In the typical dietary pattern of low-income groups in developing countries, the staple grain is only occasionally supplemented with vegetables and inexpensive bits of fowl, meat, or fish (A.I.D., 1973). The diet has limited variety, and so the cereal becomes the main source of protein as well as of calories.

In general, cereals provide 47 percent of the per capita protein intake of developing countries (F.A.O., 1965). It has been estimated that bread is responsible for 83 percent of the protein intake in the Middle East. Corn provides 44 percent of Mexico's protein, and rice contributes approximately 58 percent of the protein consumed in Thailand. Thus, rice, corn and wheat -- generally

Table 2.1

Calorie Levels per Capita and Percentage of Calories from Food Groups by Subregion in Ascending Order of Percent of Calories from High Carbohydrate Foods, Average 1959-61[a]

Subregion	Calorie Level No.	High Carbohydrate Foods[b] %	Wheat %	Rice %	Corn %	Other Grains %	Other Starchy Crops %	Pulses and Nuts %	Sugar %	Vegetables and Fruits %	Fats and Oils %	Meat, Fish, and Eggs %	Milk Products %
United States	3,190	40	17.4	0.9	2.0	0.5	3.1	3.3	15.7	6.2	20.5	16.9	13.5
Canada	3,100	42	18.8	0.6	1.0	0.9	4.5	1.9	16.3	4.8	15.1	22.0	14.1
Oceania	3,260	43	25.2	0.6	0.3	1.0	2.7	1.3	13.4	4.7	14.3	24.8	11.7
Northern Europe	3,060	48	23.4	0.6	0.4	3.6	6.9	1.7	13.4	4.5	17.8	16.4	11.3
River Plate	3,200	56	33.2	1.7	1.2	1.1	6.0	1.0	12.4	3.3	12.5	21.0	6.6
Southern Europe	2,720	60	40.1	2.4	2.5	1.3	6.0	4.4	7.6	7.4	15.6	6.9	5.8
Eastern Europe	3,000	66	32.1	1.0	5.7	10.8	7.8	1.3	8.5	2.9	11.4	11.9	6.6
Central America and Caribbean	2,240	69	8.8	9.4	19.2	3.8	12.7	5.9	15.0	4.2	8.6	7.4	5.0
Mexico	2,580	70	11.1	1.6	42.0	0.2	1.8	8.0	13.0	2.8	8.1	6.1	5.3
Other South America	2,260	70	16.9	5.9	13.8	2.2	15.5	3.9	15.9	3.9	7.5	9.0	5.5
Brazil	2,710	71	8.6	14.5	11.0	0.2	20.9	8.9	15.4	2.3	5.9	8.4	3.9
Southern Africa	2,670	72	14.0	1.1	39.1	2.5	1.1	1.7	14.0	2.4	5.3	12.4	6.4
West Asia	2,350	72	48.0	4.2	4.2	4.6	1.6	4.1	9.4	7.6	8.1	4.0	4.2
USSR	3,040	73	35.7	0.8	0.4	16.5	9.9	1.4	9.8	1.9	8.9	8.1	6.6
North Africa	2,210	73	26.4	3.1	7.6	28.6	1.3	5.7	6.1	6.1	6.0	4.3	4.8
India	2,060	74	11.3	33.1	4.0	15.0	2.6	13.2	8.2	2.0	4.2	0.9	5.5
Japan	2,360	78	11.7	46.9	--	4.6	7.7	5.9	6.7	4.2	5.0	5.0	1.4
Other East Asia	2,150	78	1.8	50.1	7.1	0.6	12.7	6.6	5.2	5.4	5.7	4.1	0.7
Other South Asia	2,120	79	19.4	47.1	1.9	3.0	1.0	5.9	6.7	3.6	4.0	3.0	4.4
West Central Africa	2,460	81	1.2	5.7	10.0	17.2	45.3	6.5	1.5	1.0	[illegible]	2.0	0.6
East Africa	2,390	83	2.3	8.4	34.1	21.8	12.4	6.5	4.3	0.8	3.4	3.6	2.4
Communist Asia	1,790	87	12.2	44.3	--	18.1	11.1	5.9	1.2	1.7	3.1	2.3	0.1

Source: [a]Economic Research Service (1964). The World Food Budget. U.S. Department of Agriculture, Washington, D.C., October 1964.

[b]Cereals, sugar, and other starchy crops.

thought of as calorie-providing foods -- are actually key protein sources for two-thirds of the world's population (Shertz, 1970). The greater the diet's dependence on cereals and cereal products, the more likely that a protein-deficient diet will also be deficient in calories.

Limitations of Cereals as Protein Sources

Although grains serve as primary sources of calories and protein for a major part of the world's people, cereals have nutritional shortcomings. The nutritive value of cereal protein is inferior to that of the higher quality protein of milk, meat, and eggs. This superiority of animal proteins has usually been attributed to their better ratios among the essential amino acids (Swendseid, 1969). Another reason for the superiority of animal protein is that essential amino acids form a higher proportion of its total amino acids than in plant protein. The eight essential amino acids plus arginine, histidine, cystine, and tyrosine comprise more than 62 percent of the total nitrogen in egg protein. In corn, the figure is only 48 percent.

The efficiency with which cereal proteins will promote growth and maintain body tissue is a function of their quantity and quality.

The absolute amount of protein in cereal grains is low, averaging between 8 and 12 percent of total calories. Rice, however, contains only 7 percent protein. Corn has slightly less protein than wheat. A comparison of the protein content of the major grains is shown in Table 2-2.

The quality of any protein source is determined by the essential amino acid content. All essential amino acids must be present and in the proportion necessary to optimize tissue growth and maintenance.

Infants need approximately 2g of protein/kg of body weight, whereas adults only 0.5g of protein/kg body weight (El Lozy and Hegsted, 1975). In addition, 37 percent of the infants' total protein need must be supplied by essential amino acids; in adults, amino acids must supply only 15 percent of the total protein. Infant growth demands more total nitrogen and essential amino acids. If a grain lacks one or more essential amino acids, then they become the limiting factor in the use of other amino acids.

Table 2.2

Relative Nutritive Value and Utilizable Protein in Various Protein Sources

Product	Protein Content %	Relative Nutritive Value %	Utilizable[a] Protein %	Literature Values[b]			NPU %
				Based on FAO Amino Acid Pattern %	Based on Milk Protein %	Based on Egg Protein %	
Lactalbumin	77.60	100	77.6				
Defatted egg	63.00	99	63.0	100	90	100	100
Casein	86.30	75	64.6	80	75	60	72
Fibrin	87.40	89	77.7				
Fish protein concentrate	81.10	77	62.5	70	70	75	83
Cottonseed flour I	58.90	66	38.9	70	95	80	66
Cottonseed four II	51.60	48	24.8				
Cottonseed flour III	37.70	65	24.5				
Soya flour, heated	51.90	60	31.1	70	85	70	56
Full fat soya	39.40	58	22.9				
Wheat gluten	71.00	24	17.0	40	40	40	37
Peanut flour	48.40	54	26.1	60	80	70	48
Rice flour, high protein	19.10	44	8.4	70	75	75	57
Sorghum I	9.80	31	3.0	70	60	60	56
Sorghum II	12.80	26	3.3				
Sorghum III	12.40	34	4.2				
White flour	13.75	28	3.8	50	50	50	52
Rice	8.30	50	4.2	70	75	75	57
Corn meal	7.95	37	3.0	40	40	45	55

[a]RNV x percent protein.

[b]Source: World Health Organization, (1965) Protein Requirements. Report of a Joint FAO/WHO Expert Committee, WHO Technical Series No. 301, World Health Organization, Geneva.

The calories from human breast milk are only 5 to 6 percent protein, less than the amount found in most cereals. But the milk protein is of greater value because it is of significantly higher quality.

There are essentially two different approaches to the assessment of protein quality. The first is to compare the amino acid composition of proteins or diets with the amino acid pattern required by man, the so-called amino acid score (El Lozy and Hegsted, 1975). This is a most attractive approach, but unfortunately our knowledge of human amino acid requirements is very imprecise at present. Indeed, Irwin and Hegsted (1971), after reviewing the available literature on amino acid requirements, concluded that "For most of the amino acids the estimated requirements may be no more accurate than ± 50 percent. Furthermore, we know very little about the amino acid requirements of children after the first few months of life. The FAO/WHO recommendations (1973) seem to assume that their needs are similar to those of infants, whereas one theoretical model (El Lozy and Hegsted, 1975) suggests that by the age of two years the amino acid requirements of children may be close to those of adults.

The second approach is to assay protein biologically by their growth-promoting effect in rats. The most widely used methods are the Biological Value (B.V.), Net Protein Utilization (N.P.U.), and the Protein Efficiency Ratio (P.E.R.). Recently, Hegsted, (1974) has criticized these methods and suggested a more sophisticated (and more time consuming) method of slope ratio assays, leading initially to what they call the Relative Nutritional Value (R.N.V.) and more recently to a slightly different Relative Protein Value (R.P.V.).

The result of this research is that the term "protein quality" is almost meaningless in isolation: any meaningful statement must discuss both the quality and the method of assay used. We have noted the difficulty in comparing a protein with human "requirements"; the same problem occurs with rats because different methods give different results (Miller, 1977). Furthermore, the weanling rat is not really a suitable model for human protein requirements since it uses about 80 percent of dietary protein for growth, whereas in a child over two years the figure is around 10 percent.

Finally, an added complication is that the response of animals to lysine deficiency is different from their response to deficiencies of other essential amino acids. Recently this difference has been attributed to a mechanism that causes

the main enzyme responsible for the degradation of lysine to decrease in animals fed diets low in lysine (Chu and Hegsted, 1976). This mechanism does not operate in the case of threonine, and it is not known whether it operates for any other essential amino acid.

Bearing these reservations in mind, it is interesting to see how various cereals compare to each other and to animal proteins when measured by these different methods. Table 2.3 summarizes the amino acid score of rice, wheat, and corn as compared to the reference amino acid pattern of milk and other high quality proteins.

Table 2.3

Amino Acid Score of Common Foods

Protein	Amino Acid Score
Whole Egg	100
Human Milk	100
Cow's Milk	95
Soya Bean	74
Milk	
Flour	
Toasted Grits	
Sesame	50
Groundout	65
Cottonseed	81
Maize	49
Millet	63
Rice, Polished	67
Wheat, Whole	53

Source: World Health Organization, 1973. Energy and Protein Requirement. Report of a Joint FAO/WHO Ad Hoc Expert Committee, WHO Technical Series No. 522, World Health Organization, Geneva.

Table 2.2 compares the Relative Nutritive Value (R.N.V.) for rice, wheat, and corn. The R.N.V. of rice is high in comparison to the other grains. Its higher lysine values account for rice's better score.

The amount of usable protein available from cereal grains is the product of the quantity of protein present and its quality. Therefore, although the protein quality of rice is high, its nutritive value as usable protein is low because of the small quantity of protein present. Table 2.4 illustrates the usable protein available from two thousand calories of wheat, maize, and rice. A total of 67.2 grams of wheat protein is available, but with protein quality scoring 40, the net usable protein is only 26.9 grams. Similar calculations can be made for corn and rice.

From a practical standpoint, the low amounts of usable protein in cereal grains suggests that large amounts must be eaten to achieve recommended amounts of protein. The FAO/WHO Joint Committee on Energy and Protein requirements (1973) has stated that it is possible to obtain useful amounts of protein from cereals if they are consumed in sufficient quantity. Bolourchi et al (1968) have demonstrated the possibility of maintaining a positive nitrogen-equilibrium in adults and in children aged seven and older with a diet based almost exclusively on a single cereal protein. However, this feat may not be possible for other groups in the population. Consuming enough vegetable protein to meet protein and lysine requirements is difficult for infants and preschool children because of sheer volume of food required. Graham et al, (1969) have estimated that a one year old infant of 10 kg with a lysine requirement of 9 mg/kg of body weight/day and a caloric requirement of 90 K calories/kg of body weight/day, consuming as his only source of protein a wheat flour with 11 percent protein and 2.5 grams lysine/100 grams protein, would have to consume 327 grams of flour daily to satisfy his lysine requirement. Even if he could consume and digest such a volume of food (which is impossible), he would become obese because of excess caloric intake.

Rice- and corn-based diets run up against similar bulk constraints. A rice diet is generally considered inadequate for normal growth in infants and toddlers (Huang and Tung, 1971). Here again, the protein content of the rice is low and it is deficient in lysine and theonine. It would be difficult for a weaning baby to eat enough rice to meet its protein requirements. A ten-month infant would have to consume 232 grams of rice per day to meet that requirement. Studies carried out in India show that children who were fed rice diets grew less well than those given protein-supplemented rice diets (Huang and Tung, 1971).

Table 2.4

Nutritional and Economic Evaluation of Cereal Protein Enrichment

Product combinations giving 2000 kcal per day						
Cereal Product	(gm)	Supplement	(gm)	Total Protein (gm)[a]	Chemical Score[b]	Usable Protein (gm)[c]
1	2	3	4	5	6	7
Whole wheat	551	-		67.2	40	26.9
	551	Lysine-HCL	0.78	68.0	52	35.3
	523	Soybean flour	22.9	75.3	47	35.4
	524	Skim milk powder	26.6	73.5	48	35.3
	529	Meat	35.5	73.6	48	35.3
	527	Fish	36.3	73.0	49	35.8
Wheat flour (60-70 percent extraction rate)	542	-	-	49.9	26	13.0
	542	Lysine-HCL	1.09	51.0	48	24.5
	507	Soybean flour	29.0	61.1	41	24.5
	506	Skim milk powder	36.1	59.6	42	25.0
	514	Meat	45.8	58.9	42	24.7
	513	Fish	44.6	57.9	42	24.3
	548	FPC	2.5	69.3	51	35.4
Bulgar (parboiled wheat)	542		-	60.7	37	22.5
	542	Lysine-HCL	0.76	61.5	50	30.7
	515	Soybean flour	22.5	68.9	45	31.0
	515	Skim milk powder	27.2	67.5	46	31.0
	520	Meat	36.0	67.4	46	31.0
	521	Fish	32.5	66.2	47	31.1
Maize meal	532			50.5	38	19.2
	532	Lysine-HCL	0.97	51.5	59	30.4
	499	Soybean flour	28.3	61.5	50	30.8
	497	Skim milk powder	35.6	60.0	51	30.6
	504	Meat	46.7	59.7	51	30.4
	503	Fish	45.4	58.7	52	30.5
Rice, polished	543			34.4	51	18.6
	543	Lysine-HCL	0.42	36.8	63	23.2
	532	Soybean flour	9.4	40.4	58	23.4
	532	Skim milk powder	11.0	39.6	58	22.9
	533	Meat	17.3	40.1	58	23.3
	533	Fish	16.7	39.7	58	23.0
Rice, parboiled	543		-	38.6	50	19.3
	543	Lysine-HCL	0.55	39.4	73	29.9
	509	Soybean flour	28.5	50.4	61	30.8
	508	Skim milk powder	35.0	48.7	63	30.7
	516	Meat	45.0	48.0	64	30.7
	515	Fish	43.8	47.1	65	30.6

Notes: [a]Analytical Data: FAO (1970) Amino Acid. Content of foods and biological data on proteins. FAO Nutritional Studies No. 24, Rome.

[b]Percentage of the first limiting Amino Acid to the Reference protein. World Health Organization (1973), Energy and Protein Requirements Report of a Joint FAO/WHO Ad Hoc Expert Committee WHO Technical Report, Series No. 522, World Health Organization, Geneva.

Source: Adapted from a table of Dutch State Mines, Agriculture, and Food Products Division, Heerlen, The Netherlands, November 1968.

Corn has identical handicaps. To maintain a positive nitrogen balance, a 10 kg child requires 338 grams of maize per day, which is the equivalent of what a Guatemalan adult would consume (Bressani et al., 1972). This amount of corn is difficult for a child to digest.

Discussion thus far has centered on the protein and amino acid limitations of grains. However, because staple cereals are the primary food consumed, they supply the major portion of calories and protein and also contribute a significant proportion of the vitamin and mineral content of the diet.

A diet of limited variety based solely on one cereal may precipitate a micronutrient deficiency. A study in rural Iran (Maltloudji et al., 1975) of children between 6 and 12 consuming a cereal-based diet found that 48 of 59 with a suboptimal concentration of plasma zinc. The authors suggest that the pathogenesis of malnutrition may be due to insufficient zinc intake. Zinc insufficiency has been shown to decrease the net synthesis of DNA, RNA, and protein; inadequate growth may point to a deficient micronutrient intake. An inadequate intake of zinc might negate the beneficial effect expected of lysine fortification. In the case of zinc, 34 percent of Tunisian children studied had hair zinc levels significantly below the normal or less than 75 ppm (Dept. of Nutrition, Harvard, 1976).

These micro-level deficiencies are probably exacerbated by the high phytate and fiber content of local grains. The concurrence of iron-deficiency anemia despite the high iron content in the diet of a rural Iranian population is attributed to the substantial intake of phytate supplied by unleavened wheat bread (Haghshenass, 1972).

Unlike other endeavors, fortification projects have alleviated micronutrient deficiencies. The erradication of endemic goiter in parts of Africa and the United States by iodinization of salt is but one example.

Nutritional Impact Rationale for Fortification

The nutritional status of populations consuming a diet based primarily on cereal does not seem adequate. Reports from countries where rice, corn, or wheat is the staple consistently show a high prevalence of protein-calorie malnutrition (PCM) among infants and preschool children of low income groups who are unable to supplement the staple with adequate quantities of other foods (Hedayat et al., 1973). The prominence of cereal grain proteins in the world's

diet raises concern that these plant proteins are not enough for normal growth and development.

Fortification is one means of combating both macro- and micro-level nutrient deficiencies in particular foods. The nutrients employed as the fortificant can be protein, amino acids, vitamins, minerals, or fat. The primary rationale for balancing deficient amino acid patterns by fortification is that it increases protein use without increasing the volume of food (Altschul, 1969). Fortification of a food with amino acids eliminates or reduces the deficiency of the limiting amino acid in a diet. This approach has the practical advantage of selectively improving the protein component of the diet without changing eating patterns.

If one is willing to make certain assumptions, improvements possible by fortification with limiting amino acids are impressive. The addition of a limiting amino acid can increase the biologically usable protein. The data in Table 2.5 show that the usable protein in 100g of wheat can be increased over 60 percent by the addition of 0.2g of lysine · HCl.

Milner (1974) estimates that the entire food supply of a country like Tunisia can be improved by adding lysine to the wheat flour which is its major source of protein and calories. Assuming an annual consumption of one million tons of wheat, Tunisia would gain the equivalent of 20,000 tons of high quality protein by adding lysine at 0.3 percent of the weight of wheat. Likewise, the usable protein of rice in a Thai village could be improved by the addition of 0.3 percent lysine and 0.1 percent theonine at the mill (Gershoff, 1975). Guatemalan villages' corn would be more nutritious if 0.1 percent lysine and 8 percent soy flour were added to it (Chopra, 1974). Thus, amino acid fortification can increase usable protein without requiring an increase in grain consumption.

Much of the interest in amino acid fortification stems from early experimental work on animals. Osborne and Mendel (1914) showed poor growth and low protein efficiency ratio (P.E.R.) values where wheat protein was the sole source of protein fed to rats. This finding has been repeatedly confirmed in the last fifty years, not only in the case of wheat but for all cereals. The extensive literature on this subject has been reviewed by Jansen (1974). The results are often difficult to interpret, as many of these experiments were carried out under conditions so artificial that they are not much more relevant than rat studies and dealt with very small numbers of children. We will nevertheless review a few representative studies.

Table 2.5

Supplementary Effects of Amino Acids and Protein Concentrates on Cereal Proteins

Exp. No.	Products	Protein Content Percent	RNV Percent	Utilizable Protein Percent
I	White flour	13.75	24 ± 1.5	3.2
	White flour + 0.2 L-lysine · HCl	13.94	38 ± 1.7	5.3
	White flour + 5 percent fish flour	16.66	42 ± 1.1	7.0
II	White flour	13.75	29 ± 1.7	4.0
	White flour + 0.5 percent lysine	14.25	46 ± 1.3	6.6
	White flour + 0.5 percent lysine + 0.3 percent DL-threonine	14.55	56 ± 1.5	8.2
	White flour + 0.5 percent lysine + 0.3 percent DL-theonine + 0.3 percent methionine	14.85	57 ± 1.5	8.4
	Whole wheat flour	16.03	33 ± 1.1	5.3
III.	White flour	13.75	29 ± 2.1	4.0
	White flour + 0.3 percent lysine	14.00	50 ± 1.7	7.0
	White flour + 0.3 percent lysine + 0.15 percent DL-threonine	14.15	53 ± 2.2	7.5
	White flour + 2 percent protein from fish flour	15.75	46 ± 2.8	7.2
	White flour + 2.8 percent protein from soy protein concentrate	16.56	48 ± 2.6	8.0
IV	White bread	13.40	27 ± 1.8	3.6
	White bread (88.8 percent) + peanut butter (11.2 percent)	15.30	27 ± 1.8	4.1
	White bread (92.2 percent) + skim milk powder (7.8 percent)	15.00	40 ± 1.0	6.0
	White bread (81.0 percent) + peanut butter (10.8 percent) + skim milk powder (8.1 percent)	16.80	41 ± 1.4	6.9
V	White rice	8.30	50 ± 2.5	4.2
	White rice (90.6 percent) + beans (9.4 percent)	9.60	58 ± 1.8	5.6
	White rice (83.7 percent) + beans (9.4 percent) + skim milk powder (6.8 percent)	11.30	70 ± 1.9	7.9
VI	Yellow corn meal	7.95	37 ± 2.6	3.0
	Yellow corn meal + 0.1 percent tryptophan	8.01	37 ± 2.6	3.0
	Yellow corn meal + 0.3 percent lysine	8.31	45 ± 2.7	3.7
	Yellow corn meal + 0.1 percent tryptophan + 0.3 percent lysine	8.37	61 ± 1.7	5.1
	Yellow corn meal + 0.1 percent tryptophan + 0.3 percent lysine + 0.1 percent threonine + 0.1 percent isoleucine	8.51	67 ± 1.3	5.7

Source: Hegsted, D.M. 1969, Nutritional Value of Cereal Protein in Relation to Human Needs. In: Protein Enriched Cereal Foods for World Needs Ed. by M. Milner, American Association of Cereal Chemistry, St. Paul, Minnesota, Pg. 38.

Graham and co-workers (1969) conducted one such study at the British-American Hospital in Lima, Peru. They measured nitrogen retention in six infants aged 11 to 48 months who were recovering from Protein Calorie Malnutrition (PCM). Their dietary protein was supplied by wheat. Protein intake was 1.5 to 2.0 g/kg body weight/day with adequate caloric intake. They concluded that a 0.12 percent lysine enrichment of white wheat flour would significantly enhance its protein value and increase rates of weight gain and nitrogen retention in growing infants.

Pereira and co-workers (1969) studied the effect of lysine supplementation of wheat on the growth of preschool children in South India. They found a moderate but significant increase in the height of children consuming lysine-supplemented wheat compared with children in a control group who continued using unsupplemented wheat.

Huang and Tung (1971) provided rice diets supplemented with lysine and threonine to infants aged 6 to 12 months. The protein level in their diet was 1.32g percent wet weight and its caloric value was 79 kal/100g. The authors found that four out of five infants older than 7 months grew normally for one to four months with this diet. However, they cautioned that it may be too early to conclude that rice supplemented diets are adequate for feeding infants. Evidence from other studies has shown that in human experiments wheat (Hoffman and McNeil, 1949; Cremer et al, 1951; Rice et al, 1970; Bressani et al, 1960), rice (Handley et al, 1957; Parthasarathy et al, 1964; Bressani, 1969) and corn (Truswell and Brock, 1961; Gomez et al, 1957), protein can be improved by the addition of lysine, theonine, and tryptophan.

Other studies, however, have failed to demonstrate such positive effects. Reddy (1971) conducted nitrogen balance studies in six children aged 2 to 5 years who were moderately undernourished but did not show signs of severe PCM. The test diet consisted of 2.0 grams of protein/kg of body weight - supplied solely by whole wheat - and 100 kcal/kg of body weight. The experimental diet, supplemented with lysine, contained 72 mg of lysine/kg of body weight; the unsupplemented diet had 56 mg of lysine/kg of body weight. Both diets were 10.7 percent protein. Reddy alternated his subjects randomly between the unsupplemented and supplemented diets. In all subjects he found that nitrogen retention remained

largely the same despite diet; the children gained weight. The lesson of this study appears to be that supplementing wheat with lysine at a 0.1 percent level does not promote greater retention of nitrogen.

Results were similar in Abernathy's study of sixteen healthy 7-to-9-year-old girls (1972). His addition of the three amino acids he calculated to be the most limiting failed to raise apparent nitrogen retention above the level observed for a group receiving the same basic diet plus an iso-nitrogeneous amount of ammonium citrate.

In Iran, Hedayat et al, (1975) monitored the effect of lysine fortification of bread in three groups of children. One group received a free school lunch without lysine fortification; the second group received a free lunch with lysine-fortified bread; and the third group, receiving no school lunch, served as a control. Children in both groups eating the school lunch had greater increases in height and weight than the control-group children. Apparently the lunch itself, not the lysine supplement, was the determining variable.

The lysine supplementation of the diets of rural Haitian school children did not produce increases in height and weight greater than those that occurred in a control school (King et al, 1963).

Finally, although Graham's study (1969) shows positive results, he notes that unsatisfactory results have been found in the treatment of marasmic infants. He suggests that mixtures of wheat and soy are not adequate sources of protein for malnourished or sick children.

In view of these conflicting results, the United States Agency for International Development (USAID) decided to resolve the controversies about fortification with field trials of sufficient scale and duration and under sufficiently realistic conditions to produce convincing results. Three large scale trials were organized involving the fortification of wheat with lysine in Tunisia, of rice with lysine and threonine in Thailand, and of corn with lysine and tryptophan in Guatemala. The Guatemalan study produced very slight evidence of a decrease in morbidity and mortality rates, and the Tunisian and Thai studies showed no detectable beneficial effects at all.

Impact Limitations

To evaluate the potential effects of amino acid fortification projects, a planner must consider several factors simultaneously. First of all, it is important to remember that amino acid fortification can only improve the nutritional value of protein by increasing its usable protein; it cannot increase the total quantity of protein, nor can it increase a diet's total calories. Improved protein quality will not reverse a negative nitrogen balance caused by inadequate caloric intake. Therefore, although enhanced protein quality may improve a negative nitrogen balance, it cannot totally reverse a negative nitrogen balance precipitated by an inadequate energy intake (Swendseid, Harris, and Tuttle, 1969). In their review of wheat supplementation efforts, Vaghefi et al (1974) emphatically state that adequate caloric intake is a precondition of an accurate evaluation of lysine-fortified wheat products. Under no circumstances, they maintain, will improvements in protein quality be of any significant value unless calorie intake is sufficient to meet energy demands. The message is clear: in the face of caloric insufficiency, do not fortify with amino acids.

Srikantia's surveys (1969) among Indian preschool children indicate that their primary dietary problem is a caloric deficiency of approximately 20 to 30 percent. Furthermore, Reddy (1971) has stated that when a preschool child consumes enough wheat to meet its protein needs, his lysine needs are also met.

El Lozy and Hegsted (1975) are now suggesting that the protein requirements for growth may represent, after the first one or two years, only a very small proportion of total protein needs. Table 2.6 presents the percentages of protein required for growth. It demonstrates that growth needs fall rapidly with age and become similar to the adult pattern between ages 1 and 2. These data indicate that preschoolers' protein needs, especially for essential amino acid requirements, may be much smaller than once assumed.

Data from a survey of dietary habits in Guatemala (INCAP, 1965), indicate that caloric intake in low-income groups at 86 percent of requirements is more limiting than protein intake at 118 percent of requirement. In a recent article, Hegsted (1976) comments that low total food intake is universally observed in countries where malnutrition exists. It is unclear whether protein-requirement standards are applicable when energy intake is below the recommended level.

Table 2.6

Percentage of Protein Required for Growth and Essential Amino Acids per gram Protein at Different Ages

Age	Percentage Protein for Growth		Essential Amino Acids (mg/g Protein)	
	M	F	M	F
Months				
0-2	50		373	
3-5	43		343	
6-8	27		272	
9-11	19		235	
Years				
1-2	13		210	
2-3	11		199	
3-4	9		193	
4-5	8		189	
5-6	10		195	
6-7	10		195	
7-8	10		194	
8-9	8		189	
9-10	9		190	
10-11	8	12	186	203
11-12	9	11	192	201
12-13	11	14	199	215
13-14	15	11	218	200
14-15	13	7	210	182
15-16	10	4	194	167
16-17	7	2	181	160
17-18	3	2	166	160
Adult	0	0	152	152

Source: El Lozy, M. and D. M. Hegsted, 1975, "Calculation of the Amino Acid Requirements of Children at Different Ages by the Factorial Method." American Journal of Clinical Nutrition 28:1052.

Scrimshaw et al (1973) have published data indicating lysine supplementation may be beneficial despite inadequate caloric intakes. Over two months they studied sixteen healthy male students on an adequate and inadequate (20 percent less than recommended) caloric intake. Lysine supplement of wheat gluten was their sole protein source. Lysine fortification significantly improved the use of wheat protein even at the lower level of caloric intake in subjects undergoing loss of weight. Raising caloric intake from an inadequate to an adequate level increased nitrogen retention even more. The study results show that even at inadequate caloric intake, the use of wheat protein in adult subjects can be improved by supplementing the diet with the limiting essential amino acid.

In his discussion of these results, Scrimshaw underscores that a population's caloric intake is classified as inadequate on the basis of a comparison with established requirements, not with actual needs. Individuals customarily consuming diets providing markedly less energy than the suggested allowance must reduce their physical activity and perhaps make metabolic adaptations to survive. Thus, although a diet might by reference standards be deficient, over a prolonged period it must correspond to individual, actual energy expenditure.

It is important to note that the beneficial effects of lysine supplementation despite inadequate caloric intake was demonstrated in adults. Infants and preschool children, however, have greater protein and energy requirements because they are growing. The evidence in adult studies does not permit extrapolation to younger age groups. To date, there are no data suggesting that young children can attain a positive nitrogen balance on an inadequate caloric intake.

A second consideration in evaluating the feasibility of fortification projects are the public health implications. The ability to use dietary protein is affected by health and malnutrition is unfortunately often associated with infection (Scrimshaw, 1968). The effectiveness of amino acid fortification can be lessened or totally negated by acute or chronic infections. They can induce a reduction of food intake and cause malabsorbtive, catabolic, and internal losses of nutrients.

Because infection's are highly prevalent in areas where malnutrition is common, it is logical to consider both problems together.

A third consideration -- that of bulk constraints -- has been discussed earlier. It is doubtful that an infant could consume enough amino-acid-supplemented grains to maintain a positive nitrogen balance if a single grain were its sole protein source.

Hegsted (1968) disputes the belief that adding small amounts of lysine and threonine to cereals will produce enough high quality protein to meet the needs of infants. If one assumes that P. E. R. values are proportional to nutritional value, then lysine-fortified white flour will have 64 percent of the nutritional value of the reference protein casein. According to FAO/WHO, a child between 6 and 9 months old requires a 1.5g of high quality protein/kg of body weight, or an equivalent of 3.33mg lysine/kg of body weight. An infant would probably be unable to consume enough grain to insure this level of protein.

The final standard for evaluation is the composition of the total diet. Although cereal grains supply the major portion of dietary calories and protein, other foods are generally also present in the diet. As Reddy points out, wheat or another grain is rarely the exclusive source of protein anywhere, even for preschool children (Reddy, 1971). Pulses, milk, or both are usually at least a small part of the diet, and these foods contribute to the diet's lysine content and increase the total nutritive value of its protein. In Latin America, a mixed diet of corn and beans or rice and beans is common. Jeliffe recommends such a multi-mix diet in which protein is supplied by different foods, as a practical alternative to amino acid fortification (Jeliffe, 1971). Fortification and multimixes could complement each other, especially if other foods increase caloric intake.

Feasibility Questions

Preliminary results of the three large fortification efforts in Guatemala, Thailand, and Tunisia do not reveal a clear positive effect. Many hypotheses explain the data. However, for future amino acid fortification efforts, Jansen (1977) has clearly pointed out the two issues that must be addressed. The first is whether protein quality is really the overall limiting factor in the diet. The second issue is the extent to which the fortification of staple foods is the best way to address nutritional need.

Undoubtedly, in situations where caloric and protein deficiencies exist, micronutrient inadequacies are also common. It would be logical to use fortification to also address these deficits.

The following checklist is designed as a guide for future macro- and micro-fortification program design.

For Problem Diagnosis:

(1) What information (dietary, biochemical, clinical) is available for a nutritional profile of the population?

(2) What nutrient deficiencies exist in the general population and in specific groups within it?

(3) How great is the deficiency?

(4) Who is most severely affected?

For the Choice of Carrier:

(5) What are the dietary habits of the population and of the target groups?

(6) What food would be the best fortificant carrier?

(7) How much of this carrier do the target groups consume?

(8) Are variations of the fortificant mix needed to address regional deficiencies?

For a Protein/Amino Acid Fortificant:

(9) Is protein intake inadequate?

(10) Is caloric intake adequate?

(11) If caloric intake is inadequate, would an increase in calories alleviate the protein shortage?

(12) If calories are adequate, is the protein problem the lack of a specific amino acid or general nitrogen intake?

(13) Will the positive effect of the amino acid supplement be offset by other nutrient deficiencies?

For Other Nutrient Supplements:

(14) What nutrients in addition to, or in place of, the amino acid supplement should be added?

(15) Is the fortificant toxic at the level contemplated?

(16) Do any of the substances in a mineral mix compete for absorption?

(17) Does phytate or fiber interfere with absorption?

(18) If absorption is hindered, would another carrier be effective?

General Issues:

(19) How is the health of the general population and of the target groups?

(20) Does widespread infection threaten the probable results of fortification?

(21) Is the health of the target population being monitored during the fortification effort?

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CHAPTER 3

COMMODITY SYSTEM STRUCTURE

James E. Austin

Interventions and Commodity Systems

"Nutrition intervention" is more than a piece of technocratic jargon. It is a literal description of an event: a disruptive intrusion into an on-going food system. Failure to recognize this fact may blind planners to several obstacles to effective nutrition programming. Consequently, it is essential that planners understand the commodity system into which they wish to introduce a fortification program.

The fortification program's purpose is to adjust the food system to improve the nutritional quality of the food reaching a target group. To achieve this goal, the planner must identify the best place and method of intervention to reach that group. Knowledge of the structure and operation of the cereal grain system is crucial to this determination.

Davis and Goldberg (1959) define the agribusiness commodity system as including:

> all the participants involved in the production, processing, and marketing of a single farm product. Such a system includes farm suppliers, farmers, storage operations, processors, wholesalers, and retailers involved in a commodity flow from initial inputs to the final consumer. It also includes all the institutions which affect and coordinate the successive stages of a commodity flow such as the government, futures markets, and trade associations.

In effect, we are dealing with everything from the seed to the consumer in this closely knit system. The interdependence of its elements dictates a systems approach to analysis because action at one point in the chain will produce reverberations at others. A change in processing, for example, will affect the consumer. The utility of such an analysis of commodity systems has been demonstrated in both developed (Goldberg, 1968) and developing countries (Austin, 1972).

More recently, the systems perspective has also been applied to nutrition planning. The resulting strategies have ranged from relatively simple to more complex frameworks - even econometric models (Burkhalter, 1974). Most of these plans, however, have not been widely applied in the field; nutrition planning is a relatively new art, and the field data that would permit the application of some plans do not exist. This study's commodity systems analysis derives from the agribusiness systems approach and some other nutrition-planning models. Its scope has been narrowed in tailoring it to the aspects of fortification intervention that we hypothesize are serious implementation barriers. The two main system characteristics we examine here are the system's structure and the commodity's movement through it. These are the dimensions with the greatest implications for target-group coverage and intervention organization. Analysis of structure involves documentation of the number, size, and location of the actors at each stage in the food chain. An understanding of commodity movement is based on knowledge of the volume, direction, and timing of grain's progress through the system.

Target-Group Coverage

The first thing to find out is the extent to which the target group participates in thecommodity system, for participation is a prerequisite to coverage. Fortification intervention is sometimes criticized for not being able to reach remote, rural families who, as subsistence farmers, are not part of the commercial commodity system. Given that these families farm over 40 percent of the world's farm land (Wharton, 1966), cereal fortification may well be unable to correct rural malnutrition. For this reason alone it is vital that the feasibility analysis document the target group's participation.

Grain is not consumed directly; it is first converted into a more palatable form by grinding (corn and wheat) or pounding (rice). The key factor in participation, then, is the location of that conversion. If it takes place within the home, then the family cannot be reached by a fortification program operating in the commercial mill. Our three country surveys, which are detailed in chapters 7-9, revealed that participation was high and therefore not a serious barrier. Over 90 percent of the rural families had their own grain milled for a service fee at the local mill (Table 3.1).

Table 3.1

Rice and Maize Processing Patterns

Thailand		
Province	Percentage processed in mills	Percentage pounded in home
Phrae	99	1
Phichit	99	1
Ayuthya	100	0
Cahyaphum	88	12
Kalasin	100	0
Songkhla	85	15
Guatemala		
Area	Percentage processed in mills	Percentage ground in home
Rural Highlands	99	1
Rural East	98	2
Rural South	98	2
Semi-Urban	99	1

Such rural families generally enter the commercial commodity system, not as sellers or buyers but as users of its processing capacity. Although this form of participation is high, it is important to consider that the small percentages of families using in-home milling may do so because they cannot afford modest milling fees. If a fact, their poverty may also mean that they are among the most nutritionally deprived - a target group of greater importance than their numbers suggest.

Unlike these small rural farmers, other segments of the nutritionally needy population are totally dependent on the commercial system for their grain. Rural landless laborers, small farmers producing cash rather than consumption crops, the urban poor, and some small grain farmers producing less than their family's needs all enter the system as buyers.

Distribution channels can vary. For example, Mock's analysis of the Tunisian wheat system in chapter 8 shows that about 60 percent of the nation's wheat flows through large government-regulated mills and the remainder is processed in local mills. The large mills supply the cities; their wheat reaches the urban poor. The village mills provide for rural farmers. However, southern Tunisia's wheat is largely supplied from surpluses in the north. Rather than shipping grain, central mills supply the south with processed flour. In this instance, then, the rural southern consumers could be reached by using the city rather than the village mill. Welsch et al point out in chapter 9 a similar big mill/small mill structure in Thailand, with the large mills acting largely as service millers and the small ones buying, milling, and selling. Some of the large mills, however, are located outside main cities and therefore provide both rural and urban populations.

Cereal grains are staples; they are consumed by the entire population, but lower income and nutritionally vulnerable groups are the planner's priority targets. Structural analysis should therefore identify the distribution channels that would best reach these needy groups. In Thailand, for example, the government sells its rice at a subsidized price through retail outlets, presumably for lower-income groups. Elsewhere there are similar targeted retail outlet systems: Pakistan's Ration Shops (Rogers and Levinson, 1976), India's Fair Price Shops, and Mexico's Milk Ration Outlets. Such distribution channels can help overcome the cost barrier discussed in chapter 6.

Organizational Implications

The structure and operation of the commodity system influence the organization of a fortification intervention in several ways. Program management is certainly affected. Conventional wisdom has it that fortification programs are feasible only where processing is centralized and therefore easy to control:

> The processing of the carrier food should be relatively centralized (P. A. G., 1970).
>
> It is desirable that a single centre be designated within the region or country (F. A. O., 1971).
>
> Carriers are being evaluated on the basis of a fairly well defined checklist: --- Is the carrier processed centrally (Levinson and Berg, 1969).

This idea has intuitive appeal and reflects a healthy appreciation for the practical problems of implementation. Nevertheless, it fails to recognize the importance of targeting. The potential weakness of fortification using centralized milling is that the fortified product will reach many people who do not need a nutritional supplement. Such overcoverage results in extra economic burdens without accompanying nutritional benefits. The smaller the target group and the more centralized the milling, the greater the cost of overcoverage. Fragmented, decentralized milling lends itself much better to geographical targeting and can greatly reduce overcoverage. Our country studies reveal that cereals, unlike other possible carriers like sugar, have widely scattered processing points, most villages having one or more service mills. This decentralization permits the planner to identify and reach groups as small as village populations with precision. A decentralized system, however, does create a greater burden in logistics and control costs. The planner must identify the optimum balance between higher administrative costs and lower overcoverage costs. These economic issues are dealt with in more detail in chapter 6.

The system's operation as well as its structure must be examined for its operational implications. The volume of grain passing through each mill must be documented if the proper quality of fortification is to be delivered to that processor. Fortificants are added at predetermined quantities per pound of cereal processed, and as discussed in chapter 7 these levels can vary by region depending on nutritional deficits and consumption levels. Accordingly, the total fortificant required for the intervention is determined by the addition level and output of each mill.

Another vital aspect of the commodity system's operation is timing. Cereals are not necessarily milled at uniform rates throughout the year. For example, in Thailand the milling pattern is irregular (Table 3.2).

Also affecting fortification management are seasonal fluctuations in the incidence and severity of malnutrition. At the end of the crop year, for instance, supplies may be low. If it is desirable to intervene only during such a period, program logistics would have to adapt to this requirement.

Table 3.2

Average Monthly Utilization, Expressed as a Percentage of Full Capacity of Rice Mills Classified by Size (Nakorn Pathon, Thailand, 1974)

Size	Number of Mills	Month of Year												avg. per month
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Very small	16	27	35	35	28	25	24	25	26	27	26	20	20	26
Small	25	66	63	55	79	52	53	54	64	65	62	43	44	56
Medium	29 (Diesel)	54	68	76	60	55	51	53	80	82	76	51	42	62
	33 (Steam)	73	82	85	70	64	73	73	78	82	75	63	53	73
Large	39 (Steam)	100	100	100	88	88	88	100	100	100	100	90	83	95

Source: Nopmanee Somboonsub, (1976) "Rice Milling Technology and Some Economic Implications: The Case of Nakorn Pathon, Thailand." Masters Thesis, Dept. of Economics, Thammasat University: Bangkok.

A final administrative consideration concerns the role of millers in fortification. The mill is a more desirable intervention point than the home, so the miller's cooperation is essential to an effective program. But intervention may require disruptive changes in the millers' operations, so it could engender resistance. Accordingly, identifying the nature and seriousness of the required changes and their effect on millers is essential to a complete feasibility analysis.

The potential effects of intervention on millers are basically either operational or economic. Operational difficulties arise because millers have to add a new step and a new ingredient to their milling process. If fortification is complicated and demands highly trained people, the scarcity of such human resources in the villages and even at the larger urban mills might discourage or prevent miller cooperation. Our analyses of the technical aspects of fortification (chapter 4) and the fortification experience in the field (chapters 7-9) do suggest that the technical demands on the millers are not excessive. Nonetheless, the process demands considerable care to assure the addition of the correct quantity of fortificant. This requirement places an extra time burden on the millers. And unless they have been properly trained and motivated, they may not perform this critical function with the requisite care.

The millers' incentive to do this work may have to be financial: fortification requires the miller to spend more time and purchase new equipment. True, the additional time required to insure the proper addition level is small, but it is not insignificant. The capital outlay for fortification feeder equipment is also small, ranging from $1300 in village mills to $2200 in central mills (chapter 4). But the millers' profit margins could not absorb such added costs without serious erosion of their investment return. Also, survey data indicate that the consumers are price sensitive and would resist paying the incremental costs themselves. In Guatemala, for example, higher milling service fees were given as a primary reason for switching patronage from one mill to another (chapter 7). Although the fortifying costs and even the larger fortificant costs are not large relative to the price of the cereal (e.g., .00038 percent to 0.0058 percent of maize), they are almost equal to the milling fee and consumers would surely notice them.

Resistance to fortification might also arise if intervention threatened increased government control of milling. Incidents of miller resistance to outside control have been reported. In one Asian country, millers refused to participate in a fortified rice program because they feared that if the government knew their real production and income it would increase their taxes. Similarly, sugar millers in one Latin American country resisted efforts to fortify sugar. Their lack of cooperation reportedly stemmed from a desire to prevent governmental monitoring of their sugar shipments. They wished to ship sugar out of the country without the requisite governmental permission and profit from prices considerably higher elsewhere.

These experiences reveal the importance to planners of understanding the dynamics of the commodity system and the motivations of its actors. Without that understanding, they will be unable to identify the most effective means of nutrition intervention. The planner has three basic strategies for dealing with the system's potentially resistant actors: confront, circumvent, or co-opt. Confrontation might take the form of mandating fortification by law. If the operational or economic burden placed on millers is not excessive, this may be a reasonable approach. If the burden on millers is great, however, the law might result in the fortificant's fattening pigs and chickens instead of people. In such a situation, it is doubtful that any practical, economical enforcement system could outwit the millers' ingenuity in avoiding their burden.

Circumvention might be possible where some but not all millers are amenable to participation. By involving some millers, administrators can at least begin the program and demonstrate to the hold-outs that intervention is possible and not as burdensome as they believe. This circumvention strategy may also encourage cooperating millers to put social and maybe even economic pressure on the hold-outs if they believe the program is important to the community.

Millers will be co-opted only if the program offers them an adequate incentive. The primary incentive will likely be economic, in the form of a subsidy in kind or in cash - providing the fortificant, for example, or paying for some of the miller's fuel costs or the replacement of grinding blades and wheels. The issue of who should pay for the intervention is addressed further in chapter 6.

Feasibility Questions

The analyst should address the following questions about a commodity system's structure when considering a fortification intervention.

Target Group Coverage:

(1) What portion of the target group uses commercially milled grain?

(2) How nutritionally needy are those families who mill their own grain?

(3) Which mills supply which population groups?

(4) What distribution channels reach the most needy?

Organizational Implications:

(5) To what extent is the grain centrally processed?

(6) How much overcoverage would result from using central mills?

(7) How decentralized is the milling structure?

(8) Will the decentralized system permit adequate targeting of fortified grain?

(9) How much greater will administrative costs be for the decentralized system?

(10) How do these additional costs compare with the savings from reduced overcoverage?

(11) What is the volume of grain milled in each mill, and how much fortificant would this quantity require (given the consumption patterns and deficit levels of the consumers served by that mill)?

(12) What is the seasonal milling rate pattern?

(13) Will the fortification program cause operational problems or an economic burden for the miller?

(14) How is the miller likely to react to these factors?

(15) What incentives or tactics would increase miller cooperation?

(16) How resistant will millers be to the increased government intervention encouraged by the program?

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CHAPTER 4

FORTIFICATION TECHNOLOGY

Samuel H. Yong

Introduction

This chapter will discuss various technological aspects of cereal fortification: the chemical, physical, and nutritional properties of the fortificants, methods of adding nutrients to cereals, and nutrient stability during processing and storage. Problems in these technical dimensions can frustrate fortification interventions. Costs figure in this chapter as a descriptive parameter. Their implications will be discussed more fully in chapter 6. Because decentralized fortification programs have begun to receive increasing attention due to the need to avoid overcoverage, reach target populations not participating in a centralized commodity system, and adapt fortification to various nutritional requirements within one country (Austin and Snodgrass, 1976), we will pay particular attention to aspects of fortification at the village level.

Fortificants: Their Properties and Costs

In theory, almost any nutrient can be added to basic cereals, depending on the needs of the target population. From chapter 2 we know that vitamin A, thiamine, riboflavin, niacin, iron, calcium, lysine, threonine, and tryptophan are the most likely candidates as fortificants (Tables 4.1 - 4.2) of staple cereals. In cases where the limiting amino acids are supplied in legume proteins like soy protein, methionine's addition must also be considered because it is often limiting in legumes.

Vitamins

The chemical structures of commercially produced vitamin A, thiamine, riboflavin, and niacin are illustrated in Appendix B. These vitamins are manufactured in different chemical and physical forms to achieve various processing and stability characteristics. Currently, Hoffman-La Roche Inc. and Merck & Co.

Table 4.1

Nutrients in Cereals Compared with Recommended Daily Allowances (Nutrients/1000 cal)

Nutrient	White Flour	Polished Rice	Corn Meal	RDA-Infants
Vitamin A activity (IU)	0	0	1440	1650
Thiamine (mg)	0.2	0.2	1.1	0.5
Riboflavin (mg)	0.1	0.1	0.3	0.6
Niacin (mg)	2.5	4.4	5.6	8
Vitamin B_6 (mg)	1.2	1.0	1.2	0.4
Ca (mg)	44	66	56	630
P (mg)	240	260	720	560
Mg (mg)	71	77	300	80
Fe (mg)	2.2	2.2	6.8	15

Source: G. R. Jansen, (1974). "The Amino Acid Fortification of Cereals." In New Protein Foods. Ed. by A. M. Altschul, Academic Press, New York, P. 39.

Table 4.2

Limiting Amino Acids of Cereals

Cereal	First	Second
Rice	L-lysine	L-threonine
Wheat	L-lysine	L-threonine
Corn	L-lysine	L-tryotophan
Sorghum	L-lysine	L-threonine
Millet	L-lysine	L-threonine

Source: F.R. Senti and J.W. Pence, (1971), "Technological Aspects of Adding Amino Acids to Foods." In Amino Acid Fortification of Protein Foods. Ed. by N.S. Scrimshaw and A.M. Altachul. MIT: Cambridge, Mass. P. 467.

produce large portions of the world's vitamins by chemical synthesis (Wuest, 1972; Wagner-Jauregg, 1972; Isler et al., 1967; Robinson, 1951). Vitamin A is commercially available as acetate and palmitate esters, which are more stable than vitamin A alcohol (Borenstein, 1975). Both the acetate and palmitate derivatives are marketed in oil solutions, emulsions, and dry encapsulated beadlets of standard potencies. Although the acetate form is less stable than the palmitate form, both are practically insoluble in water and labile in the conditions discussed later. Thiamine is commercially available in the mononitrate and the hydrochloride forms (Borenstein, 1975). Thiamine mononitrate, which is less hygroscopic and much less soluble in water than thiamine hydrochloride, is the traditional choice for dry mixes with long storage life. Where flavor is crucial, coated thiamine may be used and water-insoluble derivatives (like dibenzoylthiamine, thiamine naphthalene disulfonate, and thiamine dicetylsulfonate) are available to reduce leaching losses (Mitsuda, 1969). Niacin is commercially available as nicotinic acid and nicotinamide, both of which are non-hygroscopic and soluble in water and alcohol. Nicotinic acid is almost tasteless, but nicotinamide has a bitter taste, so its coated form is most appropriate for pharmaceutical uses (Borenstein, 1975). Riboflavin is manufactured as a yellowish product in different crystalline forms and sizes for a variety of color effects. Because it is not very soluble in water, liquid preparations usually require the use of riboflavin-5-phosphate. Riboflavin is also available in coated forms when it is necessary to mask its flavor (Borenstein, 1975). Because of riboflavin's adverse effect on the color of some carriers, colorless riboflavin precursors (like 6,7-dimethyl-8-ribityllumazine) have been suggested for some fortifications (Mitsuda, 1963).

The vitamin quantities needed for cereal fortification (listed in Table 4.3) are so infinitesimal that they generally have no adverse effects on the processing and organoleptic properties of fortified cereals. But vitamin fortification is not without risk. Added vitamin A and thiamine reportedly cause undesirable odors when broken down by heat in toasted cereals, (Aylward and Morton, 1970; Borenstein, 1975). Riboflavin-fortified rice granules are known to impart to cooked rice the yellow splotches often associated with significant amounts of fine bran particles or mold (Mitsuda and Yasumoto, 1974). Riboflavin and thiamine are practically nontoxic when taken orally (Unna, 1972; Czaczkes and Guggenheim, 1946). But in addition to the well-publicized toxicity of vitamin D, vitamin A and niacin have caused adverse physiological effects when given orally in great excess.

Table 4.3

Actual and Recommended Vitamin Fortification Levels
(Per kg of Cereal Grain)

Cereal	Vitamin A (IU)	Thiamine[a] (mg)	Riboflavin (mg)	Niacin (mg)	Reference
Enriched flour, U.S.	-	4.4-5.5	2.6-3.3	35.2-44	Code of Federal Regulations
Enriched corn meals and grits, U.S.	-	4.4-6.6	2.6-4	35.2-52.8	Code of Federal Regulations
Enriched milled white rice, U.S.	-	4.4-8.8	2.6-5.3	35.2-70.4	Code of Federal Regulations
Fortified milled white rice, Thailand	23,700	5	4	-	Gershoff et al., 1975
Fortified corn flour Guatemala	6,250	21.4	13	154.4	Austin, 1976
Fortified milled white rice, Taiwan	-	2.5	7.5	37.5	Couslozio, 1966
Fortified wheat flour, Tunisia	10,000	8.5	5.4	63.3	Wooden, 1974
Fortified wheat flour, recommended	11,000	2.2	2.2	23.1	Rubin and Cort, 1969
Fortified milled white rice, recommended	16,720	4	4.4	39.6	Rubin and Cort, 1969
Fortified corn grits and meals, recommended	7,700	-	2.2	15.4	Rubin and Cort, 1969
Fortified wheat flour, recommended	4,000	4.4	2.6	35.2	MIT INP Program, 1975

Note: Recommended levels are for grain-eating nations.

a. Based on thiamine mononitrate equivalent.

Even after the cessation of excessive dosage, abnormal bone growth and enlargement of the liver persisted in a child who ingested 240,000 IU of vitamin A daily between the age of 3 months and 3 years (Josephs, 1944). Nicotinic acid (but not nicotinamide) is a powerful vasodilator: a single dose of 50 to 100 mg produces transient flushing of the ears, face, and neck (Borenstein, 1975). To avoid these adverse effects, care should be taken to ensure adequate mixing, lack of segregation stability, and good taste and appearance.

Former and current vitamin prices are tabulated in Table 4.4. Although the sharp price decline sparked by technological innovations in the 50's and early 60's (Brooke, 1968) has come to an end, current prices should remain relatively stable unless petroleum-based raw material costs increase drastically.

Table 4.4

Current and Past Prices of Vitamins (U.S. $/kg)

Vitamins		1977	1975	1972
Vitamin A	palmitate beadlet (250,000 IU/g)	15	15	13.1
	palmitate in oil (10^6 IU/g)	30	-	-
	acetate beadlet (500,000 IU/g)	23	-	-
Thiamine (hydrocholoride or mononitrate)		25	23	14
Niacin	nicotinic acid	5	5	3.75
	nicotinamide	5.25	5.25	4.0
Riboflavin		42	40	28

Note: Prices are quoted for food-grade, "stabilized" vitamins in quantities greater than one kg fob N.J. Vitamin premixes for cereal fortification can be made by blending these ingredients at desired levels.

Source: Hoffman - La Roche, 1977.

Minerals

Iron and calcium are often considered cereal fortificants because, as with iodine and fluorine, a significant number of people consume too little of them (Harris, 1970). We will not consider iodine and fluorine fortification here because the means of adding them to salt and water respectively are already well established. The various quantities of iron and calcium recommended for cereal fortification are listed in Table 4.5, partly reflect the difficulty of assessing actual body requirements for these minerals. In addition to wide variations in the requirements determined by age, sex, activity, and metabolic stress, the biological availability of calcium and iron is considerably influenced by diet patterns and the mineral's chemical forms. Calcium and iron are absorbed poorly from diets rich in bulky carbohydrates, phosphates, oxalates, and carbonates because of the formation of precipitates and polymers excreted in the feces (Harris, 1970). Certain forms of iron and calcium are more readily absorbed than others. In general, biological availability parallels solubility under conditions resembling those in the digestive system (Davidson and Russo, 1976; Harris, 1970). Food manufacturers, however, prefer forms of iron and calcium with low solubility because they are less liable to cause flavor and taste problems by themselves or in combination with other substances. For instance, iron is a well-known catalyst in the oxidative degradation of unsaturated fats and vitamins, which may yield off-flavor compounds.

The sources and current prices of iron and calcium are given on Tables 4.6 and 4.7. Although electrolytically and chemically reduced iron powder and calcium carbonate (chalk) are the most widely used sources of iron and calcium in cereal fortification, their biological availability is low compared to some other sources. Reduced iron powder has less than 50 percent of the biological availability of ferrous sulfate or ferrous fumarate, but sodium iron pyrophosphate and ferric orthophosphate are even less available biologically and are generally not recommended for fortification because they are extremely expensive (Davidson and Russo, 1976). A greyish powder with high bulk density, reduced iron, presents off-color problems and is difficult to incorporate uniformly in a dry mix. Furthermore, the magnets used to remove tramp metals from cereal products will also entrap the iron powder which, unlike iron salts, is magnetic. Ferrous sulfate, a low cost fine white powder, is therefore the iron source of choice whenever it can be used without adverse organoleptic effects (Davidson and Russo, 1976). In those

Table 4.5

Actual and Recommended Calcium/Iron Fortification Levels
(Per kg of Cereal Grain)

Cereal	Calcium (mg)	Iron (mg)	Reference
Milled white rice, Thailand	-	80	Gershoff et al, 1975
Corn flour, Guatemala	-	480	Austin, 1976
Wheat flour, Tunisia		56	Wooden, 1974
Wheat flour, U.K.	3320	-	Akyroyd and Doughty, 1970
Wheat flour, recommended	800	96	MIT INP Program, 1975
Wheat flour, recommended	1980	17.6	Rubin and Cort, 1969
Milled white rice, recommended	2200	35.2	Rubin and Cort, 1969
Corn grits and meal, recommended	1980	6.6	Rubin and Cort, 1969
Enriched milled white rice, U.S.	1100-2200 (optional)	28.6-57.2	Code of Federal Regulations
Enriched wheat flour, U.S.	1100-1375 (optional)	28.6-36.3	Code of Federal Regulations
Enriched corn meal and grits, U.S.	1100-1650 (optional)	28.6-57.2	Code of Federal Regulations

Note: Recommended levels are for grain-eating nations.

Table 4.6

Current Prices of Commercially Available Calcium Sources Important for Cereal Fortification

Calcium source	Cost per kg (U.S. $)	Percentage of contained calcium	Cost per kg calcium (U.S. $)
Calcium carbonate[a]	0.15	40	0.375
Calcium phosphate, dibasic (dicalcium phosphate)	0.792	23.3	3.40
Calcium phosphate, tribasic (tricalcium phosphate)	0.792	38.8	2.04
Calcium sulfate	0.638	23.3	2.74

Note: Prices are quoted for food-grade calcium sources in bulk quantities (e.g., 15 x 100 lb bags, 5 x 225 lb drums).

Source: Mallinckrodt, Inc., 1977.

a. Calcium carbonate is supplied by Pfizer Inc., N.J.

Table 4.7

Current Prices of Commercially Available Iron Sources Important for Cereal Fortification

Iron source	Cost per kg (U.S. $)	Percentage of contained iron	Cost per kg iron (U.S. $)
Ferrous sulfate, dried	0.66	32.1	2.05
Ferrous sulfate, heptahydrate	0.84	20.1	4.16
Chemically reduced iron	1.56	96.0	1.63
Electrolytically reduced iron	2.55	97.0	2.64
Ferrous fumarate	2.24	32.9	6.82
Ferric orthophosphate	1.63	28.6	5.70
Sodium iron pyrophosphate	1.80	14.5	12.45

Source: J. T. Davidson and M. E. Russo, "Iron Fortification in Breakfast Cereal", Cereal Foods World, 21 (1976), Pg. 534.

cases where organoleptic stability is a problem, previously mentioned iron sources of low solubility and low biological availability must be used (Anderson et al., 1976). Stability problems have been reported when ferrous sulfate is added to wheat flour; apparently the additive enhances chemical changes in flour during storage. To avoid this problem, scientists are developing a "stabilized" form of ferrous sulfate. Ferrous fumarate, due to its reddish-brown color and relatively high cost, is usually not considered for fortification of basic cereals. As a calcium source, calcium phosphate dibasic (dicalcium phophate) is generally accepted as a good compromise between biological availability and taste/flavor stability (Harris, 1970).

Although a high intake of calcium may result in hypercalcaemia and excessive calcification when combined with high levels of vitamin D or an alkali, adverse effects seldom result from an excess of calcium or iron alone. This effect is probably because a healthy individual absorbs less than 15 percent of dietary calcium and iron (Harper, 1971). The fortification of cereals with iron may not be the most efficient way to reach a target population because the dietary requirement for iron is much greater in women and in infants than in healthy adult males and women after menopause (Harper, 1971).

Amino Acids and Proteins

As shown in Table 4.2, many cereals contain low quality proteins which are limiting in one or more essential amino acids. L-lysine is the most important limiting acid in all cereals, and L-tryptophan and L-threonine are also limiting in corn and rice respectively (Senti and Pence, 1971). It is possible to add these limiting amino acids to basic cereals synthetically or with rich protein supplements. Researchers found no difference in L-lysine use between supplements in the form of L-lysine·HCl and as protein (Longenecker and Hause, 1959; Schwartz et al., 1959). However, one must be aware that protein supplements may create a new limiting amino acid. In the case of soy protein, that limiting acid is methionine.

The chemical structures of commercially synthesized lysine, threonine, tryptophan, and methionine are given in Appendix C. Except for methionine, which has the same biological value in both the D- and L-form because of the human enzyme system's capacity to convert the former into the latter, only the

L-forms of most essential amino acids are biologically active (Jansen, 1974; Ottenheym and Jenneskens, 1970). Primarily due to the difficulties and costs in resolving chemically produced DL-mixtures, methionine is currently the only essential amino acid manufactured by chemical synthesis from petroleum-based raw materials (Reisman, 1977; Denkenwater, 1976; Kacem, 1976). L-lysine, L-threonine, and L-tryptophan are all manufactured by fermentation, which yields only the L-forms. The process requires molasses, starch hydrolysates, sugars, and similar substances for energy and carbon sources. All fermentation methods are patented, and practically all of the world's L-lysine, L-threonine, and L-tryptophan is manufactured by the Kyowa Hakko Kogyo Company and Ajinomoto Company of Japan (Reisman, 1977). A diagram of the fermentation process used to produce L-lysine·HCl is included in Appendix D. Although the current production capacity for L-lysine is estimated at 55 million pounds per year (Austin and Snodgrass, 1976), the requirement projected for 1980 is 143 million pounds (Reisman, 1977). At this moment, L-tryptophan and L-threonine production are limited to pharmaceutical uses, and production capacity is estimated at less than 1 percent of that for L-lysine (Reisman, 1977). Markets for these amino acids will probably not develop until a major market for L-lysine as a protein fortificant emerges (Denkenwater, 1976). Production of DL-methionine and methionine hydroxy analogue is estimated at 205.5 million pounds, of which 64 percent is in Europe, 22 percent in Japan, and 11 percent in the U.S. (Austin and Snodgrass, 1976). Approximately 98 percent of the methionine and 90 percent of the lysine output is used for animal-feed supplements (Japan Chemical Annual, 1974). Only a very small fraction of these amino acids is used for cereal fortification.

Table 4.8 lists former and current prices of the amino acids. At present, it appears L-lysine and DL-methionine are the only amino acids that could be seriously considered for fortification on the basis of price and availability. Although the prices of L-threonine and L-tryptophan could decline considerably if production were to rise, their manufacturers are unlikely to commit resources to expanded production unless governments interested in fortification programs assure increased demands. However, the interesting nutritional relation between niacin and L-tryptophan may allow programs to avoid the latter's high price. L-tryptophan is a significant precursor of niacin in human beings at approximately 60 mg L-tryptophan = 1 mg niacin (Borenstein, 1975). High-corn diets resulting

Table 4.8

Current and Historical Prices of Synthetic Amino Acids for Cereal Fortification

U.S. $/kg

	L-lysine·HCl	L-threonine	L-tryptophan	DL-methionine
1972	3.80	-	-	4.20
1973	3.80	-	-	4.20
1974	7.30	57.70	86.80	4.20
1975	5.60	57.70	86.80	5.30
1976	5.60	57.70	86.80	5.30
1977	5.60	57.70	86.80	5.30

Notes: Prices are quoted for food-grade L-lysine and DL-methionine in bulk quantities (a ton or more); for L-tryptophan and L-threonine, prices are quoted for pharmaceutical-grade in quantities greater than 50 kg. Except for DL-methionine prices, which are obtained from Chemical Marketing Reporter, amino acid fob Japan prices are estimated from the "delivered prices" given by Ajinomoto Co., U.S.A., using the following formula:

estimated price = delivered price/(100 percent + handling and transportation charge and customs duty)

where customs duty is 6 percent for L-lysine·HCl and L-threonine, 12.5 percent for L-tryptophan; and transportation and handling charge is estimated at 6 percent.

in clinical deficiencies of niacin (pellarga) because corn is particularly limiting in L-tryptophan may, therefore, be improved with niacin instead of the more expensive L-tryptophan. One should also note the price fluctuations for L-lysine. They reflect the precarious balance between supply and demand, which is strongly affected by the markets for other lysine-rich protein feed supplements like soy or fish meal (Denkenwater, 1976; Wooden, 1974; Ajinomoto Company U.S.A., 1977). Only pharmaceutical-grade L-thronine and L-tryptophan are currently produced, but L-lysine and DL-methionine are available in three major grades: pharmaceutical, food, and feed. They differ primarily in the amounts of impurities present. According to the Food Chemicals Codex (1972), food-grade amino acids must have a minimum purity of 98 percent, low levels of heavy metals (e.g., less than 50 mg iron and 20 mg lead/kg), and no pathogenic micro-organisms.

As of January 1977, food-grade L-lysine is approximately one-and-a-half times more expensive than its feed grade ($5.60 vs. $3.90/kg), and food-grade DL-methionine is more than twice as expensive as its feed grade ($5.30 vs. $2.40/kg).

With the exception of methionine, all the previously mentioned essential amino acids are on the U.S. Food and Drug "Generally Regarded as Safe" list and on the "List of Approved Food Additives" (Beigler, 1969). Rat-feeding studies have demonstrated that L-lysine and L-threonine are the least toxic of all essential amino acids, and that methionine is the moxt toxic, though closely followed by L-tryptophan (Harper et al., 1970). The addition of 3 percent L-lysine·HCl to a 20 percent casein diet did not lower the rates of weight gain and food consumption for rats (Acheampong-Mensah and Hill, 1970). On the other hand, methionine in excess of 1 to 2 percent of rations containing 10 percent protein reduces growth by 40 to 60 percent of control values, except in cases where the protein is deficient in methionine (Benevengu et al., 1968). In human studies, short-term vomiting, refusal to eat, and reduced nitrogen retention resulted when infants were fed cereals to which methionine was added in excessive amounts (Jansen, 1974). These adverse effects have not been observed in children fed a cereal diet fortified with L-lysine and L-threonine (Jansen, 1974).

The solubility, color, and taste of cereals fortified with L-lysine, L-threonine, and L-tryptophan all seem acceptable (Senti and Pence, 1971). The taste threshold for L-lysine in white bread is 0.5 g per 100 g of flour, which is more than double the amount recommended for addition to wheat flour (Ehle et al., 1959; Matthews et al., 1969; Graham, 1969). A number of double-blind taste panel tests conducted in Japan and using 0.2 percent L-lysine in bread verify this level's acceptability. Corn products fortified with L-lysine and L-tryptophan are well accepted, even when used for tortillas in Central America (Beigler, 1969; Austin and Snodgrass, 1976). Ferrel et al. (1970) report that wheat kernels infused with up to 15 percent L-lysine, added to yield a final fortification level of 0.1 percent, cannot be detected in whole wheat by odor or appearance. However, consumer resistance may arise if the added L-lysine is not uniformly distributed in the carrier cereal. Uneven distribution may be the result of errors in the fortification process or in handling, but in the case of fortified simulated rice granules it is inevitable. Mitsuda and Yasumoto (1974) report "salty spots" that reduce the palatability of boiled rice to which fortified simulated rice granules

containing 20 percent L-lysine have been added for final fortification level of 0.2 percent. Unlike other amino acids, methionine has flavor and taste problems even at low concentrations (Senti and Pence, 1971; Jansen, 1974). Although it has been added at 0.5 percent of soy protein (which is equivalent to approximately 0.01 percent in the final preparations), new methionine derivatives with better flavor are needed to ensure the acceptability of the fortified product. Chapter 5 addresses the issue of acceptability more fully.

Of the protein sources which have been considered for cereal fortification in different parts of the world (Bauernfeind, 1970), soybeans, fish, milk, and microorganisms are rich in L-lysine, the most limiting amino acid in cereals (Chemical Week, 1974; Jansen, 1974; Milner, 1969). Cereal supplementation with these proteins raises the quantity as well as the quality of proteins in the final mixture. Groundnut and cottonseed proteins on the other hand, contain just a little more L-lysine than cereal proteins (Jansen, 1974; Hegsted, 1969). Accordingly, these proteins have only limited value for cereal fortification unless synthetic L-lysine or lysine-rich proteins are added with them. Although cottonseed flour has been degossypolized by extraction and heating and then used in Incaparina and other protein-enriched cereal foods (Shaw, 1969; Dalby, 1969; Bauernfeind, 1970), human-grade cottonseed flour with the brand name "Proflo" (60 percent protein) is no longer produced by Traders Oil Mill Company, Texas. The primary reason for stopping "Proflo" production was the manufacturer's inability to meet EPA regulations (Martinez, 1977), but the underlying cause appears to be the failure to expand the "Proflo" market beyond its limited use in baked goods. For a few years, the Plains Cooperative Oil Mill, Texas, also manufactured de-gossypolized cottonseed flour, using the liquid Cyclone Process which was developed by the USDA Southern Regional Research Center. Contrary to expectations, technical difficulties prevented the plant to operate continuously and achieve a commercially viable production level. In late 1975, the Plains management closed their plant after suffering severe financial losses in their oil mill operation (Kraemer et al., 1977). Cottonseed protein, in addition to its inferior nutritive value per unit cost, has been expected to impart a strong yellow-green color to food in some applications.

The current prices of different protein sources and their nutritive values are given on Table 4.9. One can infer from the data that milk proteins, despite

Table 4.9

Current Prices and Nutritive Values of Different Protein Sources

Protein source	Percentage of protein[a]	Percentage of L-lysine[b]	U.S. $/kg	U.S. $/kg protein	U.S. $/kg L-lysine	P.E.R.
Spray-dried whole milk	26.4	2.3	1.89	7.14	82.17	3
Spray-dried skim milk	35.9	3.1	1.35	3.75	43.55	3
Defatted soy flour	50	3.6	0.35	0.70	9.72	2-2.5
Soy protein concentrate	70	4.2	0.77	1.10	18.33	2-2.5
Soy protein isolate	95	5.7	1.46	1.54	25.61	1.1-1.6
Fish protein concentrate	80	7.2	1.50	1.88	20.83	3
Full-fat soy flour	42	3	0.40	0.95	13.33	2-2.5

Note: Prices of milk products and soy products are fob bulk rates quoted by Borden, Inc., and Central Soya, respectively. Price for fish protein concentrate is estimated from fob Sweden prices quoted by Astra Nutrition U.S.A., Inc., for bulk quantities at $0.235 - 1 Swedish Krona. Price of full-fat soy flour quoted by ADM, Bordon, Inc., Decatur, Ill.

a. Percentage of protein values are obtained from the manufacturers.

b. Percentage of L-lysine values are obtained from Jansen and Ehle (1965a), Wolf and Cowan (1971), and Astra Nutrition U.S.A., Inc.

their high nutritive values, are too expensive to be protein supplements for cereals in poor developing countries that have to import dairy products. Furthermore, due to their high content of reducing sugars which may readily combine with lysine in the Maillard Reaction and Strecker Degradation (discussed later), supplements of milk solids may reduce the biological availability of lysine. Although no significant lysine loss has been reported for CSM containing 5 percent added milk solids, Jansen and Ehle (1965b) note a drastic reduction in lysine retention during bread baking when a large amount of skim milk solids is added with the lysine. Another possible protein source is single-cell protein, which is made by rupturing the cells and discarding the cell-wall debris of microorganisms grown primarily on petroleum-based raw materials. Such proteins, however, are currently manufactured only on a pilot-plant scale, and the process is not expected to be drastically cheaper than other protein sources because of escalating petroleum prices. Therefore, soy proteins and fish protein concentrate should be considered the major protein supplements for fortification of basic cereals.

Soy protein for food uses is available as full-fat soy flour, defat soy flour, soy protein concentrate, and soy protein isolate. Except for full-fat soy flour, which is made by toasting or the extrusion cooking and milling of cleaned, dehulled whole soybeans, all other soy proteins are manufactured from the soy solids that remains after the extraction of the bean's oil. The ways these soy products are produced are illustrated in Appendix E. Like many other pulses, soybeans contain growth inhibitors (e.g., trypsin inhibitor, hemagglutinins, saponin) and enzymes that may help form off-flavor and bitter tasting compounds. These substances must be inactivated by carefully controlled heating which minimizes the destruction of vitamins and amino acids (Smith, 1969; Nordal and Fossum, 1974). Full-fat soy flour of good flavor and high nutritive value can be commercially produced by high-temperature, short-time extrusion cooking. In addition to its use in cereal-based protein-enriched food, it is useful in the production of bread, pastries, sausages, and pasta products. Because of its high fat (20 percent) and protein content (40 percent), full-fat soy flour may serve both as a high quality protein supplement and as a compact source of energy. Unfortunately, it lacks long-term stability because of its high content of unsaturated fats. Defatted soy flour, with its relatively low price and good stability, is the most widely used protein supplement for the fortification of cereal-based foods. However flours with defatted soy added produce Western and native breads of

darker crumb, smaller loaf volume, beany flavor, bitter taste, and reduced shelf-life (Hulse, 1974; Austin and Snodgrass, 1976; Milner, 1969). Toasting the defatted soy flour largely eliminates these adverse effects and deactivates growth inhibitors at the same time (Hulse, 1974). Generally, breads supplemented with up to 6 to 7 percent toasted, defatted soy flour suffer no changes in their physical and organoleptic properties, but beyond this level adverse effects increase with the level of supplementation (Hulse, 1974; Jansen and Ehle, 1965a). Recent research has demonstrated that chemical treatment of soy protein or the addition of chemicals will largely offset the adverse effects of protein supplementation at high levels (Rainey and Horan, 1961; Pomeranz et al., 1969; Teen et al., 1971), but this strategy may be impractical for less developed nations. Soy protein concentrate contains approximately 70 percent protein and is prepared by removing water-soluble sugars, ash, and other minor constituents from defatted soy flakes and flours. Although its high protein content, bland taste, and whiteness make it superior to soy flours for many applications, it has not been used widely for cereal fortification, probably because of its high unit protein cost compared to soy flour (see Table 4.9). Soy protein isolate, containing approximately 95 percent protein, is the most refined form of soy protein. It is prepared by the isoelectric precipitation of proteins under mildly acidic (pH 4.5) conditions after solvation and clarification in dilute alkali. As a sole source of protein, soy protein isolate has repeatedly been found inferior to soy flour and soy protein concentrate because methionine-rich proteins remain in solution when the majority of soy protein is precipitated (Bressani and Elias, 1974; Pruiett, 1977; Cogan, 1968). Although the addition of 0.3 percent methionine brings its P.E.R. value above that of casein (Cogan, 1968), soy protein isolate is not an adequate protein supplement because of a high unit protein cost and methionine's flavor problems. Unlike defatted soy flour, growth inhibitors appear to be largely removed or inactivated in soy protein isolate and concentrate (Jansen and Ehle, 1965b).

Commercially available fish protein concentrate contains approximately 80 percent protein. It is manufactured by the extraction with isopropyl alcohol of fat from the flesh of schooling finfish. A detailed description and schematic representation of the manufacturing process is given in Appendix F. It is widely acknowledged that the high nutritional value of fish protein concentrate as a protein supplement (evidenced by Tables 4.9 and 4.10) is not matched by its utility

Table 4.10

Nutritional Value of Fish Protein Concentrate

Nutritional Comparison of ASTRA Protein with Common Protein Sources

Protein (Nx6.25)	80	percent[a]
Fat	0.1	percent
Water	5	percent
Ash	14	percent
Calcium	3	percent
Phosphorus	2	percent
Magnesium	0.3	percent
Sodium	0.3	percent
Potassium	0.5	percent
Chloride	0.2	percent
Iron	150	ppm
Zinc	120	ppm
Manganese	15	ppm
Copper	6	ppm
Fluorine	80	ppm
Mercury	0.15	ppm
Iodine	0.7	ppm
Residual isopropanol	50	ppm
Total bacterial count	1000/g	
Pathogenic bacteria	absent	

a. Percentage of total composition determined by proximate analysis.

Amino acid	Astra Protein	Casein	Egg	Beef	Wheat	Soy
Lysine	9.0	8.1	7.2	8.4	2.3	6.3
Leucine	8.0	10.1	8.8	8.4	7.2	7.7
Isoleucine	4.6	6.6	5.7	5.1	3.2	5.3
Methionine	3.3	3.1	3.8	2.3	1.4	1.3
Phenylalanine	4.1	5.4	5.7	4.0	4.8	4.8
Threonine	5.0	4.3	5.3	4.0	2.9	3.8
Tryptophan	1.5	1.3	1.3	1.1	1.1	1.3
Valine	5.7	7.4	8.8	5.7	3.9	5.2

Note: Values for protein, ash, and minerals vary with the fish used as raw material.

Source: Astra Nutrition U.S.A., 1977.

in practice. Although fish protein concentrate is available as a fat-free, tasteless, odorless, and stable light-greyish powder (Astra Nutrition U.S.A., 1977), it has poor solubility and hydration characteristics (Milner, 1969). Due to its relatively high price (Table 4.9) and poor functionality (e.g., solubility and hydration characteristics), it has not been able to compete with soy proteins in the U.S. market as an ingredient in baked goods, meat products, beverages, and other foods (Astra Nutrition U.S.A., 1977; Wolf and Cowan, 1971). Nevertheless, fish protein concentrate has been used in cereal-fortification programs that have benefited many people in developing countries, primarily through the World Food Program of the United Nations (Astra Nutrition U.S.A., 1977). Because of its high nutritive value and lack of functional properties the addition of only 2 to 4 percent of fish protein concentrate will greatly increase protein quality and quantity in the end product without causing any adverse interactions with other ingredients (Jansen, 1974; Milner, 1969; Sanber-Maria, 1969). In general, the supplementation of basic cereal flours with 5 to 6 percent fish protein concentrate does not result in significant organoleptic changes in baked breads, tortillas, and pasta products (Sanber-Maria, 1969; Milner, 1969; Astra Nutrition U.S.A., 1977). It is interesting to note that tortillas fortified with 7.8 percent defatted soy flour spoil faster than unfortified ones; the added soy flour increases the tortillas' ability to retain moisture (Austin and Snodgrass, 1976). This effect will probably not occur with fish protein concentrate due to its low solubility and poor hydration characteristics. This low solubility is very helpful in fortified pasta products, where the loss of added nutrients by leaching is a serious problem.

Table 4.11 compares the cost of wheat flour fortification with L-lysine with the costs using other protein sources. Caloric supply is constant at 2000 Kal, and all mixes provide approximately equal amounts of usable protein. Minor corrections for differences in vitamin and mineral content are required to establish actual nutritive value, but the ingredient cost for fortification with L-lysine is approximately 40 percent lower than that with defatted soy flour, the cheapest protein supplement (Table 4.9). Fortification with fish protein concentrate costs about three times more than with L-lysine, and fortification with skim milk powder costs eight times more. Provided there is no excessive loss of lysine during storage and cooking, L-lysine= supplementation of cereals is superior to supplementation with proteins not only for its failure to produce detectable organoteptic and textural changes, but also because it is cheaper.

Table 4.11

Economic Evaluation of Cereal Enrichment with L-lysine and with Protein Supplements

Wheat flour(g)	Supplement(g)	Total protein(g)[a]	Chemical score[b]	Usable protein[c]	Energy (Kcal)	Cost of Enrichment (U.S. $)[d]	Percent Enrichment level
542		49.9	26	13	2000	0	0
542	1.09 L-lysine·HCl	51	48	24.5	2000	0.0061	0.2
507	29 soy flour, defatted	61.1	41	24.5	2000	0.0102	5.4
506	36.1 skim milk powder	59.6	42	25	2000	0.0487	6.7
535	12.5 fish protein concentrate	58.3	42	24.5	2000	0.0188	2.3

a. Analytical data from FAO, 1970.

b. The chemical score is the percentage of the first limiting amino acid to "Amino Acid Content of Foods and Biological Data on Proteins." FAO Nutritional Studies No. 24. FAO: Rome. Reference.

c. Usable protein is the protein content (x), the chemical score.

d. Prices (U.S. $/kg) of supplements:

L-lysine·HCl	5.60
Defatted soy flour	0.35
Skim milk powder	1.35
Fish protein concentrate	1.50

Source: Adopted from a table in H. H. Ottenheym and P. J. Jenneskens, "Synthetic Amino Acids and Their Use in Fortifying Foods." Journal of Agricultural and Food Chemistry 18. Pg. 1010.

Practically all the nutrients (vitamins, minerals, amino acids, proteins) which have been considered as cereal fortificants in this paper are produced in the developed countries, particularly the United States, Japan, and Western Europe. Their major markets are also in the developed world where they are used as feed ingredients, pharmaceuticals, and food additives. Fluctuations in the availability and cost of these nutrients could easily jeopardize a fortification program. Vitamins and minerals account for less than 10 percent of the ingredient cost for cereal fortification with vitamin-mineral-amino acid or vitamin-mineral-protein premix, so price fluctuations for these micronutrients should not greatly affect cereal fortification programs. However, the market prices of soy proteins and L-lysine, which generally constitute over 90 percent of the ingredient cost for protein fortification of cereals, have changed drastically between 1972 and 1976. Fish protein concentrate is not produced from fish meal, and it is relatively removed from such fluctuations. On the other hand, soy proteins for food uses are produced from soy solids after solvent extraction of oil. The market price of this raw material is determined by the present and future prices for the substitutes of soy meal, soybean oil, and soybeans (Figure 4.1). In the past few years, the market for L-lysine has expanded rapidly because of escalating soybean prices (Chemical Week, 1974). Fluctuations in the market prices of food-grade L-lysine and protein supplements between 1972 and 1976 are illustrated in Figure 4.2. Although a detailed analysis of the data in Figures 4.1 and 4.2 is well beyond the scope of this paper, we can observe that the market prices of soy proteins and L-lysine for human consumption are strongly influenced by the animal-feed and the edible-oil markets. This relation is partly the result of the overwhelming importance of both soybeans and L-lysine to the feed market: approximately 90 percent of the world's L-lysine (Japan Chemical Annual, 1974) and 95 percent of soybeans in the United States (Pruiett, 1977) are used as feed ingredients.

One way to circumvent the deleterious effects of market-price fluctuations is to manufacture the desired nutrients in the country where the fortification program is carried out. Of course, the investment required to do so is not justified unless the following criteria are satisfied:

(1) Improvements in the nutritional status of the target population must be demonstrated in large-scale fortification studies like the ones conducted in Thailand, Tunisia, and Guatemala.

Figure 4.1

Fluctuations in the Market Prices of Soybean Products and Cottonseed Meal Between 1972 and 1977

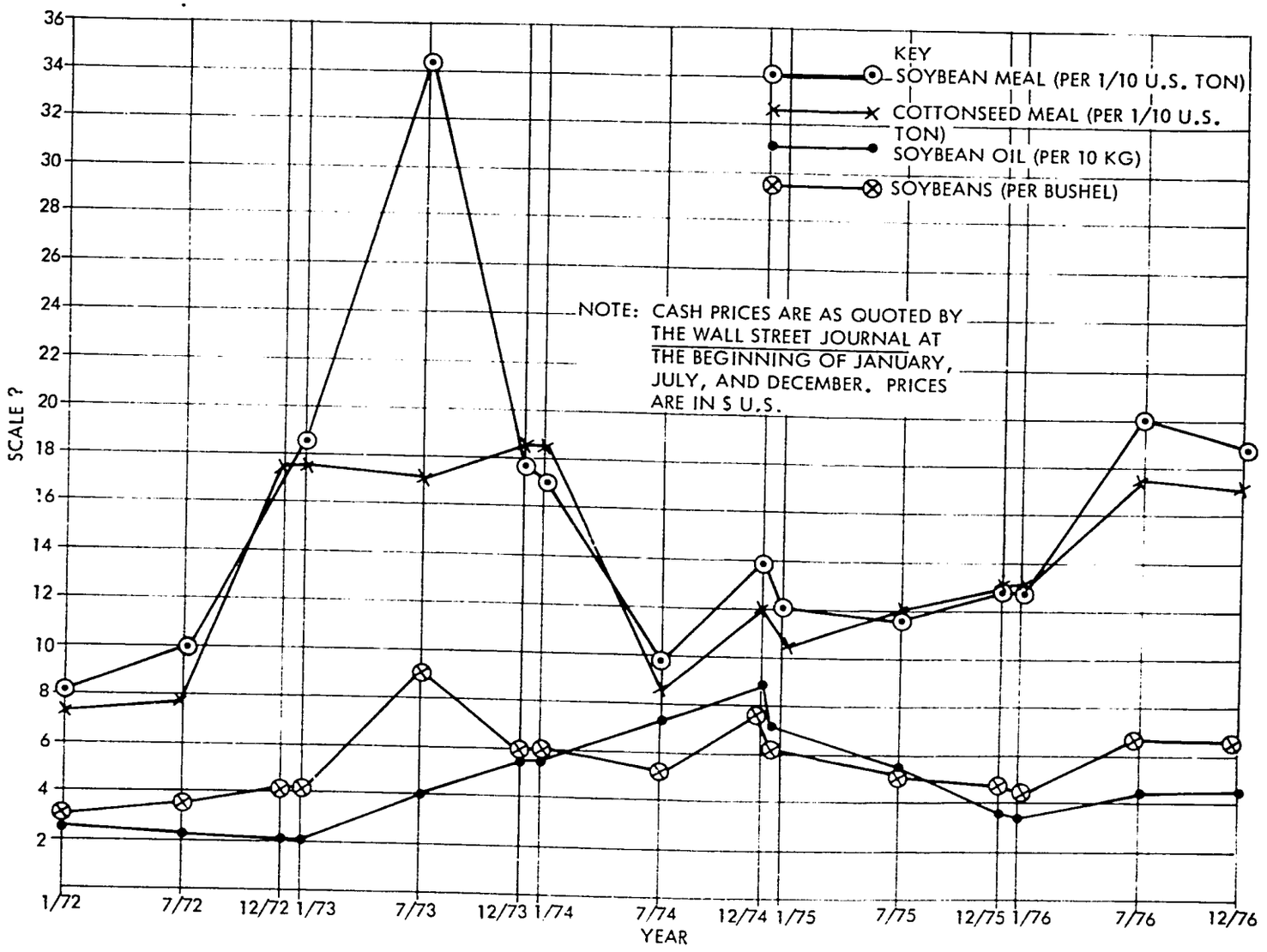
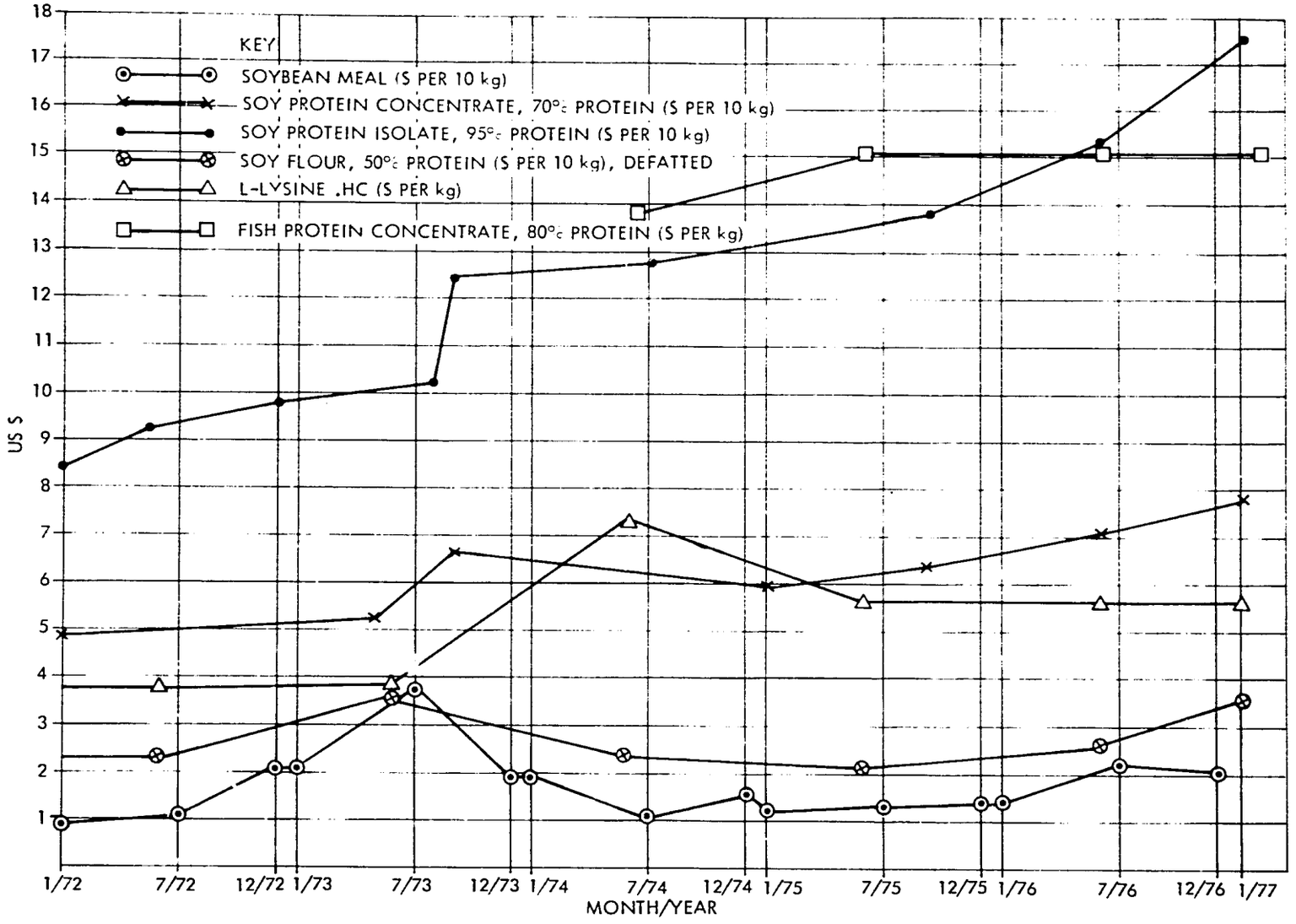


Figure 4.2

Fluctuations in the Prices of Amino Acid and Protein Supplements Between 1972 and 1977



(2) The demand for the protein supplement or L-lysine must be large enough to create a market for the output of a plant large enough to produce the nutrient economically.

(3) A cheap and abundant supply of raw materials for the production of protein supplements (e.g., schooling finfish, pulses) or L-lysine (e.g., blackstrap molasses, corn syrup solids) must exist.

(4) The technological basis of the host country must be able to support the manufacturing facilities.

An economic evaluation of manufacturing facilities for protein supplements and L-lysine is given on Table 4.12.

Fortification Technologies

The following general technological considerations apply to the fortification of all basic cereals to be discussed in this section:

(1) The selection of a method of nutrient addition must be carefully considered. The availability of reliable equipment is a factor in this decision.

(2) The fortification process should assure the uniform distribution of added nutrients at the mill as well as during the transportation, storage, and preparation of the food.

(3) Precise quality-control procedures must be used to determine the level and the distribution of nutrients in the fortification premix and in the fortified cereal. To monitor the level of cereal fortification at the mill, a rapid and reliable assay for an indicator nutrient must be available.

(4) The effects of processing, transportation, and storage on added nutrients must be defined and understood.

(5) The nutritional gains brought about by the addition of certain nutrients to cereals must be balanced against their adverse effects.

The form of the nutrients and the point and manner of their addition must be treated individually because so many factors related to them can affect the nutrient levels of the final product.

Table 4.12

Economic Evaluation of Manufacturing Facilities for Protein Supplements and L-lysine

	Production capacity (tons/year)[a]	Capital cost[b] (Million U.S. $) 1977	Capital cost[b] (Million U.S. $) 1980	Manufacturing cost (Million U.S. $) 1977	Manufacturing cost (Million U.S. $) 1980	Cost of supplement (U.S. $/kg)[c] 1977	Cost of supplement (U.S. $/kg)[c] 1980	Quantity of cereal fortified (tons/year)[d]
L-lysine·HCl	4500	12.1	16.1	7.8	10.4	4.42	5.89	2,255,000
Fish protein concentrate	7000	7.1	9.1	1.7	2.3	1.26	1.67	297,000
Soy flour, protein flour from native sources	10900	0.8	1.2	1.2	1.8	0.18	0.28	190,000

Note: Estimates are based on 1972-73 data from Denkenwater (1976) for L-lysine via fermentation, on 1975 data from Astra Nutrition U.S.A. (1977) for fish protein concentrate, and on 1976 data from Wenger Manufacturing (1977) for soy and other proteinaceous flours.

a. Production capacity is based on a continuous three-shift operation, 6000 hrs/yr.

b. Capital and manufacturing cost estimates are based on 10 percent increments per year. Capital cost consists of expenses for machinery, buildings, and supporting facilities, wiring and piping, and installation. Manufacturing cost consists of expenses for raw materials, energy, operating supplies, labor, management, and maintenance. The following table illustrates how the cost estimates are actually derived from available data:

c. Compare the U.S. $/kg cost of supplement values with those in Table 4.8 and 4.9.

d. The quantity of cereal fortified (tons/year) is based on fortification with L-lysine·HCl at 0.2 percent level or its equivalent with protein supplements (refer to Table 4.11). Soy flour or other protein-rich flours are assumed to contain 40-50 percent protein with a P.E.R. equivalent to that of soy flour protein.

Table 4.12 (Cont.)

	L-lysine·HCl		Fish protein concentrate		Soy and other protein-rich flour	
	Capital	Manufacturing	Capital	Manufacturing	Capital	Manufacturing
1972	7.5	4.8	-	-	-	-
1973	8.3	5.3	-	-	-	-
1974	9.1	5.9	-	-	-	-
1975	10.0	6.5	5.85*	1.4	-	-
1976	11.0	7.1	6.4	1.6	0.8*	1.2**
1977	12.1	7.8	7.1	1.7	0.9	1.3
1978	13.3	8.6	7.8	1.9	1.0	1.45
1979	14.6	9.4	8.6	2.1	1.1	1.6
1980	16.1	10.4	9.4	2.3	1.2	1.8

* Capital costs for a fish protein concentrate production plant and a protein flour manufacturing plant are broken down as follows:

** According to Wenger Manufacturing (1977), total operating cost for 4000 lb/hr. Unit is $16.2/hr, or $97,200/6000 hr/yr. To calculate total manufacturing cost, the protein source (pulses, etc.) is estimated at $0.1/kg, which is about half of the current soybean price in the U.S. Thus ($0.1/kg (x) 10,900,000 kg) + $97,200 ≅ $1.2 million.

	Capital cost (million U.S. $)	
	Fish protein concentrate	Protein-rich flour
Process machinery	3.59	0.24
Buildings and related facilities	1.97	0.40
Miscellaneous (running-in, etc.)	0.29	0.16

Wheat

Wheat is primarily consumed as flour in breads, cakes, biscuits, gruels, and porridges. In some parts of the world like the Near East, bulgur, a parboiled wheat, is an important staple. There is no need to make the nutrients added to wheat flour and bulgur water-resistant because these products are mainly used in preparations which involve no rinsing or discarding of excess cooking water.

Wheat flour produced in large commercial mills -- most of the imported wheat in Peru (Beigler, 1969), Indonesia (MIT INP Program, 1975), and other developing countries (Senti and Pence, 1971) -- can be efficiently enriched at the mill by metering a vitamin-mineral-amino acid or vitamin-mineral-protein premix into the flour flowing into packing bins (Brooke, 1968). In large U.S. mills, which are equipped with mechanical or air conveyors constructed to ensure the uniform distribution of supplements, vitamin-mineral premix is usually added at the rate of 1 ounce per 100 pounds of flour (1 part premix into 1600 parts flour). Smaller U.S. mills with less sophisticated conveyors and feeders prefer to add a less concentrated premix at the rate of 2 ounces per 100 pounds to minimize addition and distribution errors (Brooke, 1968). As the inclusion of L-lysine (or its equivalent in protein supplements) at a 0.2 percent level increases the amount of premix to be added to the wheat by a factor of at least ten or eleven (Tunisia Report, 1977), most of the centralized mills in developing countries should be able to add the premix without much difficulty. They will have to install break and reduction rolls and a dry chemical feeder between the packing bins, and also slightly modify the flour conveyor to assure the uniform distribution. A diagram of flour milling and the point of premix addition is in Appendix G.

Volumetric dry chemical feeders, which supply constant preset or proportional delivery by volume and do not recognize changes in material density, are usually used to dispense the fortification premix. Gravimetric feeders are commercially available, and they deliver accurately by weight regardless of variations in density. But, these devices are much more expensive and require much technical knowledge for maintenance (Margiotta, 1977). The prices and feed rates of the volumetric feeders commonly used in wheat flour fortification are listed in Table 4.13. Variable-speed drives easily modulate their feed rates.

From time to time though, these rates must be checked because the feeder is volumetric and the bulk density of the fortification mixture may vary (Brooke, 1968).

Table 4.13

Prices and Feed Rates of Volumetric Feeders

Type	Feed rates (ft^3/hr)	Feed rates (kg/hr)[a]	Price (U.S. $)[b]
Roll-type	.000167 to .16	.00227 to 2.176	1300
Screw-type	.001 to 11.4	.0136 to 155.04	1800
Screw-type	.001 to 18.5	.0136 to 251.6	2200

Source: Wallace and Tiernan, 1977.

[a]Assuming the bulk density of the premix is 30 lb/ft^3 or 13.6 kg/ft^3.

[b]FOB Belleville, N.J. price from Wallace and Tiernan (1977).

To minimize errors in feed rates, the premix must be free-flowing and consistent in bulk density. Furthermore, to avoid the separation of added nutrients and flour during transportation and storage, the premix must have a particle size ("mesh") and bulk density similar to wheat flours. Accurately compounded, finely milled fortification premixes with wheat or cornstarch as the binder for vitamins and minerals are available from the U.S., Europe, and Japan at low incremental costs (less than 5 percent of the cost of vitamin and mineral ingredients). By buying preblended vitamins and minerals to order, the host country will avoid the many problems of premix manufacturing (Wooden, 1974). The imported vitamin-mineral premix can easily be blended with L-lysine, soy flour, fish protein concentrate, or a properly prepared native source of protein at some central location with a spiral ribbon mixer. Table 4.14 shows the prices and capacities of several such mixers. When the host nation can afford to buy both the vitamin-mineral premix and the L-lysine or protein supplement from the same developed country, it may choose to eliminate its own blending operation to avoid the unnecessary expense of quality-control facilities. Data from the Tunisian Study (Tunisia Report, 1977) indicate that both the vitamin-mineral and

the vitamin-mineral-L-lysine premixes shipped from the U. S. are stable for twelve to eighteen months when packed in drums lined with an inert material and kept dry and cool.

Table 4.14

Prices and Specifics of Ribbon Mixers

Working capacity[a]		Bowl dimensions (inches)			Flush plug gate diameter (inches)	Agitator speed (rpm)	Nominal	Price (U. S. $)[b]
ft^3	kg	length	width	height				
5	68	48	16	19	4	65	2	8,500
25	340	96	24	27	8	50	7.5	13,000
50	680	120	30	35	10	40	10	17,000
125	1700	120	48	56	12	25	25	32,000
260	3536	144	63	75	12	20	30	45,000
490	6664	144	87	101	12	12	50	76,000

[a]Assuming the bulk density of the premix is 30 lb/ft^3 or 13.6 kg/ft^3.
[b]FOB York, Pennsylvania price provided by READCO (1977).
Source: READCO, 1977.

The final vitamin-mineral-amino acid or vitamin-mineral-protein premix must be checked for uniform composition with a statistical sampling plan. This testing requires a quality-control laboratory capable of carrying out quantitative assays of the nutrients according to the standard analytical methods, such as those listed in "Official Methods of Analysis of the Association of Official Analytical Chemists". If the levels of nutrients in the final premix have been carefully controlled in the manner we suggest, a check of the fortified flour for a single ingredient should be enough to ensure that all the other nutrients are present in the correct amounts. For example, many mills use a quick, roughly quantitative test for riboflavin. The tester examines a flattened, wetted wedge of enriched flour on a glass or metal strip in the dark, under ultraviolet light. The intensity of fluorescence emitted by the wetted particles of riboflavin allows him to estimate the level of enrichment (Brooke, 1968). Both this method and the ninhydrin test for L-lysine are judged adequate for routine quality control of fortified flour in the Tunisia Study (Tunisia Report, 1977). The Tunisia Study also finds no significant separation of added nutrients during transportation and storage, and very small variations in the premix feeding rate, even on a gravimetric basis.

There are numerous technological difficulties and logistic barriers to the fortification of wheat flour at village mills. Unfortunately, a major portion of the wheat flour produced at central mills in developing countries is consumed by the middle- and upper-income groups in urban areas. Fortification of their wheat results in excess nutritional coverage; it is an undesirable expenditure, in terms of achieving nutritional improvements. Most native wheat, which is often consumed by the nutritionally deficient rural populations, is processed at small local mills. For instance, most milling in Tunisia is performed in the villages with attrition mills of stone or iron, as illustrated in Appendix H. These mills grind grain once, and the customer sifts the product. It is approximately 50 percent semolina, 30 percent flour, and 20 percent bran, which the livestock eat (Food and Feed Grain Institute, 1974). The quantity of wheat milled for each customer is small. Under these circumstances, there are three possible methods to fortify the semolina and flour:

(1) At a central location, two premixes differing only in particle size, one at the mesh range of semolina, and the other at the mesh range of flour. Each premix can be mixed with sifted semolina or flour at the village mill with a simple mixing bucket agitated by hand-rotated paddles. The mixing bucket and the measuring cups used to scoop the premixes can be standardized so the semolina and flour will be fortified at the proper levels (see Appendix I).

(2) Prepare a premix in the form of tablets or pellets. The village miller can add them to his attrition mill at controlled rates by slightly modifying the milling machine and attaching a simple volumetric feeder similar to the one used in the Thailand Study (Appendix M). The premix tablets will be added to the wheat stream just before it enters the attrition rollers, and mixing will take place during milling. Tablets or pellets can also be mixed with wheat by hand before the mixture is added to the milling machine.

(3) Prepare a premix in the form of heavily fortified whole-wheat kernels, which can be added to wheat as in the second method above.

The advantages and shortcomings of each of these methods are tallied in Table 4.15. The first method is by far the most efficient in terms of premix and equipment costs, but to be effective it requires extensive cooperation from the mill operator and his customers. Powdered premixes cannot be added accurately to the outcoming stream of milled wheat because its amount is small and always changing. To avoid the separation of premixes with different bulk densities in the feeder unit, one feeder must be installed for each premix. Furthermore, because there is no build-in mixing step, fortified semolina and flour must be mixed, possibly by hand.

Both the second and the third methods require much less cooperation from the miller, especially if he can attach an inexpensive feeder to his milling machine. The reliability and accuracy of such feeders (1 ± 0.03 percent) is demonstrated in the Thailand Study (Gershoff et al., 1975). Nevertheless, the second method suffers from the high cost of the premix, possible customer resistance to the addition of exogenous material to food, and the uncertain distribution of the added nutrients between semolina and flour after sifting. Unless the pellet or tablet is physically similar to the whole wheat kernel, a greater portion of the added nutrients will end up in either the semolina or the flour. Unfortunately, no experimental data is presently available to pursue this discussion further. Unlike the second method, the third assures the uniform distribution of fortificants between semolina and flour (Table 4.16) and provokes the least customer resistance.

Fortified whole wheat kernels are produced in the following manner (Graham et al., 1968). First, a machine fitted with abrasive surfaces scores the surfaces of wheat kernels in a very light pearling treatment; second, the kernels are soaked in a 35 percent solution of L-lysine at 160°F for 3 hours. After draining for one hour and careful drying to avoid giving the kernel surfaces a powdery, salted appearance, the fortified wheat kernels - containing 10 to 15 percent L-lysine - are ready for use. When blended into ordinary wheat at 1 to 2 percent, they are undetectable in appearance and taste. Upon milling, the retention of L-lysine follows the extraction rate of the flour fairly closely. Washing the wheat kernels will remove 25 or 30 percent of added L-lysine (Graham et al., 1968). Vitamin A cannot be added to whole wheat kernels in this infusion process because of its low solubility in water, but water-soluble B-vitamins can be readily incorporated at desired levels. Our third method, therefore, appears to be the best way to

Table 4.15

Advantages and Shortcomings of Different Methods Proposed for Flour Fortification at Village Mills

Methods	Cost of premix (U.S. $/kg)[a]	Cost of Premix (U.S. $/kg flour fortified)[b]	Cost of equipment (U.S. $)	Mill Modification	Distribution of nutrient	Limitations to nutrient addition	Extent of cooperation required from the miller and customers
Premix	4	0.008	10-15 (mixing bucket)	None	Uniform only if cooperation is good	None	Very much from both
Tablets/ pellets	7	0.07	50-100 (feeder); 0 (hand)	Minor None	Unknown	None	Some from the miller
Fortified wheat kernels	2.5	0.05	50-100 (feeder); 0 (hand)	Minor None	Uniform	Only L-lysine and water-soluble vitamins; no vitamin A	Some from the miller

[a] The cost of normal premix containing 60 percent L-lysine is estimated from data provided by Wooden (1974) with a corrective factor (2.3) for increase in L-lysine and vitamin prices. The cost of tablets/pellets is based on data provided by Mock (1977): $10 for Ajinomoto simulated rice granules containing 20 percent L-lysine, less $3 for L-threonine. The cost of fortified wheat kernels containing 10 percent L-lysine is estimated by allowing $0.6 for nutrients (0.1 kg L-lysine at $0.56 and $0.04 for vitamins), $0.1 for 1 kg wheat, and $1.8/kg for processing cost.

[b] Estimates based on flour fortification at 0.2 percent L-lysine level.

Table 4.16

Distribution of L-lysine in Whole Wheat Containing 8 Percent L-lysine after Infusion

	Weight fraction (percentage of whole wheat)	Percentage of free L-lysine content	Free L-lysine as a percentage of L-lysine input
Bran	0.5	5.27	0.3
Groats and middlings	7.2	14.92	6.6
Semolina and flour	92.3	7.99	93.1

Source: H.H. Ottenheym and P.J. Jenneskens. "Synthetic Amino Acids and Their Use in Fortifying Foods." Journal of Agricultural Food Chemistry 18. Pg. 1010.

fortify wheat semolina and flour at village mills where there is no special need for vitamin A and protein supplements. But for all of these methods, the quantities and distribution of added nutrients in semolina and flour can be monitored by the semiquantitative riboflavin test and the ninhydrin test for L-lysine, described previously.

Bulgur, which is an important staple in the Near East, is prepared by parboiling whole wheat kernels and removing the bran with friction after drying. Rarely rinsed before consumption, bulgar can be fortified with powdered nutrients or by spraying a concentrated solution into a moving stream of grain. Subsequent mixing of the grain distributes the fortificants uniformly as particles adhere to the kernel surfaces (Senti and Pence, 1971). This process, currently used to fortify bulgur exported from the U.S., is readily applicable to bulgar produced at central locations in developing countries. However, bulgur is also often prepared from wheat kernels at home, and no fortification method appears to be effective in this instance. Even if fortified whole wheat kernels were provided individual households, soaking and parboiling would inevitably result in the excessive loss of added nutrients.

Rice

Rice is the staple of Asia. It is consumed mostly in a completely polished form and, in many countries, highly polished white rice is prized for its palatability (Mitsuda and Yasumoto, 1974; Somboonsub, 1976). As shown in Tables 4.1 and 4.2, polished rice is deficient in a number of vitamins as well as L-lysine and L-threonine. Many biological experiments have demonstrated that the fortification of rice proteins with both L-lysine and L-threonine improves their nutritive value, but that fortification with L-lysine alone is less effective (Mitsuda and Yasumoto, 1974). Results from laboratory animal and human studies indicate that the quantity of usable protein in polished rice can be increased significantly by the addition of 0.2 to 0.3 percent L-lysine and 0.1 percent L-threonine (Rosenberg, 1959; Hegsted, 1971; Mitsuda and Yasumoto, 1974).

Like corn and wheat, the majority of rice consumed in rural areas beset by chronic nutritional deficiencies is processed by small village mills. For instance, over 90 percent of the rice consumed in Thai villages is processed at the village level (Gershoff et al., 1975; Austin and Snodgrass, 1976). Thailand in fact has over five thousand rice hullers scattered throughout the country (Somboonsub, 1976; Call and Levinson, 1973). To carry out a successful rice fortification program there, logistic and administrative problems must be solved with government cooperation.

Rice is almost always rinsed and foreign particles are eliminated before cooking. Furthermore, it is common practice in South Asia to cook rice in excess water which is later discarded. With fortified rice, the excessive nutrient losses due to leaching and the willful exclusion of exogenous fortified rice granules must be prevented. Currently, three methods have been used commercially or in large-scale field studies to produce rinse-resistant fortified rice kernels which can be added to milled rice.

Surface Coating Method

Used to fortify rice kernels with vitamins in the famed Bataan experiment (Brooke, 1968) and in Japan (Mitsuda and Yasumoto, 1974), this approach requires that a suspension of amino acids and vitamins be sprayed onto clean polished rice as it is tumbled in a large rotating cylinder. The solvent evaporates, leaving a relatively insoluble coating on the rice. The desired level of fortificants is built

up by repeating this operation. The surface is then covered with a rinse-resistant coating such as food-grade shellac, rosin, or ethyl cellulose. The coating material can also be incorporated into the nutrient suspension, eliminating the final coating step. In one Japanese process, a commercial coating mixture (17.9 percent L-lysine, 3.6 percent L-glutamic acid, and 78.5 percent dextrin and vegetable oil) is dissolved in water at 35 percent (weight/volume), and the resultant emulsion is applied to clean polished rice at the rate of 1.6 percent (volume/weight) in a tumble coating machine. There are two serious drawbacks to the surface coating method: the lengthy processing time required to build up the desired level of nutrients, and the resemblance of the fortified kernels to pills (Mitsuda and Yasumoto, 1974) because of the large quantity of amino acids that must be deposited on the rice to make the premix contain 20 percent L-lysine and 10 percent L-threonine. Thus, this method is not recommended for rice premixes fortified with amino acids and vitamins, although it is acceptable for uniformly fortified rice (produced in Japan) or premixes fortified with only vitamins and minerals. In principle, proteins of low water solubility can serve as the coating material if protein rather than amino acid supplementation is preferred. However, such heavily fortified rice will not appear very much like rice.

Infusion Method

Described in Appendix J, this is probably the best method to make fortified rice premix because of the similarity between treated and untreated kernels. Furthermore, the technology of the infusion method is well established because it has been used in Japan for years to enrich rice with the B-vitamins (Senti and Pence, 1971; Mitsuda and Yasumoto, 1974; Akino, 1969). Unfortunately, it is of no use in protein supplementation. Also, because the premix it produces contains approximately 6 percent L-lysine, 2 to 3 Percent premix has to be added to ordinary rice to achieve final fortification levels of 0.1 to 0.2 percent. Those parts of the soaking tank that come into contact with acidic amino acid solutions must be made of stainless steel or coated with acid-resistant plastics to avoid corrosion.

Simulated Kernel Method

Simulated rice kernels are made by extruding a dough of fortificants and a binder of starch or proteins through a short-goods die in a macaroni press after

gelatilization at temperatures between 250 and 400°F (Brooke, 1968; Mitsuda and Yasumoto, 1974; Senti and Pence, 1971). Patended by the Ajinomoto Company of Japan, this method permits the incorporation of nutrients at high levels. To prevent excessive nutrient losses during precook rinsing, the simulated granules are coated with water-resistant films of food-grade shellac, ethyl cellulose, or other materials (Mitsuda and Yasumoto, 1974; Gershoff, et al., 1975). A schematic outline of this process is presented in Appendix K. Because the technique can be adapted to simulate kernels of other cereal grains, Appendix L lists estimates of equipment and production costs. The high cost of extrusion equipment and related facilities prevents economical premix production unless the machinery's capacity (2000 to 4000 pounds/hour) is fully used. At 6000 production hours per year and at 1 percent premix addition, a single installation can fortify 540,000 to 1,080,000 tons of basic cereals per year. In the early stages of a fortification program, it is therefore more practical to import simulated kernels or to contract a macaroni plant, with some equipment modifications and additions, to produce them. Simulated rice kernels reportedly reduce the palatability of rice and clump together when stored in a humid atmosphere like that of Southeast Asia (Mitsuda and Yasumoto, 1974). And because the fortification nutrients are exposed to high temperatures at moisture ranges of between 10 and 60 percent during extrusion cooking (Steele, 1976; Smith, 1971), reducing sugar content must be kept at less than 0.1 percent to a oid excessive loss of amino acids through Maillard Reaction or Strecker Degradation. Unless they are properly encapsulated to withstand these processing conditions, heat-labile vitamins such as thiamine and vitamin A should be applied just before coating to avoid excessive loss or off-flavor development (Smith, 1971). With extrusion-cooked, ready-to-eat cereals, spraying vitamins on the surface prior to coating has made the product more acceptable to the consumer (Steele, 1976). Although the simulated kernel technique can fortify rice with protein supplements instead of amino acids, the ratio between rice and simulated kernels would probably be 20 or 30 to 1 instead of 100 or 200 to 1. The increase in simulated kernals would undoubtedly cause noticeable -- and probably objectionable -- changes in the taste and texture of the cooked rice.

Fortified rice premix prepared by any of the above methods can be added to milled rice at fixed rates if a simple feeder unit is attached to the milling machine. The reliability and accuracy of the feeder have been

amply demonstrated in the Thailand Study (Gershoff, 1975). The rate of premix addition is determined by the fortification level desired and the concentration of the nutrients in the premix. With simulated kernels containing 20 percent L-lysine, 0.2 percent L-lysine fortification can be achieved by adding 1 part premix to 100 parts milled rice. But with infused kernels containing 6 percent L-lysine, 3.3 parts premix must be added to achieve the same fortification level. As stated by Gershoff et al , 1975, a perfect premix would look like rice, cook like rice, taste like rice, and maintain its nutrient qualities through rinsing and cooking. Although fortification premixes made by any of the above methods will retain their nutrients relatively well, none has perfect organoleptic properties. All premixes have problems with salty-tasting spots from amino acids and yellow spots from riboflavin (Senti and Pence, 1971; Cousolozio, 1966). Unfortunately, these problems increase as the effectiveness of the coating material and concentrations of added amino acid and riboflavin rise. So there are advantages and disadvantages to using a concentrated premix with highly water-resistant coating. To maintain quality control, the level of nutrients in the premix should be monitored with analytical procedures and a statistical sampling plan, as in the case of premixes for wheat flour fortification. Fortified rice kernels must be fully ground to ensure that analysis reveals all added nutrients. The level of fortification at the village mill can be monitored by grinding the final fortified product and testing it much as one does semiquantitative analysis for riboflavin and L-lysine in wheat flour.

The advantages and shortcomings of various methods of making rice fortification premixes are listed in Table 4.17.

Corn

Like wheat and rice, the majority of corn consumed in rural areas is processed through village mills. In Guatemala, where corn is an important staple, over 95 percent of rural families mill their corn at the village nixtamal mill (Austin and Snodgrass, 1976). At home, corn is culled of foreign particles and soaked in lime water to remove the hull. After washing and drying, the village nixtamal mill wet-mills the dehulled kernels into a dough for tortillas or tamalitos. Traditional stone mills found in almost all areas of Guatemala further refine the corn dough (Garcia and Urrutia, 1976). It is then made into tortillas and, once in a while, tamalitos.

Table 4.17

Advantages and Shortcomings of Different Methods Used in Making Rice-Fortified Premix

Methods	Cost of premix ($ U.S./kg)[a]	Cost of Premix ($ U.S./ kg rice fortified)[b]	Limitations to nutrient addition	Organoleptic and handling properties
Surface coating	4.0	0.04	Theoretically none	Looks like drug pill at this level of added nutrients
Infusion	1.31	0.043	No proteins	Closest to ordinary milled rice
Simulated	3.5 (10)[c]	0.035 (.1)	None	Problems with clumping during storage. Salty spots. Texture differs from that of rice.

a) The cost of the premix (U.S. $/kg) is derived in the following way:

	Surface coating	Infusion	Simulated kernel
Production cost	0.66 (Senti and Pence, 1971)	0.24 Mitsuda and Yasumoto, 1974)	0.18 (Appendix 11b, at 6000 tons/yr)
L-lysine	1.12 (20%)	0.336 (6%)	1.12 (20%)
L-threonine[d]	2.00 (10%)	0.600 (3%)	2.00 (10%)

Table 4.17 (Cont.)

	Surface coating	Infusion	Simulated kernel
Starch, coating material	0.10	0.100	0.10
Vitamins	0.10	0.035	0.10
	3.98	1.31	3.5

b) Cost of premix (U.S. $/kg fortified rice) is derived by assuming a final fortification level of 0.2 percent L-lysine and 0.1 percent L-threonine.

c) Ajinomoto Company estimates that simulated rice kernels would cost $10/kg, assuming $5.50/kg L-lysine and $57/kg L-threonine. Using these values for amino acids, we obtained $7/kg premix. The remaining $3/kg is probably the company's charge for process development, etc.

d) L-threonine is assumed to cost $20/kg instead of the current price of $57.70 for commercially available pharmaceutical-grade.

When a milled cereal product is consumed without rinsing or discarding the cooking water, it can be fortified is the same ways as wheat at the village level. Fortification of nixtamal dough (wet-milled corn) should be easier than fortifying milled wheat because there is no need to sift the product into two particle sizes (semolina and flour). Wet-milled corn can be fortified by simply adding the fortificant mixture by hand or with a cheap feeder. Although the addition of 7.8 percent soy flour reportedly darkens tortillas, reduces their storage stability, and changes the handling properties of the dough (Garcia and Urrutia, 1976), vitamin-mineral-amino acid and vitamin-mineral-protein premixes can also, technically, be milled along with dehulled corn. Because pelletization has no benefits but to make the premix look more real, it is not recommended for premix preparation unless consumer and miller resistance to powdered premix is very strong.

Premixes for fortifying wet-milled corn can be manufactured with the procedures and quality-control measures used in the central mills (pages 80 - 82) for powdered premixes for wheat flour. The level and distribution of nutrients can be monitored at the village nixtamal mill with the simple, semiquantitative tests described previously. As stated previously L-tryptophan is a significant precursor of niacin in human beings, so high corn diets limiting in both niacin and tryptophan may be nutritionally improved by adding the less expensive niacin ($5 to 5.25/kg) instead of L-tryptophan ($86.80/kg). With 1 mg niacin roughly equivalent to 60 mg L-tryptophan, a smaller amount is also necessary to adequately fortify corn. Nicotinamide, coated to mask its bitter taste, is recommended because nicotinic acid produces transient flushing of the face at oral doses of 50 or 100 mg.

Corn grits present more fortification problems than wet-milled corn dough because they are often rinsed before cooking. But technologies like those for fortifying milled rice are readily applicable here.

Stability of Added Nutrients

The losses of added nutrients during fortification, storage,* and cooking must be evaluated to determine the fortificant quantities required and fortifications

*Although losses of cereals to insects and rodents are often significant in developing countries (FAO, 1969), such losses will not be discussed here because all cereals, fortified or not, are susceptible to them.

"actual cost: the expensive of delivering the nutrients the target population actually

causes:

(1) Chemical reactions that so alter nutrient molecules that they are not digested, absorbed, or metabolized properly

(2) Leaching, in which the added nutrients are removed from cereals during washing, rinsing or cooking,

(3) Microbes, can yeasts or molds, render the added nutrients nutritionally unavailable and may, at the same time, produce dangerous toxins or unsightly pigments.

Chemical Reactions

Although amino acids and proteins (actually amino acid subunits linked with peoptide bonds) are relatively sturdy in dry, cool atmosphere, their stability is threatened by the high temperatures and humidity in many developing countries and by reactive carbonyls and oxidizing agents in the diet. Nutrient loss in aminc acids and proteins can occur by the destruction of essential amino acids or by a decrease in total nitrogen available from the digestive process. Lysine, tryptophan, methionine, and threonine are among the most labile amino acids in food subjected to certain processing or storage conditions (Roubal and Tappel, 1966; Buttkus, 1967; Tannenbaum et al., 1969).

Of the various chemical reactions which may reduce the biological availability of added amino acids and proteins during processing and storage, the Maillard Reaction (fully described in Appendix M) is probably the most important. In it, the amino groups of amino acids or proteins combine with carbonyl groups from reducing sugars or oxidized fats to form N-substituted derivatives, which the body digests and absorbs poorly (Tanaka et al., 1976; Erbersdobler, 1976). Beyond its adverse nutritive effects, the Maillard Reaction leads to extensive, unappealing browning. Another reaction that may reduce the biological availability of added amino acids under certain processing conditions, such as baking or frying, is called the Strecker Degradation (see Appendix N), in which free amino acids are degraded by the carbonyls to aldehydes and ketones containing one carbon atom less (Schonberg and Moubacher, 1952). In spite of its adverse nutritive effects, this reaction contributes importantly to the flavor of baked and fried foods (Linko et al., 1962).

Amino acids added to cereals as proteins or as free amino acids may also be destroyed under such oxidizing conditions as the bleaching of flour with benzoyl peroxide, the sterilization of milk with hydrogen peroxide (Cuq et al., 1973), and the oxidation of fats during storage (Tannenbaum et al., 1969; Lea, 1962). These oxidation reactions are described in Appendix N.

Although a nutritionist thinks of vitamins as a single group of nutrients, to an organic chemist, they are heterogeneous and without common structural attributes. To properly discuss the stability of vitamins during processing and storage is to consider each vitamin separately.

Vitamin A and its precursor beta-carotene are sensitive to air, oxidizing agents, and ultraviolet light. Their decomposition is catalyzed by metal ions and accelerated by increasing temperature. Under acidic conditions (with pH less than 4.5) or high temperatures, partial isomerization of vitamin A from all trans form to the less potent cis form will occur (De Ritter, 1976). Vitamin A losses in fortified food can be reduced substantially with the combined use of food-approved antioxidants (e.g., BHT, BHA, propyl gallate) and protective coatings, and by minimizing exposure to high temperatures and acidity.

Thiamine, one of the most unstable vitamins, breaks down rapidly when exposed to neutral or alkaline conditions (pH greater than 5), high temperatures, oxidizing conditions, ultraviolet light, gamma-radiation, nucleophiles, and thiaminases (enzymes found in vegetable and animal products, particularly sea-foods). Metal ions catalyze its breakdown and proteins often have protective effects (De Ritter, 1976). Thiamine degradation odors are objectionable in some cereals but almost unnoticeable in others (Borenstein, 1975).

Riboflavin and niacin are much more stable than thiamine and vitamin A. With the exception of riboflavin's susceptibility to light and alkali, these two vitamins are practically stable in the conditions of food processing and storage. Schematic representations of the chemical pathways leading to the degradations of vitamin A, thiamine, and riboflavin are given in Appendix O.

Unlike vitamins, amino acids, or proteins, minerals are rarely destroyed through chemical reactions in food. Instead, chemical binding to oxalates and phytates renders them biologically unavailable forming insoluble salts which pass through the digestive tract.

Leaching

Leaching is an insignificant cause of nutrient loss when fortified cereals are consumed without precook rinsing or disposal of the cooking fluid. Such is often the case for flours and grits, which are used to prepare Western and native "breads" (e.g., chappatis in India and Pakistan, baladi and tannour in the Middle East, tortillas in Central America, couscous in North Africa, buns in China) and porridges (e.g. fereek in the Middle East, wholemeal flour porridge in India and Pakistan). In the United States and some European countries, even rice may fall into this category because it is rarely washed prior to cooking. On the other hand, leaching may contribute significantly to the loss of water-soluble nutrients if fortified cereals are washed prior to cooking or if the cooking water is discarded. This treatment is most often true for rice in Asia and pasta products all over the world. In the Far East and Southeast Asia, polished rice is rinsed with water at least once to remove impurities before cooking. In South Asia, it is cooked in excess water later discarded (Parman, 1968). Subjected to these conditions, rice inevitably looses some of its nutrients, even from the fortified rice kernels treated to minimize leaching losses. Among the nutrients we have considered for cereal fortification, thiamine, niacin, free amino acids, and minerals are most susceptible to leaching losses. The previous section treated the technologies to minimize such losses.

Microbial Actions

Fortified cereals offer microorganisms a more favorable nutritional environment for proliferation. At the high temperatures (80 to 100°F) and humidity (greater than 80 percent) characteristic of the tropics and subtropics, microbial actions may render the added nutrients biologically unavailable and also produce toxins and unsightly pigments. During storage and transportation, the equilibrium moisture content of cereals easily exceeds 13 to 16 percent, the level at which molds and fungi grow (Appendix P). If the fortification premix is more hygroscopic than the bulk cereal, granules with added nutrients and higher surface water may provide the ideal environment for mold and fungi growth. High temperatures will further aid these microorganisms. Mistsuda and Yasumoto (1974) point out that simulated rice kernels tend to clump together in storage under humid conditions because of their hygroscopicity. Austin and Snodgrass (1976) report that some families refuse to have their corn fortified, knowing that tortillas of

protein-fortified corn dough tend to decompose more quickly than conventional ones. Protein-fortified tortillas retain more water than the conventional ones. So cereal fortification may adversely affect the microbial stability of the carrier, particularly in warm and humid climates. Unfortunately, this problem has not been addressed sufficiently either in the laboratory or in field studies.

Stability of Added Nutrients under Specific Processing and Storage Conditions

Up to this point, the factors which may affect the stability of added nutrients in cereal foods have been discussed in general terms. Table 4.18 summarizes the stability patterns of different fortificants under specific processing and storage conditions. It shows that stability depends on processing and storage conditions as well as on the chemical and physical form of the fortificant and the fortification process. The table further shows that very little work has evaluated the storage stability of added nutrients under the high temperature and humidity common in developing countries or the overall loss of added nutrients between fortification and consumption. Also, practically no experimental data exist to compare the stability of protein and amino acid supplements. Free amino acids are, however, thought to be less resistant to losses from leaching and chemical reactions than the corresponding amino acids in proteins. Schnickels et al. (1976) report that 50 percent of the free L-lysine they added to a model food system which contained 20 percent moisture and 10 percent glucose (a reducing sugar) was lost in less than a day when they incubated the system at 35°C (88°F). By contrast, "bound" lysine in soy and fish protein did not suffer a 50 percent loss until the seventh and the nineteenth day of incubation, respectively. Table 4.18 shows that losses of added free L-lysine can rise to 40 or 60 percent when fortified flour is made into pasta products or exposed to an environment rich in reducing sugars. Under these circumstances, bound amino acids in proteins are apparently more stable, but there does not yet exist enough experimental data to pursue this argument.

Feasibility Questions

Fortification projects offer definite potential for addressing the nutrient deficits in populations throughout the world. Our fortification technology is well-developed, but the planners should keep certain key questions in mind if they

Table 4.18

Stability of Fortification Nutrients Under Specific Processing and Storage Conditions

Fortificant	Processing/storage conditions	Percentage loss	Reference
Vitamin A (as acetate oil) added to simulated kernel	Extrusion cooking to prepare simulated kernel and storage for three months at 86°F	45-50 (combined processing storage loss)	Gershoff et al. (1975)
Vitamin A (as palmitate beadlets containing antioxidant) added to dry mix products	Storage at room temperature	0.5/month	Borenstein (1975)
Vitamin A (as palmitate beadlets) added to wheat or maize flour	Baking of bread (Western-type, chapatis, tortillas)	0-10	Borenstein (1975)
	Five days storage at room temperature after baking	5-15	
Vitamin A (as palmitate beadlets) added to wheat flour	Three month storage at 45°C		
	9 percent moisture level	13-20	
	13.5 percent moisture level	50-90	
	Four month storage at room temperature		
	9 percent moisture level	0-2	Rubin and Cort (1969)
	13.5 percent moisture level	8-27	
Vitamin A (as palmitate beadlet) added to flour	Baking of (Western-type bread, chappatis, tortillas)	10-13 8 0	Rubin and Cort (1969)

Table 4.18 (Cont.)

Fortificant	Processing/storage conditions	Percentage loss	Reference
Vitamin A added to nonfat dry milk	Storage at 23°C for twelve months	11-31	Bauernfeind and Parman (1964)
	Storage at 37°C for three months	0-6	
Vitamin A sprayed on ready-to-eat cereal	Storage at 23°C for six months	17	De Ritter (1976)
Thiamine added to corn grit	Extrusion cooking at 300°F	39	
	13 percent moisture level	39	
	16 percent moisture level	10	Beetner et al. (1974)
	Extrusion cooking at 380°F		
	13 percent moisture level	52	
	16 percent moisture level	81	
Thiamine (encapsulated) added to protein-rich mixture	Extrusion cooking	10	Smith (1969)
Thiamine added to ready-to-eat cereal	Heating to prepare toasted cereal products	15	Borenstein (1975)
	Storage at 23°C for twelve months	0	De Ritter (1976)
Thiamine added to wheat flour	Commercial baking	21-26	Shultz et al. (1942)
	Baking of Devil's food cake (alkaline)	93-100	De Ritter (1976)
Thiamine added to pasta products	Cooking and draining	50	Rubin and Cort (1969)

Table 4.18 (Cont.)

Fortificant	Processing/storage conditions	Percentage loss	Reference
Thiamine added to dry products (e.g., cocoa)	Twelve month storage at 75°F	13	Borenstein (1975)
	at 98°F	21	
Thiamine (as thiamine naphthalene disulfate) added to simulated rice kernel	Washing, soaking for six hours and slow cooking for two hours (combined loss)	24	Gershoff (1975)
Thiamine added to bulghur	Steamed for table use	Negligible	Pence et al. (1964)
	Canned at 55 percent moisture, retorting	72	
Thiamine added to premix rice kernels by infusion method (with steaming of rice surface)	Washing	7	Kondo (1951)
	Washing and cooking	12	
Riboflavin added to pasta	Cooking and draining	30	Rubin and Cort (1969)
Riboflavin added to corn grits	Extrusion cooking at 300°F		
	13 percent moisture level	0	
	16 percent moisture level	13	Beetner (1974)
	Extrusion cooking at 380°F		
	13 percent moisture level	0	
	16 percent moisture level	46	
Riboflavin added to bulghur	Cooking and draining	40	Rubin and Cort (1969)
Niacin added to pasta products	Steamed for table use	10	Pence (1964)
	Canned at 55 percent moisture retorting	30	

Table 4.18 (Cont.)

Fortificant	Processing/storage conditions	Percentage loss	Reference
L-lysine added to wheat flour	Baking of white bread with 4-6 percent nonfat milk powder (ordinary use)	5-25	Matthews et al. (1969) Jansen and Ehle (1965b) Ericson et al. (1961b) Jenneskens (1969) Gates and Kennedy (1964)
	Baking of white bread with 25 percent nonfat milk powder (high content of reducing sugars)	40	Jansen and Ehle (1965b)
	Baking of sweet bread (high content of reducing sugars)	30	Ericson and Larson (1962)
	Baking of unleavened bread (chappatis, poories, parathas)	0-4	Matthews et al. (1969) Bains and Tara (1970)
	Boiling and draining of noodles	50-60	Akino (1969)
	Boiling or frying	33	Pereira et al. (1969)
	Storage for 51 and 83 days at room temperature	Negligible	
	Steaming to prepare couscous	Negligible	Tunisia Report (1977)
	Baking of bread	9-17	
L-lysine added to Incaparina	Boiling of Incaparina with nonreducing sugar for 24 minutes	Negligible	Bressani et al. (1964)
L-lysine added to whole wheat by the infusion method	Twelve month storage at 100°F		Ferrel et al. (1970)
	13 percent moisture level	Less than 10	

Table 4.18 (Cont.)

Fortificant	Processing/storage conditions	Percentage loss	Reference
L-lysine added to simulated rice kernels	Washing, soaking in water for six hours, and cooking for two hours	18	Gershoff et al. (1975)
L-lysine added to fortified rice premix by the infusion method (with and without steaming of fortified rice surface to form α-starch layer)	Washing for ten minutes (no steaming)	40	Mitsuda and Yasumoto (1974)
	3 minute steaming	20	
	10 minute steaming	10	
L-lysine added to parboiled rice	Cooking without draining the gruel	Negligible	Bains and Tara (1970)
DL-threonine added to wheat flour	Baking white bread	20-40	Ericson et al. (1961a)
L-threonine added to parboiled rice	Cooking without draining the gruel	Negligible	Bains and Tara (1970)
DL-threonine added to animal feeds	One year storage at 50°C	Negligible	Rohdenburg and Rosenburg (1956)

are to select the proper fortification process. The following checklist can serve as a guideline for the design and implementation of an appropriate technology.

For the Fortificant:

(1) Will the fortificant affect the organoleptic characteristics of the product? If so, how?

(2) How stable are the forms of the nutrients you propose to use?

(3) Will the proposed dosage of the fortificant have any harmful side effects?

(4) How well will the nutrients in the proposed mix be absorbed?

(5) Does absorption necessarily decline as taste acceptability rises?

(6) What are the price differentials among the various forms in which the nutrient could be supplied? Which form will be most cost-effective?

(7) Will the fortificant mix create a nutrient imbalance?

(8) Will large-scale fortification interventions create relative or absolute shortages of raw materials?

(9) How will fluctuations in nutrient availability and cost affect the program?

(10) Will chemical reactions in the fortificant mix alter nutrient digestion, absorption, or metabolism?

For the Fortification Technology:

(11) Can you include control system in the program?

(12) How stable is the mix?

(13) Can the vitamin-mineral-amino acid premix be centrally produced? If not, is the technology feasible?

(14) Can uniformity in the premix composition be attained?

(15) How easily can premix composition be tested in the field?

(16) Can the proposed fortificant mix be incorporated into a carrier that will reach the target groups?

(17) Is the necessary equipment easily available within the country?

(18) What is the cost of each processing method?

(19) What effect will local cooking practices have on the proposed fortificant mix?

(20) Will microbes contaminate the nutrient mix? How can this spoilage be controlled?

(21) What are the optimal processing and storage conditions for each of the nutrients you plan to use?

Notes:

Soy meal prices are from The Wall Street Journal at the beginning of January, July, and December of each year. Prices for soy flour, soy protein concentrate, and soy protein isolate are quoted by Cental Soya, Chicago, Ill., for truckload quantities FOB Chicago. L-lysine·HCl prices are estimated FOB Japan for quantities greater than a ton. (See Table 4.8.) Prices for fish protein concentrate are estimated FOB Sweden, as quoted by Astra Nutrition U.S.A., Worcester, Mass., for bulk quantities at $0.235 = 1 Swedish Krona.

Except for soy meal, which is used for animal feed, all the other products are food-grade.

Because only the average yearly prices were available for soy flour and L-lysine·HCl between 1972 and 1976, these prices are plotted for June of each year.

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CHAPTER 5

CONSUMER ACCEPTABILITY

Gail Harrison

Introduction

In the previous chapters we discussed how successful fortification interventions address a real nutrient gap, are tailored to the commodity system's structure, and use the appropriate technology. But even after passing these nutritional, structural, and technological hurdles, the planner confronts another basic barrier: the food's color, flavor, texture, cost, meaning or value must not change in such a way as to make it unacceptable to consumers. Consumer acceptability is extremely important when the fortified food is a staple cereal because these foods play a central role in cultural systems. This chapter addresses the crucial barrier of acceptance by consumers.

We will draw on data on the introduction and acceptance of innovations in cross-cultural situations, including this project's case studies in Tunisia, Guatemala, and Thailand. The Guatemalan study produced the most information on these subjects, so it will be emphasized. But despite this emphasis, this chapter's analysis is general enough to allow planners to use if for other situations and other countries. We hope to provide a perspective and guidelines for the collection and analysis of information on consumer reaction to fortified cereal grains.

Some Myths About Cultural Change

To assess the potential for the acceptance of any innovation, a planner must acknowledge and challenge two widespread and probably erroneous ideas. Both seem to trace their origins back to anthropologists and others acutely conscious of cultural differences, but both have given rise to generalizations that prevent effective planning.

The first myth: "People usually - or even always-resist change." True, people reject many innovations, whether they arise within their culture or come from outside it; but it is equally true that they accept many others. Cultures do change. Rates of change vary from one population to another and within a culture from time to time, and in general rates of change have accelerated in recent decades. But cultural change is a constant. Cultures reject innovations for specific and discernible reasons, not because of a human tendency to resist change in general.

It is possible to identify, on the basis of past experience, what factors are most likely to result in rejection of a proposed change. Spicer (1952:18) generalizes that people resist changes that appear to threaten basic securities; they resist changes they do not understand; and they resist forced change. Niehoff and Anderson (1966), writing about socioeconomic innovation in peasant societies, attack the common practice of blaming "fatalism" for the failure of innovative programs. They acknowledge fatalism in peasant societies, and they identify three types: supernatural fatalism involving theology and magic), situational fatalism (provoked by the situation or the innovation, rendering it inaccessible or impractical), and project fatalism (based on previous negative experiences with the agent of change or with similar innovations). Nevertheless, Niehoff and Anderson think fatalism is not usually as critical in predicting change as leadership, social structure, economics, and the behavior of the agent of change. Coercion, bad communication, the failure to get recipients actively involved, the disregard of local culture and motivations, and the lack of any perceived need all reinforce fatalism.

The second myth: "There are social classes and even particular cultures which are more innovative, or accepting of change, than others." Every innovation is unique. Every innovation requires unique changes in ideas and behavior that the culture will interpret as acceptable or unacceptable. Within a cultural group, one class or another may accept some innovations more readily than others, and other innovations may be equally popular with all groups (Graham, 1956). A culture or subculture cannot be identified as uniformly conservative or liberal, nor will any innovation (such as the fortification of staple cereals) meet with equal acceptance in all cultures. Thus, success or failure in each instance

depends on the change proposed; the degree to which it is compatible with cultural norms, values, and expectations; and the details of the situation. The astute planner will adjust the process of change to maximize the chances of success.

When a proposed change offers definite but uncertain benefits and requires a significant but risky investment, early acceptance is likely to be greatest among those with enough money or resources to risk. The rich may therefore exhibit a high degree of initial innovativeness, while the middle class is conservative. After the benefits are amply proven and the risk is lower, the middle class may support the change more strongly (Cancian, 1967). The introduction of a swamp-rice development scheme in Sierra Leone in 1965 provides a dramatic demonstration of this generalization (Isaac, 1971). For the first two years the program met with very limited participation. Those who initially took part were the wealthier farmers who could mobilize both capital and labor. After they demonstrated the benefits of the program, middle-class farmers greatly increased their own participation. Many innovations may require months or years to reach this second stage of adoption. Their planners may be tempted to abandon a program with limited initial acceptance as a bad start unless they are aware of this general process.

A fortification program for cereal grains may or may not fit this model, depending on the specific situation. If fortification requires an economic investment, for example, by grain millers, it may be well to aim initial publicity at the wealthier millers. But if, on the consumer level, fortified grain costs no more than unfortified grain, then economic risk is not at issue and classes other than the wealthy may be more receptive to the program.

Data Requisites for Planning Change

About the Innovation

If the planner decides to attack macro or micromalnutrition by fortifying cereal grains, he has already decided, some fundamental characteristics of the innovation. Nevertheless, he has other choices to make, based on his estimate of the chances for success of one alternative over another.

Graham (1973) classifies innovations with seven characteristics that can potentially affect their acceptability:

(1) The form, meaning, and function of the innovation in relation to the cultural background of the recipients

(2) The incremental or decremental nature of the proposed change, i.e., does the innovation add to a culture or require that something be taken away?

(3) Communicability: how complex or simple is the proposed change, and how easy is it to demonstrate its results?

(4) The length of time it takes to demonstrate the results of the change

(5) The number of decisions to be made for the innovation's acceptance

(6) The possibility for an easy trial period

(7) Can the public go back on a decision to adopt the change?

Other things being equal, innovations stand a better chance of adoption if they are compatible with the culture, easily understood, have immediately evident consequences, require only one or a few decisions, are amenable to an inexpensive and easy trial period, and if the decision to adopt is easily reversible. The adoption of a simple, new technology like matches for lighting fires offers the advantages of being incremental, useful for an existing and recognized purpose, easy to demonstrate and use, immediately obvious in its benefits, cheap and easy to try, and reversible should the innovator decide to use other methods of firemaking. On the other hand, to stop smoking is a decremental change. It requires many repeated decisions, and the major beneficial consequences are far in the future and may be difficult to visualize or acknowledge.

Fortification of cereal grains with protein, vitamins, or minerals has the advantage of being a rather small incremental change. Further, technology can minimize the change required of the consumer by reducing possible changes in the color, flavor, texture, keeping, and cooking qualities of the grain. On the negative side, cereal fortification has two disadvantages common to most nutritional interventions: it involves communication of relatively abstract, complex

ideas, and its benefits take a long time to manifest themselves. Thus it becomes important that the planner find and take advantage of incentives other than long-range health benefits -- financial advantage, perhaps, or social approval.

The planner may manipulate other attributes of cereal fortification to his advantage. His ability to forecase the extent of a culture's resistance depends on his knowing a great deal about it, particularly those aspects related to the staple cereal. For example, all cultures treat illnesses by using or withholding particular foods, especially in the case of children. If the population sees the staple cereal as an essential "superfood," supplying all child's needs (Jelliffe and Jelliffe, 1968), then fortifying it to combat or prevent diseases to which children are susceptible may make intrinsic sense in that culture. The proposed change merely enhances or extends an already-recognized attribute of the foodstuff. If, on the other hand, the culture holds that the carrier is "strong," or difficult for children to digest, their access to the fortified food may be restricted when they are ill (which, in many less developed countries, may be much of the time). In such a case, cereal fortification is much less likely to succeed if its goal is the treatment or prevention of disease in children.

The number and reversibility of the decisions required for the adoption of cereal fortification depend to a great extent on who makes them. If millers decide to fortify all the grain they grind for a time, there are fewer decisions to make than if the consumer were free to select fortified or unfortified products everyday. In a society with centralized food production, fortification can be accomplished by policy decision or legislative act; only one decision maybe required. However, such a decision is much less reversible than one that results from decentralized decision making.

About the Sociocultural Context

Spicer (1952:281) has noted that programs of planned technological and social change have six basic categories of recurrent problems:

(1) Problems of cultural linkage. These are the products of failure to understand the interrelatedness of cultural beliefs, customs, and behavior. For example, Sharp (1952) reports in a classic paper the profound consequences for social interaction and division of labor when missionaries

introduced steel axes to replace the traditional stone axes of the Yir Yoront group of aboriginal Australians. Although the technological change was not a great one, the distribution of axes to the Yir Yoront men, women, and even children caused extensive disruptions in sex, age, and kinship roles and in traditional trading partnerships. Why? The stone for axheads had come from distant quarries through an established network of trading partners and could only be obtained by older adult men. Younger men and women frequently needed to use axes and had, each time, to borrow an ax from an adult male. When the ownership of axes became generalized, role expectations and behaviors which were intimately tied to the frequent necessity for borrowing axes broke down.

(2) Problems of social structure. Sometimes agents of change fail to work through existing social organizations or do not identify them properly. Ignored or antagonized social institutions may actually become the centers of organized resistance to change.

(3) Problems of the role of the innovator. Poor relations between the people of the different cultures may arise if the change agent is a member of an ethnic group not trusted by the recipients, or from misunderstanding or poor definition of the innovator's role.

(4) Problems of cultural bias. Innovators and recipients will interpret one culture's behavior in terms of their own culture. Practical methods for dealing with this problem in information gathering will be treated later in this paper.

(5) Problems of participation. Often planners and administrators are reluctant to allow local leaders to do things in their own way and to make mistakes. Participation problems arise from their failure to bring others into the planning and execution of their program.

(6) Problems of buffer organization. Organized resistance to change may develop from any of the above problems. Opposition is sometimes so strong that recognized needs the innovation might serve are obscured.

The prevention of these common, recurring problems in the introduction of cereal fortification requires careful, thorough researching of the target population's culture and society, a maximally compatible program design, and continuous follow-up and monitoring to identify and solve problems as soon as they arise. The data the planner should gather fall into four categories: the staple cereal's role in the culture; the characteristics of the decision makers he must reach; characteristics of the participants; and communication and program-design variables.

Role of the Staple Cereal in the Culture

Many societies regard their staple cereal as special, basic, essential, and even sacred. In a large part of the Far East, a meal is defined as a meal only if rice is eaten. Bread is considered sacred in parts of the Middle East, and crumbs spilled on the ground must not be trod upon. Corn has assumed a central place in American Indian religions in both North and Latin America. Often these regions' inhabitants follow standard procedures for growing, harvesting, grinding, cooking, and storing these grains. In fact, the procedures may be, to one degree or another, ritualized. So changes in the staple cereal, although they may benefit many people because of universal consumption, are potentially more culturally objectionable than changes in another, less important foodstuff.

In general, fortification planners should attempt to minimize any change in the flavor, color, texture, or physical properties of the cereal. Some differences may be unavoidable, and it is important to know the possible consequences of the differences when this is the case. If technologists can enhance a property which is generally regarded as desirable, so much the better. But often cultural subgroups will put different values on certain properties. For example, preliminary testing of soy-fortified tortillas in Guatemala indicates that the Indian community finds their darker color an improvement, but Ladino communities value the whiteness of the original tortilla. Careful taste-testing for consumer preference between fortified and nonfortified products -- and a survey of the respondents' reasons for their preference -- will tell more than if the fortified product is acceptable. Survey answers should teach planners which characteristics are the most important to the target groups.

Changes in the storage and cooking qualities of the grain may be at least as important in influencing acceptability as color or flavor. Data on these characteristics is more difficult to obtain, however, because researchers must wait until the recipients actually use the new grain for a time and report their reactions. In the Guatemalan studies, the reduced storage life of fortified-flour tortillas and the effect of altered hydration properties on the texture of tamalitos were among the most important barriers to acceptability.

Before planners consider a large-scale fortification program, they should obviously gather information on the target audience's perceptions of the flavor, texture, color, storage, and cooking qualities of the fortified grain. Perhaps less obvious is the need for information on the staple cereal's role in the culture. Investigators should become thoroughly familiar with the folk-medical domain and the allocation of labor and responsibility for food procurement and preparation.

Every culture has ways of identifying, explaining, and treating illness and maintaining health by individual and group behavior. And in every culture, foods play an important role in folk medicine. Tradition names certain foods as good or bad for such people as babies, pregnant women, children with diarrhea or fever, and sick adults. Because of the special place of staple cereals in many societies, these grains and products made from them may be intimately bound up in the folk-medical system. For example, the mother of a child with diarrhea or measles may deny it all foods except the staple cereal; in another culture, she may feed the child a greatly diluted gruel instead of its usual ration of grain, or she may entirely replace the grain with herb teas. Such customs not only affect the consumption of cereal grains by vulnerable groups, they may cause recipients of fortified cereals to believe that the beneficial or dangerous aspects of the foodstuff have been enhanced or counteracted by the fortificant. Thus it is important to ascertain how the cereal grain fits into folk-medical beliefs and practice. "What should you feed a sick person? A child sick with fever? With diarrhea? What should these people avoid eating? Is maiz (or rice, or couscous) good for your health? Why? Do you prepare maiz differently for a sick person? How? Why?" With such questions the planner can discover potential barriers or even helpful aspects of the local folk-medical system.

The planner must also find out who procures, handles, and cooks the product to be fortified, because the fortification system may otherwise disrupt established patterns. To take a hypothetical example: women are responsible for taking the day's grain to a mill, but only men are empowered to make decisions about family expenses. The new fortificant will raise the milling cost to the consumer. If the financial decision makers are not first brought into the program, it will probably encounter problems.

Characteristics of the Decision Makers

Householders adopt fortified cereal grain after making decisions regarding food patterns, health (if the reason for fortification is promotion of health), and finances (if the fortification raises the consumer-level cost of grain). So it is important to ascertain where, in any culture or subculture, the decision-making power in these areas resides. If grandmothers act as the final authorities on health, for example, it may be crucial to involve them in any educational programs undertaken. To gather information that leads to a clear picture of decision making power requires interviewing more than one adult per household. García reports an example of this methodology in his Guatemalan fortification feasibility study (García, n.d.). A male and a female interviewer visited each home in the sample, spoke separately with the husband and wife, and talked to them together only when the couple suggested doing so.

Once the crucial decision makers are identified, planners should attempt to find characteristics of those individuals or their households that make them likely to accept the program. A man's concern for his family's health would logically seem to predispose him toward acceptance. Based on the Guatemalan data on the acceptability of slightly darker tortillas, we might hypothesize that Indian households would be more quick to accept fortification than Ladino households. Flexibility and experimentation in food patterns and cooking, the amount of social contact, and the variety or complexity of a family's information sources are variables planners might consider along with more obvious demographic variables: age, occupation of the head of the household, educational level, etc. In any case, it is well to carefully follow the pilot efforts to introduce fortified cereals

to confirm or disprove one's hypotheses about acceptors and rejectors. Continued open-ended interviews will help define acceptors and rejectors and elucidate their reasons for participating in or resisting the program.

Characteristics of the Participants

At the household level in health interventions, very often the nature and extent of the need for the program are determined by someone outside the target group. Any program of planned change, to be effective, must meet the needs recipients believe they have. Finding out these needs is the planner's responsibility when designing a program of cereal fortification. The reduction of illness in infants and children by providing them more nutritious foods is likely to be a credible goal only if the target population thinks the amount of illness among its children is a problem, if it recognizes that the food one eats affects one's health, and if it is not concerned about other, presumably more immediate needs.

Often a program can be designed to address problems the recipients believe are more pressing while it accomplishes the program goal. The possibility of such a strategy is clear in the reasons villagers in Santa María Caqué expressed for using soy-fortified grain in the INCAP feasibility study (García n.d.). Four of thirty-nine persons who gave specific reasons for using fortified corn said that their principal reason was that they were poor and the fortification provided, at the same price, a greater volume of masa and thus more tortillas. Certainly if a family does not routinely have enough food, the need for more will take precedence over other needs. In such a case, therefore, it would be worthwhile to make sure the fortified grain costs the consumer no more and that the fortification method does indeed add volume to the product.

In developing a sense of felt need among participants, planners must take the time to involve the local community in all phases of planning and implementing the program. This stage in the process is likely to be slow, but circumventing it may prove disastrous. Spicer (1952) states the case for cooperation:

> People do not vary their customary behavior unless they feel some need which existing ways do not satisfy. The response to feeling such a need is to invent or to borrow from some other people a

> technique or form of organization or belief which is felt to satisfy that need. This in essence is the basic process of cultural change.
>
> Needs cannot be established by fiat. Ordering people to adopt a new custom may focus them on resisting the command rather than on the advantages of the required change. Since people often behave in this way in response to commands, it is clear that resistance may be forestalled by finding ways to establish a sense of need before proceeding with the change. One technique... is securing participation by the people in all phases of the innovation process. Real participation involves taking part in the planning and discussion of advantages to be gained, in the devising of methods for introduction, and in the execution of the innovation. Participation through their own social organization not only gives people a chance to develop a feeling of need for the change, but also enables them to work out in their own way adjustments of the new to the pattern of existing customs. (Spicer 1952:292-3)

Lewin has shown (Lewin, 1958) that group discussion and decision making, can have a greater effect on behavior than information giving followed by individual decision making. It may be that the concensus and its joint articulation of the felt need for change is a major reason for the success of group discussion and decision making.

Process and Communication Variables

Communications are vital when the program works through a decentralized system and therefore requires many decisions by many individuals. Planners must answer many questions, among them: Who should participate in planning for the change? Who must make the ultimate decisions? What are their sources of information? What communication channels should be used?

Graham (1973:331) has pointed out four possible sources of contact for cultural innovations: (1) the mass media; (2) commercial change agents, such local retail dealers or millers; (3) professional change agents, such as public health nurses and extension workers; and (4) personal contact with a community opinion leader who has already accepted or rejected the innovation.

Research in the U.S. suggests that mass media are most effective in publicizing innovations whose characteristics are easily explained or demonstrated. Personal contact may be much more important in conveying information about relatively complex innovations (Graham, 1956). Other research suggests that mass media work well with those inclined to be initial acceptors, but less well with people who accept somewhat later. The latter group is more subject to personal contact with influential individuals who have already accepted (Beal and Rogers, 1960; Katz and Lazarsfeld, 1955).

Spector et al. (1971) tested the effectiveness of radio messages, small-group audiovisual presentations, and both methods combined on the adoption of four innovations in several villages in rural Ecuador. They measured success by participation in the desired behavior at the end of the campaign and three months and nine months after it. The most successful medium depended to some extent on the behavior the researchers proposed, and the nature of the behavior had more effect on participation than did the medium through which they advocated it. With all four behaviors (building latrines, constructing smokeless stoves, making marmalade, and obtaining vaccinations against smallpox), the most important determinant of participation was the cost/benefit ratio. Vaccination was the only free activity. It was the most popular of all.

Cereal-grain fortification's characteristics are relatively covert: administrators may have to develop a felt need for it, and its advantages may take a long time to demonstrate. Therefore, personal contact with professional and commercial change agents and influential members of the community is probably extremely important, especially when fortification renders a product all agree is desirable, but which is somewhat different than the original. This is certainly the case with the fortified tortillas tested in Guatemala, and it may be true for any fortification program that alters the carrier even slightly.

The crucial questions then become: Who are the community leaders? What type of change agent will be most effective? Bock (1965) has written a field guide for assessing and identifying community leadership. His analysis is based on U.S. towns, but the framework is broadly useful and helps find the influential, not the merely visible. As he points out, the individual others identify as the most frequently contacted person may be merely a communication channel rather than an important decision maker. Bock advocates a method which combines the

sociologist's reputational method, in which a panel of individuals are asked to identify the community leaders, and the political scientist's "pluralistic method," in which community events are analyzed for leadership. Most communities have leadership structures which vary with the subject at hand. The influential individuals with regard to a change in the food supply may, therefore, be different from the ones who would decide other matters.

The results of the field trial in Santa María Caqué, Guatemala, demonstrate the importance of personal contacts in cereal fortification acceptance. Of thirty-nine persons asked to give their reasons for accepting and using fortified grain, twenty-three cited the recommendations of clinic personnel and four others mentioned other people who had tried the product and recommended it. That the acceptors were providing still further influence is shown by the fact that twenty-one of the thirty-nine stated that they had spoken with friends or relatives about the benefits of the fortified grain. Of forty-six nonacceptors asked to give their reasons for not using fortified grain, ten responded that relatives or friends had told them of the poor keeping quality of tortillas made from the fortified flour, of flavor changes, or of their belief that it produced indigestion and diarrhea (García, n.d.).

Given the importance of personal contacts in implementing a program of cereal fortification and the necessity for repeated decisions by consumers over time, administrators should choose change agents for their continuing association with the community as well as for their credibility and rapport.

Consumer Acceptability Research Strategy

All we have had to say so far suggests that consumer-acceptability research is localized and that one's approach will depend a great deal on the situation. Nevertheless, there are some general methodological strategies planners should bear in mind. They are to collect data relevant to the local culture rather than to the scientist's cultural frame of reference; strive for a holistic approach to the process in any given locale; and spend enough time in research to allow ongoing evaluation as a logical outgrowth of the initial data collection.

Culturally Relevant Data: Etics and Emics

A critical problem in cross-cultural behavior research is that of collecting and interpreting data so that conclusions are relevant to the cognitive decision making framework of the target population. Cultural bias interpreting behavior from one culture in terms of another faces those who contemplate any planned change. The problem is obviously smaller when agencies and professional personnel native to the country help plan and direct the program. But the involvement of native scientists and professionals should not lead us to assume that the problem is solved. An equivalent word in English and Spanish and Thai is not really a literal equivalent. And remember that there is often a cultural gap between scientists in developing countries and the village people who are usually the targets nutritional intervention programs.

The methodology for ensuring that one's questions are culturally relevant is based on the concept of the emic/etic distinction, originally delineated by Pike (1954) and based on the structure of language. Other researchers have further developed the concept, and in its expanded version it refers to systems of cognitive categories and their behavioral concomitants (see, for example, Tyler, 1969; Pelto, 1970). In this context, "emic" refers to categories used by the people of a given culture (the "inside" view), and "etic" refers to a system of categorization and interpretation which is ostensibly objective and absolute (the "outside" view of the scientific observer). A shared etic framework allows scientists from diverse cultures to communicate with one another, but consumers make their decisions within the emic framework. To influence decision making behavior, a planner must understand and use the emic context. Too often, scientists interpret consumer behavior in etic terms or -- where the decision making behavior is in a domain beyond their knowledge -- in their own emic system.

Obtaining data on emic classifications requires intensive interviewing with a few informants who are willing to teach the investigator very basic facts about how they classify objects and concepts.

Acheson's (1972) study of accounting concepts and economic opportunities in Cuanajo, a Tarascan Village in Michoacán, Mexico, is an excellent example of a study of emic views relevant to grain fortification programs. Acheson compares the chances of business opportunities in an economist's (etic) terms and in local

(emic) terms for the nine major occupations in the village: large agriculture, large store, molinos (mills), moneylending, grain selling, commerciantes (marketers of locally made furniture), mechanized carpentry, unmechanized carpentry, and day labor. He found local businessmen ranked these businesses in a hierarchy directly related to the accounting system they used. An economist would look at net revenue and at returns to capital as indices of economic opportunity in each business, but the local businessmen measured economic gain exclusively in terms of ganancia, a term usually translated as "profit" but which they calculated quite differently from the way a North American (or urban Mexican) businessman would calculate profit. Different economic rankings of business opportunities resulted. Ganancia in Cuanajo is a measure of net cash income in the short run (daily or weekly in most cases, monthly on occasion). Acheson (1972:86) discusses the nature and consequences of ganancia as an index of business opportunity:

> The concept of ganancia is similar to the accountant's cash flow concept. For periodic planning and evaluation purposes, an accountant generally computes cash flow by taking into account the firm's cash receipts and cash disbursements over a period of one year or less. In calculating ganancia, the businessman of Cuanajo does very much the same thing. However, it should be clearly understood that while ganancia might be considered a truncated cash flow concept, it does not have the same value for business investment decision making. The basic difference is that the accountant's cash flow concept has a sufficiently lengthy time horizon to take into consideration reinvestment problems. On the whole, cash flow figures provide one of the best indicators of business profitability and long-run business opportunities .... this is not true of figures on ganancia.

In figuring ganancia a carpenter, for example, will add up his cash expenses, which he calls his gastos (wood costs, labor labor costs, glue, etc.) and then subtract the total of these short-term cash expenses from gross sales (ingreso), calling the difference his ganancia (profit). He does not include the costs of any resources for which he did not pay cash, such as family labor or wood he cut on his own land. Nor does he include any long term expenses, like taxes or depreciation. Taxes and other expenses paid at intervals are paid out of savings (ahorros). Thus, savings include what an accountant would call savings plus money which must be paid out for long term expenses.

Since the businessmen of Cuanajo judge income earning opportunities in terms of ganancia, they see storekeeping, large-scale agriculture, and molinos as the best businesses in the pueblo, followed by moneylending and the grain business. Mechanized carpentry and commercio are judged to be only fair, while unmechanized carpentry, small-scale farming and day labor are thought to be very poor.

On an etic (accountant's) basis -- figuring return to capital per year or net revenue per year -- commercio and mechanized carpentry are by far the best business opportunities; molinos and storekeeping are only fair. The pueblo's history of business failures suggests that many individuals invest in businesses with high ganancias and experience failures, leaving potentially more lucrative business underinvested.

Although Cuanajo is a Tarascan village, Acheson thinks the accounting concepts are Spanish in origin, so his findings may be applicable to other small Latin America communities. His study illustrates several relevant cautions. First, there may be danger in assuming that translated words ("profit" for ganancia) carry the same connotations for decision making. And second, what may seem irrational decision making may be quite rational given the local system of classification and definition. Simpson (1970) puts it concisely: "Rational behavior must be considered within a cultural framework."

If the concept of ganancia is shared in similar villages in Latin America, it may require planning incentives to millers. Take care that daily net income does not decline. If fortification costs millers money, make them an infrequent expense.

More generally, Acheson's study illustrates the necessity of obtaining culturally relevant data where decision making is crucial. "How many kinds of _____ are there? How do you figure out _____? What does _____ consist of? How is it different from _____? How do you decide _____? Is _____ a type of _____?" Pelto (1970) gives more suggestions for eliciting information. In general, careful interviewing by a trained person will pay dividends.

The Need for a Holistic Approach

Assessment of the public response to a program involves careful study of a living, dynamic community of many interrelated parts. Thus it is important to undertake a complete acceptability study in one place at one time. If taste-testing, cooking, and storage tests, ethnographic data, and other relevant data are collected at different times or in separate places, predictions about consumer acceptability will be difficult and uncertain. Better to understand the community as a whole. Trail runs, or pilot tests, of a program could follow soon after the gathering of initial feasibility data.

The Need for Ongoing Evaluation

That nutritional intervention programs require ongoing evaluation to adjust to situations and to demonstrate success or failure is basic and obvious. However, initial feasibility studies have seldom been designed with long-range evaluative needs in mind. Because data collection for analysis of feasibility is in itself an intervention, the most useful data collected will be directly comparable (although not necessarily limited) to those collected later, as the program is evaluated. The evaluation methodology will have to be well thought out far in advance of the program's beginning. This is another often-mentioned but seldom-put-into-practice goals (Wray, 1970).

Feasibility Questions

The nutritional effect of any fortification intervention is ultimately determined by what people chose to eat; consumer acceptability is critical in determining the overall feasibility of a fortification project.

The following list of questions will help decision makers elicit the data they need to design a fortification program appropriate to the socio-cultural context.

(1) What is the role of the staple cereal in the folk-medical system?

(2) Is the proposed fortification program compatible with existing beliefs and grain uses? If not, can the project be altered to become acceptable?

(3) How are labor and decision making allocated in the procurement, processing, and preparation of the staple cereal? Is the fortification program reinforcing or antagonistic to existing arrangements?

(4) Are the color, flavor, texture, storage, or cooking characteristics changed by the fortificant? Are these changes desirable or undesirable? How can the adverse effects be minimized?

(5) Who must decide to adopt the fortified product?

(6) Who influences the decision makers?

(7) How are the decision makers disposed to the program?

(8) Who are likely to be the initial acceptors?

(9) What are the primary concerns of the target population with regard to food and health? Do these perceived needs allow or prevent the fortificant's introduction?

(10) Are there other needs to be addressed before fortification intervention?

(11) Who stands to benefit from the project, and how can this be communicated?

(12) Who stands to lose from the program? How?

(13) What are the risks of participation? How can they be minimized?

(14) What formal or informal communications networks can reach decision makers?

(15) What local leaders are influential in matters pertaining to food and health and how can their help be enlisted?

(16) Has the community experienced similar programs? What were the results, and how do they influence your endeavor?

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CHAPTER 6

ECONOMIC ASPECTS

Donald R. Snodgrass

Introduction

This chapter deals with the "economic barrier" to the implementation of cereal-fortification programs: how planners may analyze and possibly overcome it with good program planning and evaluation. First we will discuss the nature of the economic barrier and then lay out the organization of the remainder of the chapter.

Nature of the Economic Barrier

The economic barrier exists because fortification programs require that some societal group pay for them with resources that might otherwise buy other goods and services. In itself this characteristic is hardly unique to cereal-fortification programs; all outputs of the public and private sectors (except a few "free goods") impose such costs. More important is the size of the costs involved. Microfortification programs generally cost little, but protein fortification programs often demand significantly more. Compared to earlier vitamin and mineral fortification programs, they entail higher fortificant costs and serve a smaller and harder-to-reach target population. Often, then, protein fortification's cost is relatively high compared to the cost of the carrier. Finally, a national fortification program, particularly one based on protein fortification, may claim a significant portion of a low-income nation's total resources.

Before a government decides to begin a cereal fortification program, it should have assured itself that the program's benefits fully repay its costs. To survive the competition for scarce funds, the fortification program should demonstrate that its net benefits (the excess of benefits over costs) compare favorably with those offered by competing programs.

And if the government decides the program is worth undertaking, its planners must face another aspect of the economic barrier: Who pays? Someone must sacrifice to finance the program. There are three basic possibilities: the consumers; the processors (millers and, in the case of baked goods, bakers); or the entire society, through its fiscal system. The decision on sharing the cost burden is not to be taken lightly. It has important implications for economic efficiency and social equity.

Purposes and Organization of the Chapter

This chapter will present a costing methodology for cereal fortification programs, estimate actual fortificant and fortifying costs, illustrate the methodology with field data, discuss methods of defining and measuring program effects, and examine financing considerations.

In Section II we will identify and analyze the principal components of program cost. In the case of protein fortification programs, fortificant cost will likely dominate regardless of program design. We will discuss the varieties of fortificants, their current costs and how they are determined, and their possible future prices. Then we will consider fortification and distribution and their costs. Finally comes our explanation and illustration of the costing methodology, which includes the conversion of nominal costs to social costs.

Section III concerns itself with program effect, discussing two basic methods of evaluating success. The first is cost-effectiveness analysis, with which analysts can compare alternative programs' coverage of the target population, the amounts of nutrients delivered, or the program's biological effects on recipients. The second method, more ambitious and difficult to put into practice, is cost-benefit analysis. It differs from cost-effectiveness analysis because it attempts to define and measure benefits in money terms and produces a measure comparable to the measures calculated for other types of programs.

In Section IV we analyze the financing problem. The three major options -- imposing the costs on consumers, on millers, or on the whole society -- are examined for their effects on overall economic efficiency, social equity, and incentives to program participation.

In the final section we present our conclusions.

Intervention Costs

Introduction

What resources does a fortification program use and what will it cost? We do not yet have fully satisfactory answers to these questions. This section discusses the methodological problems of estimating costs and summarizes the information available on probable costs and the factors which influence them. We begin by outlining costing methodology.

The Methodology of Costing

Program costing involves two necessary steps and a third optional one. In the first step, the planner lists the requirements of the program design. The second involves pricing these requirements in a common currency (either the local one or an international currency like U.S. dollars). The program's nominal cost results. In the optional step, the planner converts appropriate nominal cost items into adjusted social costs. The social cost principle assumes that the inputs with alternative uses should be included in the costing at their highest alternative values. Planners frequently accept nominal prices as approximations of social cost. However, significant price distortions involving an important share of program costs require price adjustment or shadow pricing. Estimates commonly shadow price unskilled labor and internationally tradeable commodities, both of which are sometimes undervalued by nominal prices.

We shall discuss the first two steps in the costing methodology here and return to the optional third step after discussing nominal cost components.

First, list as fully and accurately as possible the quantities of required inputs. Fullness and accuracy follow only from careful program design. Experience with comparable programs or pilot projects can be a valuable aid in predicting the input requirements of an untried program. But keep in mind, though, that input requirements vary substantially from setting to setting or from a pilot project to full-scale field application. The analyst must foresee these variations.

Include all program inputs in the list, regardless of who supplies or finances them. If the agency principally responsible for nutritional programs prepares the estimates, remember that other agencies (e.g., educational authorities in the

case of a school feeding program) and program participants may also incur costs. Although every agency will want to know the burden on its own budget, base program evaluation on the total cost to society.

To determine the inputs to a particular program, apply the marginal principle. That is, include only those costs which would not have been incurred in the program's absence. Allocate "overheads" only if they meet this test. For example, do not include any part of the central administrative costs of a concerned ministry or department unless its budget must be increased to undertake the program. If this is not the case, the extra services required by the program can be met by drawing on previously idle capacity -- without additional cost to society.

The list of program inputs should describe each item unambiguously. State quantities in physical rather than monetary terms when possible.

The second step in costing is the valuation of each input in market prices. Price data can be obtained from program or pilot project records, from private sources, or from general collections of price statistics. The figures used should apply to the needed quality of the input and include delivery to where they will be used. Estimating prices for some inputs, such as the time and effort required from program participants, requires ingenuity.

Anticipating price changes likely to occur within the planning period is a major estimating problem. Thinking of price changes as either general inflation or as increases beyond it may help. Most prices, in most countries, rise over time. Therefore, it is generally prudent to apply an assumed rate of inflation to the cost of all inputs to be purchased in future years. In some cases, distinguishing between the inflation for imported and domestic items or between goods and labor may be realistic.

Tables 6.1 and 6.2, which summarize more detailed tables presented in chapter 8, illustrate the first two steps of the costing methodology for two hypothetical protein fortification programs in Tunisia. The country's market for wheat, the fortificant carrier, is a dual one. The first hypothetical program (Table 6.1) is based on the conventional wisdom that an effective program requires central processing. Some 40 to 50 percent of Tunisia's wheat supply passes through eighteen large urban mills; the annual operating cost is U.S. $6.8 million to fortify this part of the wheat supply with lysine and vitamins. Table 6.2 assigns

Table 6.1

Nominal Cost of Protein Fortification through Eighteen Large Mills (in U.S. $)

Capital Cost	
Fortificant blender	$46,600
Feeders and spare parts	58,400
Training	2,500
Laboratory equipment	30,000
Warehousing	84,488
Warehouse equipment	5,000
Office equipment	2,000
Publicity	30,000
Program start-up costs	24,200
Total Capital Cost	$283,188
Annual Operating Cost	
Fortificants	$6,576,130
Shipping of fortificants	60,929
Liners	17,575
Shipping of liners	116
Additional drums	17,500
Cargo landing fee	5,254
Transportation of fortificants and liners from dock to central mill	4,565
Transportation of blended fortificant to eighteen mills	7,639
Labor	80,700
Electricity	9,795
Warehouse operation	9,340
Administration and quality control	24,000
Office supplies	1,000
Total Annual Operating Cost	$6,814,543
Total Annual Cost (assumes five-year depreciation on all capital items)	$6,871,181

Source: Chapter 8

Table 6.2

Nominal Cost of Protein Fortification through Village Mills (in U.S. $)

Capital Cost	
Feeders for fortificant tablets	$320,000
Warehouses	162,398
Warehouse equipment	15,000
Office equipment	8,000
Trucks	536,000
Training costs	310,970
Start-up costs	190,000
Quality control equipment	13,000
Publicity	305,600
Total Capital Cost	$1,860,968
Annual Operating Cost	
Fortification tablets	$9,311,165
Shipping of tablets from France to Tunis	81,577
Cargo landing fee in Tunis	7,033
Transfer of tablets from dock to central Tunis warehouse	5,489
Transfer of tablets from Tunis warehouse to twelve regional warehouses	28,814
Vehicle operation	64,719
Payments to millers	1,356,595
Warehouse operation	23,160
Feeder operation	80,160
Central administration	27,600
Labor for program administration, fortificant distribution, and quality control	497,100
On-call quality control personnel	100,800
Publicity	14,600
Total Annual Operating Cost	$11,598,652
Total Annual Cost (assumes five-year depreciation on all capital items)	$11,970,846

Source: Chapter 8

costs to an alternative or supplementary program that would fortify the remaining 50 to 60 percent of the wheat supply, which passes through some 3200 village mills. This program uses a tablet-form fortificant and requires greater outlays for training, supervision, and persuasion. It costs about U.S. $1.9 million in capital costs and U.S. $11.6 million in annual operating costs. Both tables state cost in nominal terms.

Anyone with programming experience will understand that the precision of Tables 6.1 and 6.2 is unrealistic. Nearly all of the figures cited, both quantities and prices, really represent ranges. To avoid unmanageable estimates, planners usually cite only the best estimate for each item. If the programmer does this, however, he should also conduct sensitivity analyses to get some idea of the effect of reasonable price changes on the program budget.

We can illustrate sensitivity analysis with Table 6.1, where the capital cost is shown as $283,188 and the annual operating cost as $6,814,543. Many cost increases can be possible. For example, if the program began one year late for some reason, capital costs might rise 10 percent, to roughly $311,500. On the other hand, a 10 percent rise solely in the imported components of capital cost would only raise total capital costs by 5.5 percent because imports account for 55 percent of them (assuming that all equipment is imported and that imported materials make up half the cost of construction; these estimates are based on detailed costing in Chapter 8).

Note that fortificant cost is a major influence on total operating cost in both examples. In Table 6.1, centralized system, fortificant costs account for 96.5 percent of the total. In the decentralized system of Table 6.2, the figure (including fortificant tableting) is 80.3 percent -- lower, but still by far the largest component of total cost. If fortificant cost doubles, as the price of synthetic lysine did between 1972 and 1974, the cost of the centralized system could rise by 96.5 percent while the decentralized system rises 80.3 percent -- if lower-cost fortificants could not be substituted. But if an alternative fortificant package, available at 50 percent higher cost than that programmed in Tables 6.1 and 6.2, held its price (an unrealistic assumption, since prices of competing products generally move in the same direction, although not necessarily at the same rates), fortificant cost could rise by no more than 50 percent and total operating cost by 48

percent in the centralized and 40 percent in the decentralized system. This example illustrates the calculations that afford some appreciation of the potential effect of fortificant price fluctuations on program costs.

Nature and Magnitude of Component Costs

Besides illustrating the first two steps of the costing methodology, Tables 6.1 and 6.2 identify the major cost components of a protein fortification program and establish their relative magnitudes. For convenience, we will group program cost components into four categories: (1) fortificant costs, (2) costs associated with the fortifying process, (3) logistical costs, and (4) control costs. As we have noted above, the Tunisian experience suggests that fortificant costs may be the dominant influence on total cost. In a microfortification program, as we shall see, fortificant costs are likely to be much smaller, absolutely and relatively.

Fortificant Costs: Protein fortification programs are intended to increase the amount of high-quality protein in the diet. They can do this by increasing the amount or quality of total protein, or by combining these two methods. In practice there are two major types of fortificant, which may be used singly or in combination: synthetic amino acids, which raise protein quality without affecting quantity, and natural protein sources, which increase both the quantity and the quality of diet protein. The most important amino acid is L-lysine, the first limiting amino acid in all cereals. Of secondary importance are L-tryptophan, the second limiting amino acid in corn, and L-threonine, the second limiting amino acid in rice, wheat, sorghum, and millet. Natural protein sources available for fortification programs include dried milk(whole or skim), soy flour (full= fat or defatted), fish protein concentrate, soy protein concentrate, and soy protein isolate. (See Chapter 4, above, for details.)

Synthetic amino acids are added to the carrier in minute quantities, much like vitamin and mineral supplements. Natural protein sources are added in larger quantities (e.g., 6 to 12 percent soy flour fortification in bread), displacing a significant amount of the carrier.

Because either fortificant can meet nutritional objectives -- as can any of the several natural protein sources -- fortificants actually compete with each other in price.

Micronutrient fortificants (Vitamin A, Vitamin D, iron, etc.) correct specific nutritional deficiencies. They can be added to a carrier singly, in combination with each other, or together with one or more protein fortificants.

Synthetic and natural fortificants differ greatly in actual cost and in the nature of their cost determinants. Chapter 4 discussed these matters in some detail. Only a few important general points need be reiterated here.

In discussing fortificant cost, we can distinguish between cost per fortificant unit and cost per unit of the fortified carrier. The latter is partly a function of the former, but it is also influenced by the amount of fortificant used per unit of the carrier and by the cost of the carrier it displaces. We will begin by discussing, in turn, the cost per unit for synthetic amino acids, natural protein sources, and microfortificants.

Synthetic lysine, the most important synthetic amino acid for human nutrition purposes, can be manufactured by either the enzymic (fermentation) or chemical synthesis process. At present, all commercial production uses the fermentation approach. Two Japanese companies currently supply more than 90 percent of world output (Ajinomoto Co., Inc., and Kyowa Hakko Kogyo Co., Ltd.). Chemical companies in the United States and Europe have produced or experimented with synthetic lysine in the past, and still others in France, the Netherlands, Japan, and Mexico are reported to be considering or planning entry into the industry. In general, however, the chemical industry's current outlook for marketing synthetic lysine ranges between dubious and pessimistic. With existing technology, synthetic lysine probably cannot compete with soy beans consistently enough to repay the sizable investment in fixed plant that is required. It is highly competitive when soy bean prices are high, as occasionally they were in 1972, 1973, and 1974, but such peaks are sporadic.

At present, the world uses synthetic lysine primarily for animal feed, largely for poultry and hogs. Demand for human consumption, once thought to be on the verge of a takeoff, has remained small in the absence of any demonstration of clear-cut nutritional benefits at reasonable cost or willingness to provide the necessary program financing.

This failure of synthetic lysine is partly a matter of high and rising prices. Chemical industry sources report that the unit value of imports into the U.S. rose from about $0.65 to $0.85/lb: in the late sixties and early seventies to $1.33 in 1974 and $1.30 in 1975. Prices reported by experimental fortification programs in various parts of the world ran at about $1.00/lb in the late sixties and then rose in the early 1970s. During a 1974 spurt caused by rising soybean prices and limited production of synthetic lysine, they reached $3.30/lb. In 1975 prices of L-lysine·HCl subsided to $2.50/lb, where they have since remained. Over the long run, the price of synthetic lysine is expected to remain at about this level in real terms; that is, it will rise approximately in step with world inflation. Another sharp increase in the relative price of petroleum is probably the only factor that could upset this trend and bring higher prices. The main possibility for a significant decline in real prices appears to lie with technology, which could discover a means for cheaper production. But there is no reason to think that such a breakthrough is imminent. If the demand for lysine rose significantly, lower prices might result in time because current producers might attain economies of scale and new producers might be encouraged to compete in the market. Further discussion of synthetic amino acid prices and their determinants appears in Chapter 4.

The most obvious difference between synthetic amino acids and natural protein sources is that the former are produced in factories and sold in oligopolistic markets but the latter are produced on farms or drawn from the sea and sold in competitive markets. The prices of soybeans, fish meal, and other such products therefore fluctuate widely from month to month and year to year as the markets work out the imbalances of supply and demand caused by the individual decisions of millions of producers and consumers. (For recent price fluctuations, see Figure 4.1.) As noted earlier, these products have suffered -- and will continue to suffer -- declines in their competitiveness with synthetic products. Over the long run, however, they will offer cheaper means of attaining most fortification specifications. According to a study by the U.S. Department of Agriculture (1974), no absolute resource constraints seriously inhibit the indefinite expansion of soybean production at roughly constant equilibrium real cost. Barring the possibility of a technological breakthrough, soybeans and other natural products seem capable of competing strongly with synthetic amino acids throughout the foreseeable future.

The previous paragraph referred to the world soybean market, which is dominated by the United States. The cost of soybeans in some developing countries is significantly above the present world price because of transport costs, import duties, and import quotas -- all of which raise the cost of imported beans. Yet production and marketing difficulties and the lack of a strong domestic market for soybeans as food or feed restricts the growth of local production. Still, soybeans can adapt to a wide range of growing conditions and the creation of greater domestic demand (perhaps by mandating a bread fortification program) may break the marketing barrier. Thus, as the cheapest natural protein source, the soybean seems at least potentially applicable to the nutritional needs of the developing countries and of the world.

Our discussion here focuses on soybeans and ignores other natural protein sources because experience has shown soybeans to be by far the cheapest natural source of protein and L-lysine. Table 4.9 proves this assertion. Other natural protein sources may, however, have more acceptable taste characteristics than soybeans. Soy is a normal part of the diet in only a few regions -- notably East Asia -- and soy fortification, in sufficient quantity, usually affects taste and organoleptic properties adversely. However, recent encouraging experiences with soy fortification of bakery products suggest that these problems may not be insuperable.

Although soybeans are a cheaper source of protein and lysine than other protein-rich foods, they are not cheaper source than synthetic lysine, as Tables 4.8 and 4.9 demonstrate. The current cost of one kg of lysine in the form of L-lysine·HCl is about $5.60, defatted soy flour runs $9.72, and spray-dried whole milk commands $82.17. Synthetic lysine adds nothing to the quantity of protein or to other nutritional values, so the choice between it and a natural fortificant depends largely on nutritional objectives. The displacement effect, to be discussed shortly, also influences the cost per unit of carrier and tips the balance in favor of natural fortificants.

Microfortificants vary widely in cost, as Tables 4.4, 4.6, and 4.7 show. All those in common use are standard products of manufacturers in industrialized countries. The production difficulties of synthetic amino acids are therefore not a factor for microfortificant users, who may assume a steady future supply at approximately present prices, allowing for general inflation.

Cost per Unit of Carrier: The cost per unit of carrier is a function of (1) the fortificant cost per unit, (2) nutritional objectives, (3) the planner's success in selecting the cheapest fortificant or combination of fortificants to achieve those objectives, and (4) the price of the carrier itself.

In practice, fortification programs usually use multiple fortificants, for the target population often suffers multiple deficiencies and adding several fortificants is nearly as cheap as adding one. The cost of the total fortificant package will obviously depend on the nature and number of nutritional objectives. Tables 4.3 and 4.5 show the makeup and the cost per carrier unit of the fortificant packages used in the Guatemala, Tunisia, and Thailand field trials. We see that fortificant cost, calculated with the formula on page 24, ranges from 5.4 to 22.9 percent of the price of the unfortified carrier. These cost differences are attributable to differences in the fortificant mix's price relative to the carrier price and to the amount of fortificant used. Of the three examples, Thai rice fortification costs most because the protein-quality objective requires adding expensive L-threonine as well as L-lysine. The mix for Tunisian wheat flour, which otherwise resembles it, costs only one-fourth as much. The corn fortification mix used in Guatemala is the only one of the three to use soy flour as well as lysine, and it falls between the others in price.

Microfortification programs, as is well known, are much cheaper than fortification programs with any form of protein supplement. Tables 6.3 to 6.5 verify this fact. There we see that the protein supplements make up 88, 92, and 99 percent of the cost of the fortificant per kg of grain, respectively, in Guatemala, Tunisia, and Thailand. Removing the protein supplements from the fortificant package reduces fortificant cost to only 2.2, 0.5, and 0.1 percent of the price of the carrier, respectively, in these three examples.

A program can sometimes attain its nutritional objectives with any of a range of substitutable fortificants. As the prices of the usable fortificants differ, the cost per unit of carrier will also vary with the choice of fortificants. Any given set of prices dictates one least-cost fortificant package; a change in one or more prices may change that package's makeup. Under these circumstances, what is the nutritional programmer to do? Although the least-cost package at today's prices is easy enough to determine, prices are sufficiently unpredictable to make identifying the cheapest package for a multiyear program much harder. The

Table 6.3

Fortificant Makeup and Cost: Corn Fortification in Guatemala

Nutrient	Content/kg Grain	Price ($)/kg Nutrient	Cost of Fortificant/kg Grain
Thiamine	21.4 mg	25	0.000535
Riboflavin	13.0 mg	42	0.000546
Niacin	154.4 mg	5	0.000772
Vitamin A (10^6IU/g)[a]	6,250 IU	30	0.00001875
Iron[b]	480 mg	5.70	0.002736
Soy flour	78 gms	0.35	0.0273
L-lysine · HCl	1.2 gms	5.60	0.00672
			0.0386277

Fortificant cost: $C = \frac{\alpha(P2 - P1)}{P1} = \frac{(0.08)(0.484 - 0.20)}{0.20} = 11.4$ percent

Note: Assumes flour at 20 cents/kg.

[a]Vitamin A as palmitate in oil.

[b]Iron as ferric orthophosphate.

Table 6.4

Fortificant Makeup and Cost: Wheat Fortification in Tunisia (Premix B)

Nutrient	Content/kg Grain	Price ($)/kg Nutrient	Cost of Fortificant/kg Grain
Thiamine	8.5 mg	25	0.00021
Riboflavin	5.4 mg	42	0.00023
Niacin	63.8 mg	5	0.00032
Vitamin A (10^6IU/g)	10,000 IU	30	0.00003
Vitamin D_2	2,000 IU	30[a]	0.000006
Iron	55.9 mg	2.05	0.00011
Tri-calcium phosphate	50.0 mg	2.04	0.0001
L-lysine · HCl	2 gms	5.60	0.0112
			0.012206

Fortificant cost: $C = \frac{\alpha(P2 - P1)}{P1} = \frac{(0.002)(5.59 - 0.20)}{0.20} = 5.4$ percent

Note: Assumes flour at 20 cents/kg. There is also a Premix A, which uses all listed nutrients except lysine.

[a]Cost data for Vitamin D_2 is unavailable. This price is for Vitamin A.

Table 6.5

Fortificant Makeup and Cost: Rice Fortification in Thailand

Nutrient	Content/kg Grain	Price ($)/kg Nutrient	Cost of Fortification/kg Grain
Thiamine	5 mg	25	0.000125
Riboflavin	4 mg	42	0.000168
Vitamin A (10^6IU/g)	23,700 IU	30	0.00007
Iron	80 mg	2.05	0.000164
L-lysine	2 gms	5.60	0.0112
L-threonine	1 gm	57.70	0.0577
			0.069427

Fortificant Cost: $C = \frac{\alpha(P2 - P1)}{P1} = \frac{(0.0031)(22.48 - 0.30)}{0.30} = 22.9$ percent

Note: Assumes rice at 30 cents/kg.

programmer might monitor the prices of alternative nutrient sources periodically and make any substitutions warranted by relative price changes. Manufacturers of commercial animal feeds do just that. If this flexibility is not possible, the program will have to go with the input mix that seems likely to be cheapest for its duration. This strategy entails the risk of commitment to an input mix that is not the cheapest, so programmers should avoid it if they can.

Finally, the price of the carrier itself influences the fortificant cost per carrier unit through "the displacement effect." The relation is inverse; that is, with other factors constant, the fortificant cost per carrier unit sinks as the carrier cost rises. The formal statement of the relation is:

$$\underline{C} = \frac{(P2 - P1)}{P1}$$

where

$\underline{C}$ = fortificant cost as a share of the cost of the fortified product,
P1 = price per weight unit of the carrier,
P2 = price per weight unit of the fortificant or fortificant package,
α = share of the fortificant per weight unit of the fortified product.

It is evident that $\underline{C}$ is positively related to P2 and to α, which might be termed the fortification ratio. But it is negatively related to P1, the price of the unfortified carrier. This relation reflects the cost saving that results from the fortificant's displacement of some of the carrier. Given a steady price for the fortificant, the higher the price of the carrier, the greater the saving.

The displacement effect may be insignificant in cases where α is very small -- when vitamins, minerals and synthetic amino acids make up the fortificant package. Conversely, it may become significant with the much bulkier natural protein sources. A recent discussion of bread fortification with toasted defatted soy flour in Ecuador dramatically illustrates this fact (Hoover 1976a, 1976b).

Compulsory fortification of bread and other bakery products may be attractive where most people consume these commodities, as is the case in most of Latin America, the Middle East, and urban areas practically everywhere. But it is only practical if consumers will accept the fortification and if its cost per unit of carrier is cheap enough to justify the overcoverage inevitable with universal distribution. Researchers at Kansas State University have developed a method of bread fortification using lightly toasted, defatted soy flour at a fortification rate of 6 or 12 percent. By adding sodium stearoyl-2-lactylate (SSL), they have minimized the changes in the bread's rising properties and color which soy flour would otherwise cause. At these high rates of fortification the relative prices of wheat flour and soy flour can largely determine program cost. In many circumstances, soy flour may be little or no more expensive than the wheat flour it displaces. Table 6.6 illustrates some possibilities from the Ecuadorian case. The estimates it summarizes (see Hoover 1976a) suggest the intriguing possibility of "free" bread fortification.

In this illustration, fortification is nearly rather than truly free because consumers must give up something of value: the displaced wheat flour and its calories (the fortified bread is lower in calories). Fortification could be free, however, in the sense that a loaf of fortified bread might retail for little or no more than a loaf of unfortified bread. Cost savings might provide bakers incentive to cooperate with the fortification requirement. These savings accrue not only because the soy flour may be cheaper than the wheat flour, but also because soy flour absorbs more water and so requires less mixing time (Hoover 1976b).

The important Ecuador case merits further investigation and replication elsewhere because it challenges the general conclusion that protein fortification must be significantly more expensive than vitamin or mineral fortification. With a little help from the displacement effect, a low-cost natural fortificant need not be more expensive.

Table 6.6

Price of Soy-fortified Flour Relative to Price of Wheat Flour under Various Assumptions in Ecuador

Soy-fortified Flour composed of:	Level of Fortification (Percent)				
	4	6	8	10	12
Subsidized wheat flour and soy flour (imported beans)	1.0373	1.0380	1.0388	1.0395	1.0403
Subsidized wheat flour and soy flour (Ecuadorian beans)	1.0508	1.0581	1.0656	1.0730	1.0804
Unsubsidized wheat flour and soy flour (imported beans)	1.0217	1.0185	1.0154	1.0122	1.0090
Unsubsidized wheat flour and soy flour (Ecuadorian beans)	1.0325	1.0347	1.0371	1.0393	1.0415

Source: Hoover (1976a): 44.

The Fortification Process

Chapter 4 discusses the technology of fortification in detail. As we point out there, the nature of the equipment required and the effort needed to operate it vary with the carrier, its milling process, the fortificant, and the scale of milling operations. Generally speaking, a foreign or domestic chemical plant prepares a premix of the fortificant blend and any other substances required for good appearance or binding. At the mill, a feeder adds measured amount of the premix to the grain during the milling. In a large automated mill, feeder may also be automated. However, simple hand-operated models have also been developed for use in small village mills.

The cost of fortification itself is likely to loom large in the initial setup costs, but it will take only a small share of the annual operating cost (and of the total program cost, if capital expenditure is amortized over several years). The program expenses for urban Tunisia in Table 6.1 include capital costs of $46,000 for equipment to blend the fortificant into the premix and $58,400 for the feeders in eighteen large mills. These expenditures represent 37 percent of total capital cost, but only 2.8 percent of total annual cost, assuming five-year amortization. Add the labor and electricity for blending the premix and adding it to the wheat -- another 1.2 percent of total cost -- and fortification amounts to only 4 percent of total program cost.

The program costed in Table 6.2 substitutes an imported tablet fortificant for the locally prepared premix used in the previous example. Here, blending costs are part of the fortificant cost rather than part of the fortification cost. But the decentralized program assumed in Table 6.2 also requires labor-intensive fortification on a much smaller scale at many sites. The capital component of fortifying cost falls, but its operating component increases. In the capital cost portion of Table 6.2, feeders cost only $320,000, or 17 percent of total capital cost. But payments, for feeder fuel and replacement parts, to the village millers who do the fortifying come to nearly $1.4 million, or 12 percent of annual operating cost. At about 12 percent of total program cost (assuming five-year amortization of capital costs, the fortification cost for the decentralized system is, proportionally, about three times as large as for the centralized system. It remains small, however, compared to the still-dominant fortification costs.

Tables 6.1 and 6.2 both illustrate programs relying primarily on synthetic fortificants. Fortification costs could be negligible, or even negative, in a soy flour bread fortification program like the Ecuador experiment. The substitution of soy flour for wheat flour demands little extra effort apart from the addition of SSL, and any additional expense might be more than offset by savings resulting from the improved mixing properties of the bread.

In programs using only microfortificants, fortification costs would probably approximate those for fortification with synthetic amino acids. But because of the much lower fortificant costs entailed, fortification would become a larger share of the much lower total program cost.

Logistics: If the fortification program involves adding a fortificant to grain which would be delivered to the mills anyway, then logistical costs will relate exclusively to the fortificant.* These costs will likely be very small in a centralized program but much larger in a decentralized program. In Table 6.1's centralized program, the combined cost of shipping from the dock to the premix blender, from the blender to the mills, and warehousing is $21,500 per annum,

*We will ignore the case in which the program delivers the fortified product to a narrow target population in a feeding program.

only 0.3 percent of annual operating cost. Table 6.2's decentralized program requires a much more elaborate logistical system. Its annual cost is estimated at about $360,000, or 3.1 percent of total operating cost.

We thus see that logistics costs, although small relative to total program cost, are sensitive to program structure. The quality of the nation's transportation network would also clearly affect theme.

Again, our examples have involved programs using low-bulk synthetic fortificants. High-bulk natural fortificants could raise logistics costs, especially if they were imported. However, the displacement effect might perform here as a cost-saving mechanism. If domestic soy beans fortify domestic flour, no added logistical costs need be incurred.

As for microfortification programs, the statements on fortifying costs in the preceding section apply here as well. Logistics costs should approximate those for synthetic amino acid fortification absolutely but will assume a larger share of the lower total program cost. The same is true of control costs, which we turn to next.

Control

The determinants of control costs are similar to the determinants of logistics costs, in that both are likely to be small in a centralized program and somewhat larger in a decentralized program. Again, we can illustrate by referring to Tables 6.1 and 6.2. In Table 6.1 (the centralized program) expenditures for administration, quality control and office supplies are estimated at $25,000 a year, or less than 0.4 percent of annual operating cost. In Table 6.2 (the decentralized program) annual expenditures for central administration, quality control and publicity are much larger: $378,200, or 3.3 percent of annual operating cost. In addition, under the decentralized program a sum of $819,570 is budgeted for one-time expenditures on training, planning and publicity. If capital costs are amortized over a five-year period, control costs become 4.5 percent of total cost under the decentralized system, versus only 0.4 percent under the centralized system. One can expect that control costs would become still larger as a share of total cost if delivery of the fortified foodstuff to a target population via a feeding program were undertaken.

Converting to Social Cost

Once the nominal costs of a program have been established as firmly as possible, the analyst should consider whether adjustment of some cost items to a truer social cost basis is warranted. Although we generally assume that the market price of a good or service adequately reflects its value to society, large and systematic price distortions are thought to be common in low-income countries. When these distortions have a significant effect on program costs -- "significance" being measured by the extent of price distortion times the share of the affected input in total cost -- a price correction should be made. The technique involved is called "shadow pricing."

Programmers commonly shadow price two types of program input: (1) anything which is bought with, or indirectly costs the country, foreign exchange (i.e., internationally tradeable goods), and (2) unskilled labor.* If using a shadow exchange rate or shadow wage rate is warranted, apply the same rates in all analyses. The nutrition planner will not need to calculate these rates because the project-analysis staff of the planning organization should have already done so. If it has not, however, the nutritional planner may have to supply the estimate, which he can do with the technique summarized in the Appendix Q to this chapter and described in more detail in the manuals cited there. In either case, he should understand why shadow pricing may be needed and what it does.

Tables 6.1 and 6.2 suggest that unskilled labor will be an insignificant proportion of the total cost. On the other hand, tradeable commodities, especially imported fortificants, are frequently a major cost component. In Tables 6.1 and 6.2, unskilled labor makes up no more than 10 percent of capital and operating costs (usually they are closer to 1 percent), but tradeable commodities constitute 50 to 70 percent of capital cost and from 80 to 95 percent or more of annual operating cost. Thus, a shadow wage rate could not possibly have much effect on the program's estimated social cost, but a shadow exchange rate could affect the estimate considerably. To take an arbitrary example, if the Tunisian dinar were overvalued 50 percent by means of import duties, quotas, and exchange controls, then the social value of the first program's capital cost would be over 30 percent greater than its nominal cost; its annual operating cost

*We will ignore the other applications of shadow pricing here.

would be nearly 50 percent higher in social than in nominal terms. (The approximate corresponding figures for the somewhat more labor-intensive program outlined in Table 6.2 are 25 percent and 40 percent. For a micro-fortificant program, where the fortificant represents a much smaller share of total cost, the overvaluation's effect would undoubtedly be still smaller.) These adjustments reflect the program's need for foreign exchange or its tendency to cost potential foreign exchange earnings, whose social value the official exchange rate understates.

Appendix Q briefly discusses the shadow pricing of foreign exchange. Because project analysis does not require other applications of shadow prices, the appendix does not cover them. It does include references, however, for those analysts considering shadow pricing unskilled labor or other inputs.

Conclusion

All fortification programs use scarce resources. Protein fortification programs are particularly costly compared to vitamin and mineral fortification programs of the past. High costs and the experimental nature of protein programs put a premium on their accurate costing. These factors also demand that the effects of proposed programs be carefully considered, that they be designed to maximize benefits, and that the assignment of costs be fair and pragmatic.

Intervention Impact

Introduction

As important as it is, cost analysis is only one dimension of the economics of protein fortification. It has no true meaning for the nutritional planner apart from an analysis of a program's potential effects. We shall discuss various methods of analysis, all of which fall into the general categories of either cost-effectiveness analysis or cost-benefit analysis. Both types of evaluation involve comparison of expected or actual results with estimated or real costs. But cost-effectiveness analysis measures results in nonmonetary units whereas cost-benefit analysis expresses results in monetary terms. Both methodologies have several variants which allow analysis of differing program objectives and forms of available data.

The choice of a method of analysis should be determined by the government's objectives for the program and by the availability of information on its results. Cost-effectiveness analysis focuses on either nutrient delivery and target-population coverage or on the program's biological effects. There are two reasons possible for this concentration. Either better nutrition is an end in itself, independent of any broader benefits it might produce; or these broader benefits are considered immeasurable (or not yet measured), in which case deliveries, coverage, and biological effects serve in effect as proxies. To apply cost-benefit analysis, a planner must believe nutritional improvement is an instrument of socioeconomic improvement and that its benefits can be defined and measured accurately.

Cost-Effectiveness Analysis

Cost-effectiveness analysis would be appropriate if, for instance, government policy stated that all children are entitled to a certain nutritional level, regardless of the cost to society. Acceptance of this ethically appealing principle simplifies the program evaluator's task by requiring cost analysis only of the different methods of achieving the objective. The question of whether to aim for that target would not arise.

Of course, cost-effectiveness analysis could be used to study different ways of achieving any level of nutrition. Even programs resulting in different nutritional outcomes could be compared on the basis of their cost-effectiveness ratios. However, the technique does not help determine how large a share of national resources nutritional programs should receive.

Cost-effectiveness analysis can evaluate two levels of program effect. The first, involving immediate effects, is that of coverage and delivery. Measures of nutrients delivered and members of the target population reached, when compared with cost, determine cost-effectiveness. At the second level, biological consequences of the program are measured and used in a more far-reaching study of the effects of the program. Cost-benefit analysis allows the analyst another level of evaluation: the quantification in money terms of socioeconomic effects, and their comparison with the program's monetary costs.

Coverage and Delivery: Project analysis results in the acceptance or rejection of aspects of the tested plan. But the range of choices posed does limit this selection process. Thus, if analysis leads to rejection of a fortification project -- or even a group of proposed projects -- the results do not prove that fortification programs are in general bad, but only that those particular projects are poorly designed. Similarly, if a particular formulation appears acceptable, we still do not know if an even better project could be devised. Considerably more than cost analysis should go into program design.

Among the objectives of program design are the following:

(1) Extensive coverage - to deliver the fortificant to as much of the target population as possible.

(2) Intensive coverage - to provide adequate fortification for as many as possible of those served.

(3) Low-cost coverage - to minimize the program's cost.

Obviously, there are trade-offs among these objectives, but a good cost-benefit analysis can help resolve them. The program analyst contributes to planning by developing effective and efficient program designs for consideration. The analyst might also try to solve suboptimization problems: How can the money available best improve the nutritional status of the target population? Or how can a given nutritional goal be achieved at least cost?

In dealing with such questions, the analyst may encounter three major dilemmas: extensive or narrow targeting, consumer acceptance, and financing. We will discuss the first of these problems here. Chapter 5 treated the second and the third is the subject of this chapters Section 4 on intervention financing.

Few governments would attach much value to fortification for groups outside the primary target population; deliveries to nontarget populations increase costs without increasing benefits. Thus the rationale for narrow or focused programs. But the focusing process does cost money, and it is difficult to design a project which will include all those who should be included and exclude those who should be excluded. The costs of overcoverage and the costs of narrow targeting must be balanced for optimal program operation.

It is difficult to say where the optimum balance point lies, but it is easy to point out the difficulties of extremely extensive and targeted designs. Two basic facts weigh very heavily against the efficiency of extensive program designs: the fortificant cost is frequently signficant relative to the cost of the carrier, and the principal target group is a relatively small part of the total population. Programs that reach the target group by distributing the fortificant to the general public are likely to involve substantial and expensive overcoverage.

The cost of overcoverage is a particularly important design consideration. Target groups certainly constitute less than 25 percent of the total population, and probably less than 15 percent, even in countries with the youngest populations. This fact is illustrated in Table 6.7, which contains data on a developing country in which the birthrate had been about 40 per thousand and the rate of natural increase nearly 3 percent for several years prior to the year to which the table applies. With such a population structure, the size of the target population is highly sensitive to the cut-off age. According to Table 6.7, a target population of six-month to six-year olds plus pregnant and lactating women would constitute 22.78 percent of this nation's total population. By dropping the cut-off age to five years, we reduce this figure to 19.61 percent; dropping it to three years reduces it to 13.22 percent. If we define only part of the total population in these groups as our target population (e.g., those living in the poorer regions of the country), the target population shrinks even further. The overcoverage of an extensive program, then, may multiply the cost per member of the target population served by a factor of four to eight. Clearly, this unnecessary cost may make the program prohibitively expensive.

On the other hand, focused programs also pose difficulties. Children of the most vulnerable ages do not usually go to school or participate regularly in any other program where they might be reached outside the home. Yet reaching the them -- and not other family members -- inside the home is also difficult. A well-designed program may solve this problem using some relatively new institution such as the maternal and child health clinic, or by distributing new "infant foods" that older members of the family will not eat.

Other fortification programs may have different target groups, but overcoverage remains a problem unless the target group is the entire population. However, it does pose a smaller problem for microfortification programs

Table 6.7

Selected Groups as a Percentage of Total Population

Group	Percentage of Total Population
6 months - 1 year	1.70
1 - 2 years	3.21
2 - 3 years	3.31
3 - 4 years	3.21
4 - 5 years	3.18
5 - 6 years	3.17
Pregnant women (taken as 3/4 of annual births)	3.00
Lactating women (taken as 1/2 of annual births)	2.00

Source: Department of Statistics. 1969. Estimates of Population for West Malaysia (1967), Kuala Lumpur

because of their lower fortificant costs. Whereas targeting that economizes on use of costly fortificants may be more efficient in protein interventions, some excess coverage in vitamin and mineral programs may result in net savings in logistics and control costs.

Several measures of first-level program effects are available for cost-effectiveness analysis. They focus either on coverage of the target population or on the delivery of nutrients to that group.

The extent of service to the target population is of major interest in program evaluation. The "penetration ratio" is a crude measure of program coverage:

$$\text{Penetration ratio} = \frac{\text{Recipients in the target population}}{\text{Target population}}$$

The penetration ratio is not an expression of cost-effectiveness because it takes no account of the cost of achieving the results it measures. One can, however, convert it into a cost-effectiveness measure by dividing the size of the target population through by program cost and multiplying this number by the size of the target population. The second step converts the ratio from percent to

absolute terms, which is necessary for comparing programs with target populations of different sizes. The resulting expression, which is called the coverage effectiveness ratio, is therefore:

$$\text{Coverage effectiveness ratio} = \frac{\text{Number of target population covered}}{\text{Total program cost}}$$

This ratio can be expressed in convenient units, such as "persons covered per million dollars of annual program cost."

The coverage effectiveness ratio measures how effectively the program reaches the target population, but it gives no indication of the magnitude of its effects. For this information, the analyst must resort to delivery measures. A simple indicator of this kind is the delivery effectiveness ratio, which can be defined as follows:

$$\text{Delivery effectiveness ratio} = \frac{\text{Nutrients delivered to target population}}{\text{Total program cost}}$$

This ratio measures a program's cost-effectiveness in delivering nutrients to the target population. Like the penetration ratio, it requires that target recipients be distinguished from nontarget recipients; further, it requires measurement of the share of nutrients going to each group. This data may be elusive in practice. Analysts need a formal consumption survey or at least some informal field observation to determine, even roughly, this value.

Another problem may arise in the use of the delivery effectiveness ratio to compare programs or program variants. So far we have assumed that the meaning of "nutrients" is unambiguous. This assumption would be valid if a single nutrient or mix of nutrients were involved in all the program variants being compared, but that is not always the case. When the mix varies, comparison becomes more difficult. The analyst of a protein fortification program might for example, take advantage of the fact that his principal objective may be to deliver an amino acid; other fortificants may be added merely because it is easy to do so once an amino acid fortification program has begun. In these circumstances, it would be appropriate to regard all program costs except those for the secondary nutrients as applicable to delivery of the amino acid. The delivery effectiveness ratio for

this amino acid would have amino acid deliveries in the numerator and total program costs, less the fortificant costs of secondary nutrients, in the denominator. Ratios for secondary nutrients would include the quantity of the nutrient delivered in the numerator and the fortificant cost in the denominator.

The delivery effectiveness ratio measures neither the distribution of nutrients delivered the target population nor their adequacy relative to need. The latter shortcoming can be remedied by establishing the target group's nutritional deficit. It is the difference between recommended nutritional intakes and actual intakes, i.e.:

$$\text{Recommended intakes} - \text{Actual intakes} = \text{Nutritional deficit}$$

The relative coverage of the program could be measured in terms of proportion of the deficit filled, i.e.:

$$\text{Deficit coverage ratio} = \frac{\text{Nutrients delivered to target population}}{\text{Nutritional deficit}}$$

As with the delivery effectiveness ratio, one should exclude nutrient deliveries to the nontarget population when calculating this measure. Here, however, there is an additional problem. Even deliveries to the target group should be counted only insofar as they contribute to making up the nutritional deficit; deliveries above minimum requirements should be excluded from or given a lower weighting in, the deficit coverage ratio. In practice, it is usually difficult to make this correction because it requires very detailed information on the distribution of nutrients. Where a severely undernourished target population is involved, the planner may reasonably assume that all supplied nutrients combat the deficit.

The deficit coverage ratio is not a cost-effectiveness measure because it takes no account of program costs. We could, however, conduct cost-effectiveness analysis by comparing the costs of alternative methods of correcting a nutritional deficit. To compare programs which address nutritional deficits of varying sizes, we would have to employ the delivery effectiveness ratio.

One serious limitation of the deficit coverage ratio as an evaluative device is its reliance on the concept of "nutritional requirements." This term suggests a more rigid, discontinuous, and unidirectional relation between nutrition and

well-being than exists in fact. In ordinary language, an unmet "requirement" has drastic results. Given this connotation, one might expect death or severe illness from failure to meet nutritional "requirements." Yet millions of people live out their lives on nutritional intakes below the required level. They survive only because adjustment mechanisms much less drastic than death or severe illness make it possible for them to live and function with substandard nutritional intakes. They merely lose weight and become less active than better fed individuals. The consequence of failure to meet nutritional requirements -- weight loss and a lower activity level -- do not appear drastic, so policy makers may not see the urgency of making proper nutrition a national goal.

Other problems with using nutritional requirements in evaluation relate to the difficulty of determining people's real needs. The analyst must take account of the qualitative as well as the quantitative dimensions of some nutrients, notably protein. And a reliance on averages misleads many, for one person's above-average intake in no way compensates for another's deficiency. It is hard to measure, much less influence, distributions of nutrients. Even if we knew that every household would meet its nutritional requirements, we would have no guarantee that all members of those households, particularly children, were adequately nourished. These problems and limitations with even the best of delivery and coverage measures recommend evaluation of the more far-reaching results of fortification programs.

Biological Development Measures: Protein fortification programs attempt mainly to accelerate physical and mental development. Yet most of the world's protein-short people consume too few calories, and any additional protein fortification brings them will be used largely or entirely for energy rather than tissue development. If this diversion of protein occurs, the project fails to attain its basic biological purpose. To avoid a misleadingly positive evaluation based merely on cost-effectiveness, analysts should test the biological results of their programs whenever they can.

Measures of physical growth and mortality play a vital role in evaluating any nutritional intervention aimed at children. Morbidity may also be of use, but reliable data on this standard are rarely available. Given the synergistic relation between nutrition and infection, reliable morbidity data can serve as a check on, and often as an explanation of, the other outcome variables. We must recognize,

however, that survival and physical development are also a function of many variables besides nutrition. All too often uncontrolled intervening variables have invalidated project evaluations or led to erroneous conclusions.

The ideal evaluation design follows the principles of a clinical trial and involves random assignment of individuals (from a random sample of the target population) to intervention and control groups. At intervals during longitudinal surveillance, and at the end of the trial, the analyst assesses the outcome variables for both groups.

Data on physical growth and mortality would make reliable measures of effectiveness possible. Analysis of growth-chart data permits assessment of intervention effects on weight-for-age, a sensitive indicator of infant nutritional status. Above age two, only those children who are too thin for their height can respond to most nutrition intervention programs. Weight-for-age alone does not distinguish between tall and thin and short, stock children; therefore, proper measurement of effect requires data on both weight and height as well. Growth-chart data do, however, allow some estimate of the general trajectory of growth. Children who are very malnourished at any age are usually thin, so the growth chart will reflect any improvement in their weight-for-age. The age group from 12 to 24 months is most likely to demonstrate significant improvement in growth-chart data. Birth weight can also serve as an outcome variable in cases in which malnourished mothers form a part of the target population, and arm circumference data can corroborate height and weight measurements.

We know crude death rates for infants and children between one and three years of age are useful indicators of malnutrition; differences in these rates for high-income and low-income groups reflect the malnourished status of the latter population. Mortality rates drop more rapidly in response to nutrition interventions than growth status improves. Accurate cause-specific death rates for each age group would provide a check on this discrepancy, but malnutrition is generally not recorded as the cause of death as often as it should be. Analysts can use mortality rates as an effectiveness measure only if their sample is extensive, for there are comparatively few deaths per annum per 1,000 population.

Should no control group data be available, a usable although less satisfactory body of evaluative data could be assembled using the program participants, in effect, as their own controls. Compare their growth histories before and after

joining the program. Strictly speaking, this exercise would only test the hypothesis that the growth of program participants is accelerating; it cannot provide information on whether, or to what extent, an improved growth rate is the result of the intervention itself. But proof that the program is effectively delivering nutrients to the target group makes this information an acceptable indication of its effectiveness.

The procedure for determining the growth index in the optimum data situation is as follows:

(1) Using survey data, estimate a percentage of standard weight for age (weight/age), length for age (length/age), and weight for length (weight/length) for each intervention and each control child at four-month intervals. These ratios can be readily calculated in terms of both national standards and the 50th percentile of the NCHS growth standards. (If you only have growth-chart data, perform the same analysis using weight/age only.)

(2) Test the distributions of weight/age, length/age, and weight/length for normality. The resulting distributions will almost certainly be normal or near normal on either the local or NCHS scale, particularly if you have made corrections for sampling errors and have removed obese children from the samples.

(3) Use age of entry into the program (less than 12 months, 12-24 months, 24-36 months, etc.), nutritional status at the time of entry (first, second, third degree Gomez), length of participation ("participants" must meet a minimum time requirement), and control group versus target group status as the factors in three four-way analyses of variance. Nutritional status at time of entry can alternatively function as a covariant, as can socioeconomic factors and morbidity status at the time of collection of dependent variables. The differences between adjusted cell means of control and target children represent the improvement brought about by the intervention.

By separating out the above factors, you can identify the interventions effect on small subgroups, such as malnourished children between 12 and 24 months. These results can be overlooked in an indiscriminant

comparison of control and target children. If the analysis proves too difficult, use t-tests to contrast subcells of control and target children, remembering that the resulting significance levels will be inflated. Omit either age of entry into program or nutritional status at time of entry from the calculation.

(4) It also is valuable to use duration of program participation (whose control value would be zero) as an independent variable in stepwise multiple regressions, looking at weight/age, length/age, and weight/length as dependent variables. Enter as independent variables all factors likely to affect nutritional status, including income and residential neighborhood.

When an appropriate control is unavailable, you must modify this procedure. In this case, compare measures of intervention group children (at their current ages) to measures of the same children when they entered the program. You can then calculate the effectiveness index in the same way as under the optimum data situation, but, as discussed earlier, this method's results are less reliable and harder to interpret.

In an optimum data situation, compute the mortality effectiveness index as follows:

(1) Determine age-specific death rate for the target population using life of the intervention rather than one year as the base period. This rate is expressed in terms of deaths of children under three years of age in the target group per 1000 children under three years in that group.

(2) Find the same rate for the control group.

(3) Subtract rate (1) from rate (2). The product is the number of deaths per 1000 children prevented by the program. Dividing this index by 10 yields an index representing the percentage change in the probability of death for children in the intervention group. This latter index can be used in cost-effectiveness ratios.

(4) You may want to calculate two additional mortality indices: for infants, and for children under four, excluding infants.

Some validity checks on these measures are possible. Mean arm circumference in the intervention and control groups can check weight-for-height. To check mortality results, compare cause-specific and age-specific death rates for the following nutrition-related illnesses: diarrheal diseases, upper respiratory diseases, and measles.

The compilation of cost-effectiveness ratios follows the generation of effectiveness measures. Divide each of the three effectiveness indices (growth, mortality and, if feasible, morbidity) by the cost per program participant. The resulting ratios measure the effectiveness of one unit of program expenditures in accelerating growth or preventing mortality or morbidity. The inverse of these ratios represent the cost of improving the specified developmental results by one unit. For the growth indices, one unit is the mean percentage below standard weight/age, length/age, or weight/length for the children sampled. For the mortality index, one unit is a one per thousand change in the probability that a child in the sample will die. Hence, these ratios indicate the cost to change the probability that a child will die, or the cost to change the growth indices by means of the intervention being evaluated.

Conclusion: Keep in mind that cost-effectiveness ratios measure the effectiveness of an average unit of program expenditure. Marginal expansions or contractions of the program might yield very different ratios, and these should be calculated separately. Remember also that to make a valid comparison of the cost-effectiveness ratios of two programs, you must measure their effectiveness and their costs in the same units. If the programs are in different countries, convert costs into a common currency.

Cost-effectiveness techniques, if applied carefully to reliable data, provide a valid method of program evaluation. Applied to several programs with the same goals, the measures these techniques produce can help determine the most economical way of achieving a given objective. Cost-effectiveness is thus well suited for use by objective-oriented sectoral planners. It is less useful for general planners, those interested in the allocation of resources among many programs, and sectoral planners seeking to justify their budgets. There is no way of directly comparing any of the potential benefits of fortification programs with, say, the results of spending money to increase agricultural output or educate children. To do this, a common unit for measuring results is required.

Cost/Benefit Analysis

Benefits: The characteristic of the cost/benefit approach is that it attempts to define and quantify the socioeconomic benefits of fortification. We can think of these benefits (and those of nutrition programs in general) as being of four types, as depicted in the following two-by-two matrix:

	Present benefits	Future benefits
Consumption benefits	Type I	Type II
Production benefits	Type III	Type IV

Better nutrition may make people healthier by banishing deficiency diseases and increasing physical and mental vigor, permitting them to lead fuller, happier lives. This is a current consumption benefit, designated as Type I in the matrix. Some of these benefits may also carry over into the future, especially if the youngest recipients of improved nutrition become healthy adults. Future consumption benefits are designated as Type II in the matrix.

Consumption benefits exist because we can regard helping people to enjoy better health and all the good things that go with it as an end in itself. But if the recipient of the nutritional improvement is a worker, he or she may work longer hours or become more productive, and national production also benefits. This Type III benefit is realized only if the recipient is a worker, which is conventionally defined as being economically active outside the home. Type III benefits do not involve children below working age and retirees.

Finally, we can regard nutritional improvement as an investment in "human capital": a Type IV benefit. All people with a working life before them are repositories of human capital. Expenditures that increase their future productivity are therefore a form of investment. Some estimates indicate that human capital is an enormously important factor of production. Much -- probably most -- human capital formation takes place prior to the worker's entry to the labor force. The contribution of nutrition to human capital formation is undoubtedly greatest early in life, when the potential for improving mental and physical health and strength are greatest.

When setting out to conduct a cost/benefit analysis of a nutritional improvement program, one decides which of these four benefits to include and how to value each.

Project evaluation traditionally considers only production benefits, present and future. The rationale is that increased production is an unambiguous social good: it permits someone's consumption to increase without requiring that anyone else's consumption decline. On the other hand, economists do not regard "mere" redistribution as demonstrably beneficial because to say that it is requires the "interpersonal utility comparisons" they shun. We should note, however, that economists value production increases for the additional consumption which they permit. The standard approach pays no attention to the question of who receives the increase in consumption or to the difficulty of distributing the increment in desirable way.

The standard approach tries to value contributions to present or future production at the price society puts on them. Market prices and wages approximate that price, but "shadow" valuations are substituted if observed prices are significantly different than those which would prevail in competitive markets. Future benefits must be discounted to present value terms with a discount rate that arguably represents the relative value society attaches to present and future consumption.

The traditional identification and valuation of project benefits is out of tune with the recent concern for distribution problems in development. One possible remedy -- so far seldom applied -- is the use of "distributional weights" permitting consumption benefits to vary, depending on who receives them. (For example, additional consumption for the poor might be valued at twice its social opportunity cost; additional consumption for middle-income groups might equal the social opportunity cost; and additional consumption for high-income groups might have no value.) Although distribution weights have great intuitive appeal in redistribution-oriented development programs, some economists dislike them because of the arbitrary assignment of values. This problem can be partially overcome by testing plausible valuations for sensible conclusions.

These comments relate to nutritional improvement programs in general. When dealing with protein fortification programs in particular, we need not deal with all the benefits discussed above. Since we are concerned mainly or entirely

with children, we can avoid Type III (current production) benefits. The most important benefits of protein programs lie in the future and relate to both consumption and production.

Which benefits should you include in a cost/benefit analysis, and how should you measure them? Analyzing the economic and social benefits of nutritional improvement programs is analogous to evaluating education, and we might learn from experience in that field. Like nutrition, education has a variety of present and future beneficial effects. Analysts have tended to ask whether only future production benefits justify educational investments. They have usually estimated future productivity differences (measured by income or earnings differences) associated with some level of education by extrapolating cross-sectional studies into the future. Any project that passes muster on these criteria can be regarded as ipso facto acceptable when other types of benefit are taken into account.

This kind of evaluation, or any modification of it, can test nutritional improvement programs. It only requires research results which offer an objective basis for determining what the actual production benefits of improved nutrition will be. Developing firm estimates has challenged educators because of the difficulty of sorting out the effects of education from those of other income-raising forces which are collinear with it. We should anticipate similar difficulties in applying this technique to nutritional improvement programs.

Comparing Benefits and Costs: We stress below the importance of designing several versions of the program for comparative analysis. The cost-effectiveness approach permits systematic comparison of these alternatives in terms of various nonmonetary measures. The cost/benefit approach does the same job, but it also measures the socioeconomic benefits which lie behind nutritional effects and using the general language of social valuation, it is also able to compare nutritional improvement programs with very different enterprises.

When costs and benefits occur at different times, or when either extends through time, the relative value of sums with different datings becomes important. Many investment projects involve heavy startup costs and produce benefits which begin only after startup but stretch far into the future. Protein fortification programs follow a slightly different pattern, as they do not require heavy front-end

investments. But their benefits, particularly their production benefits, are concentrated fifteen or twenty years in the future. The assessment of such a program depends heavily on the extent to which future values are discounted relative to present ones.

The treatment of time is a complicated and vexing question in project analysis, and we will not be able to discuss it in depth here. On the one hand, there is little reason to think that society strongly prefers receiving benefits and avoiding costs in the present rather than the future. This observation suggests a low rate should be used in discounting future benefits and costs, making a project with the time profile of protein fortification programs relatively more attractive. On the other hand, capital is presently scarce in most countries. Its social opportunity cost is thought to be high, making future-oriented projects less attractive than those that yield quicker benefits and do not tie up capital so long. An increased capital supply would resolve this dilemma, but the overall rate of saving remains low. We are thus forced to conclude that either society does not care much about the future, or that it does care but has been unable to increase saving and express its concern. The former conclusion would lead the project analyst to adopt a high discount rate and penalize future-oriented projects. The latter conclusion permits a lower disco rate but requires measures to increase savings or a rationing device to determine which future-oriented projects receive scarce resources.

The treatment of time must be uniform across different types of program proposals if they are to be compared meaningfully. As noted earlier, the same is true of any shadow prices used in the analysis. Bureaucratically, the necessary uniformity can be achieved if a central project analysis staff calculates standard discount rates, shadow exchange rates, and shadow wage rates for those concerned with program analysis. The end product of cost/benefit analysis are measures usually estimates of net present values and internal rates of return -- that allow comparison of nutritional and other projects.

What is the role of cost/benefit analysis in the evaluation of cereal fortification programs? Although in principle this technique is more general than the methods discussed earlier, it depends on research on the effects of nutrition on productivity. Such data will normally be unavailable, forcing the program analyst to fall back on the cost-effectiveness analysis adequate only for analyzing alternative nutrition programs. The question of how well money invested in nutritional

programs is being spent compared to altogether different uses will remain open. Unless the national government becomes one of the few to adopt an absolute -- or at least a very strong relative -- commitment to nutrition targets, the socioeconomic benefits of nutrition programs are likely to remain at issue. Only more research will clarify them.

Intervention Financing

Intervention financing may be a trivial issue with respect to microfortification programs, the costs of which are sometimes so low that millers or bakers absorb them without complaint. When we turn to protein fortification programs, with their far higher fortificant costs, it becomes much more significant. Assuming that they cost enough to talk about, fortification programs must be financed by a user charge, general taxation, or a combination of these means. Which method is best? To deal with this question, we must weigh two major criteria: efficiency and equity.

When the benefits of any good or service accrue solely (or mainly) to the individual consumer, efficiency is usually served by requiring the consumer to pay the cost. Otherwise, demand will inflate and society will allocate more resources to that particular line of production than its willingness to pay warrants. Where significant "externalities" are involved, or where the service in question is a "public good" benefiting society as a whole, this conclusion must be modified. If individual consumers do not reap the full benefits, charging them the full cost can only lead to underallocation of resources to the good or services production. The service must be subsidized, or even provided free, to ensure an efficient allocation of resources.

The foregoing argument yields one efficiency-based argument for subsidization or free provision of protein fortification. This argument could be applied only if the benefits were thought, in some sigificant degree, to accrue to society rather than to the individual who receives improved nutrition. This situation seems implausible. However, our discussion has so far been based on the economist's traditional premise of consumer sovereignty -- the assumption that consumer preferences should determine the allocation of resources. Protein fortification is one area in which an argument might be made for abandoning consumer sovereignty. Consumers are less well informed about nutrition than planners. They

might be happier if some resources were reallocated to nutritional improvement, even if they do not now realize it. This argument leads to the conclusion that subsidized or free fortified protein would be efficient. Thus one can argue the efficiency case either way.

From the point of view of equity, however, it is hard to imagine a service for which a user charge would be a less appropriate means of finance. A tax on a basic foodstuff is as regressive as any that government can levy. Both the proportion of income spent on food and the proportion of food expenditure devoted to purchases of the basic grain bear strong negative relations to household income. Thus, the burden of the charge on the low-income household which spends as much as half its income on rice, wheat, corn, or flour would be much heavier than the burden on a better-off family which spends less than five percent.

If, despite these strictures, a user charge is levied, the retail price of fortified foodgrains, flour, and grain products will rise. This increase will disrupt consumption patterns and reduce the purchasing power of household incomes. It is worth tracing out the causal linkages involved here with some care.

We begin with the cost of the fortificant and other program inputs. We have said all along that these will inevitably be significant relative to the price of the carrier. This fact rules out the possibility of the miller or other participants in the distributive process absorbing program costs and leaving their prices unchanged. Prices will definitely rise, but by how much?

The <u>minimum</u> price increase in the carrier attributable to fortification can be worked out with the displacement formula presented in Section IIC. This formula states fortificant cost as a share of the fortified product (C) as a function of the fortification ratio (α), the price of the unfortified carrier (P1), and the price of the fortificant (P2):

$$C = \frac{\alpha(P2 - P1)}{P1}$$

Thus, to work through a hypothetical example, if $\alpha = 0.10$, $P1 = 0.10$, and $P2 = 0.15$, then $C = 5$ percent. Equations assuming synthetic fortificants are characterized by a high value of P2 and a low value of α, while those involving natural fortificants have the opposite characteristics.

The formula reveals the minimum expected price increase because it reflects only fortificant costs. If the user charge is to finance the entire program, then nonfortificant costs must be added to that price. Remember also that distributors may use the cost increase to increase their profit per unit.

Whatever the precise amount of increase, it will have two effects on household expenditure patterns. The price of the basic foodstuff having risen relative to other goods and services, consumers will have to substitute expecially cheap sources of calories for it. And because the commodity represents a significant share of the total budget for the poorer households, real household income will fall as the price rises, reducing the household's consumption of goods and services in general. Putting these two results (the "substitution effect" and the "income effect") together, we see that the household's consumption of the basic foodgrain and products made from it can only drop.

The extent of the fall in the taxed items consumption is determined by the "price elasticity of demand." How large can we expect this elasticity to be? Because the foodgrain is a necessity with few close substitutes consumed by poor households, the substitution effect will be weak. But the foodgrain is also a major item of consumption in households with little margin for absorbing price increases, so the income effect will be strong. Our overall expectation is thus ambiguous. There would in fact be many different elasticities, depending on the income level of the household, its tastes, the grain or grain product taxed, and the size of the price increase. Many have attempted to measure price elasticities of demand for various categories of consumption in low-income countries but none of their results apply directly to any particular case.* A risky generalization from the research results might be to put the expected price elasticity of demand for a modest increase in the price of a basic foodstuff in a low-income country to be around -0.5. This estimate means that a price increase of 10 percent would result in a 5 percent decline in demand.

*For some estimates and more extensive discussion, see Reutlinger, S. and Selowsky, M., 1975, Under-Nutrition and Poverty, World Bank Staff Working Paper No. 202, Washington, D.C.

McCarthy, F.D., 1975, Nutrition, Food and Prices in Pakistan, MIT, International Nutrition Planning Program Discussion Paper No. 4, MIT, Cambridge, Mass.

To the extent that households consume more of some substitute food, interest attaches to the identity of that substitute and its nutritional properties. Low-income households will almost certainly choose a cheaper source of calories as a substitute commodity. Even in the poorest societies, such substitutes are usually available (e.g., various tubers in Asian countries). Such foods are generally scorned by all but the very poorest, and their protein values are probably inferior to those of the unfortified staple foodgrain. Nevertheless, their availability may help offset the deleterious nutritional effects of a price increase.

To illustrate the nature of the substitution process, let us assume that there are two possible food staples, a preferred grain and a less desirable tuber. Assume further that the grain in its unfortified state has twice the usable protein value of the tuber and also costs twice as much. Finally, assume that fortification increases the usable protein value of the grain by a factor of five, that the price elasticity of grain demand is -0.5, and that the household fully compensates for an increase in the price of grain by purchasing a quantity of the tuber.

Table 6.8 shows the consequences of these assumptions. It suggests that if the improvement in usable protein which results from fortification is as great as we have hypothesized and if the price elasticity is around 0.5, substitution will not reduce the benefits more than marginally. On the other hand, the household's real income will fall, and this drop will be especially severe for the poorest households.

To summarize the discussion of program financing with a user charge, we see that although it could possibly be defended on efficiency grounds,* it would clearly be inequitable to the poor. In principle, a user charge could also induce substitution of other products for fortified foods and undermine the nutritional aims of the program, but our quantitative estimates suggest that this outcome is unlikely in practice.

The alternative to financing the program through a user charge is to provide it "free," to finance it out of general revenues. This policy would require curtailing other expenditure programs or increasing government revenues. Increasing revenues would be more equitable than levying a user charge because the tax

*This case is partially dependent on the quality of program design, however. A well-designed program will yield benefits commensurate with the costs consumers are asked to pay, but a poorly designed program will involve higher costs without equivalently higher benefits.

Table 6.8

Example of Staple Food Substitution

	Prefortification Situation			Fortification with 5 percent Price Increase		
	Units consumed[a]	Usable protein consumption[b]	Cost of staple food[c]	Units consumed	Usable protein consumption[b]	Cost of staple food
Grain	80	160	40.00	78	780	40.95
Tuber	20	20	5.00	22	22	5.50
Total	100	180	45.00	100	802 (+446%)	46.45 (+3.2%)
	Fortification with 10 percent Price Increase			**Fortification with 20 percent Price Increase**		
	Units consumed	Usable protein consumption[b]	Cost of staple food	Units consumed	Usable protein consumption[b]	Cost of staple food
Grain	76	760	41.80	72	720	43.20
Tuber	24	24	6.00	28	28	7.00
Total	100	784 (+436%)	47.80 (+6.2%)	100	748 (+416%)	50.20 (+11.6%)

Note: a) Assumes initial consumption pattern.

b) Assumes usable protein values of 1 for tuber, 2 for unfortified grain, and 10 for fortified grain.

c) Assumes initial cost of $0.50 for grain and $0.25 for tuber in U.S. $.

systems of most low-income countries are progressive. For a rough indication of the sums involved, note the two programs for Tunisia estimated in Tables 6.1 and 6.2. Together, they would cost about $3 per head in annual operating cost. This expense would constitute about 0.7 percent of the Tunisian GNP and perhaps 3 percent of the government budget.

A Concluding Note

We have not tried to condemn or promote the fortification of cereal grains with vitamins, minerals, and protein supplements. Our analysis has merely presented a way for nutrition planners to weigh the desirability and feasibility of fortification interventions. Although most of the analysis has been directed toward protein fortification, we have offered general indications of how the methodology could be applied to micronutrient fortification programs. Our judgment is that protein fortification has a place in the nutrition planner's portfolio with microfortification and other approaches, but he should use it only when caloric deficits are also a problem. The planner should also seriously consider combining macro- and micronutrient fortificants to increase overall nutritional improvements. Finally, efforts should be made to target the fortification and avoid the costs of overcoverage or to employ natural fortificants, which minimize fortificant costs.

Feasibility Questions

About the Problem the Program Addresses:

(1) What subgroup of the population is affected? What is the program's target population?

(2) What is the nature of the nutritional problem? What symptoms of deprivation are present?

(3) What are the known or suspected economic and social consequences?

About Alternative Program Designs:

(4) How might these problems be solved? Do fortification programs figure among the possibilities?

(5) What alternative fortification program designs are worth considering? (Discuss extensive and targeted approaches, in particular.)

(6) What fortificant packages should be considered?

About Intervention Costs:

(7) What inputs -- and in what quantities -- will each program alternative require?

(8) What will these inputs cost?

(9) How does the cost structure of each program break down in terms of cost categories, i.e., fortificant cost, fortifying process, logistics, and control?

(10) What does sensitivity analysis show about the extent to which variations in timing, prices of key inputs, and other contingencies could affect the cost estimates?

(11) Do price distortions (especially of tradable goods inputs) warrant conversion from a nominal-cost basis to a social-cost basis?

About Potential Program Effect:

(12) How fully will the program cover the target population in relation to program cost?

(13) What quantity of nutrients will be delivered to the target population in relation to program cost?

(14) What biological effectiveness measures are appropriate for program evaluation?

(15) How do alternative program formulations compare in terms of various cost-effectiveness measures?

(16) Can any key benefits be valued in money terms to allow cost/benefit analysis?

About Program Financing:

(17) How can the program be financed?

(18) What are the advantages and disadvantages of each method in terms of social efficiency, equity, and consistency with the program's nutritional objectives?

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