PN ABR-424
88245

Food Fortification in Developing Countries

by
Penelope Nestel, Ph.D.

USAID

US Agency for
International Development

PRINTED BY VITAL, 1993

Table of Contents

- Summary ____ 3

SECTION I

- Introduction ____ 5

SECTION II

- Vitamin A, Iron Iodine and Multi-Nutrient Mixes ____ 7

SECTION III

- Foods Fortified with Vitamin A, Iron, Iodine and Pre-Mixes ____ 12

SECTION IV

- Quality Assurance and Control ____ 24

SECTION V

- Monitoring and Evaluation ____ 26

SECTION VI

- Economic Aspects and Sustainability ____ 28

SECTION VII

- Political and Legal Dimensions ____ 33

SECTION VIII

- Future Directions ____ 35

APPENDICES ____ 37

REFERENCES ____ 47

Acronyms

BHT	Butylated Hydroxy Toluene
CWS	Cold Water Soluble
EDTA	Ethylenediaminetetraacetic acid
FAO	Food and Agricultural Organization
ICCIDD	International Council for the Control of Iodine Deficiency Disorders
IDD	Iodine Deficiency Disorder
INACG	International Nutritional Anaemia Consultative Group
INCAP	Nutrition Institute of Central America and Panama
IVACG	International Vitamin A Consultative Group
IU	International Unit
MCH	Maternal and Child Health
MSG	Monosodium Glutamate
MSI	Mineral Safety Index
MTD	Minimum Toxic Dose
OPA	Orthophosphoric Acid
PL 480	US Public Law 480
RDI	Recommended Daily Intake
RE	Retinol Equivalent
SD	Spray Dried
WFP	World Food Program
WHO	World Health Organization

SUMMARY

There has been a recent renewed interest in food fortification, largely because it is generally recognized as being the most effective way to eliminate dietary micronutrient deficiencies, especially where micronutrient multi-mixes can be used. In addition, fortification is socially acceptable, requires no change in food habits, does not change the characteristics of the food, can be introduced quickly, has readily visible benefits, can be legally enforced, is relatively easy to monitor, is the cheapest intervention for a government, and is sustainable. The most widespread micronutrient deficiencies are vitamin A, iron, and iodine, hence the focus has been on these three nutrients.

The challenge, however, to fortifying foods in developing countries, is to find both suitable food vehicles and appropriate micronutrient compounds. The micronutrients must remain stable and biologically available after being added to the food vehicle, during storage, and during normal food preparation procedures. Pure vitamin A and carotenoid structures are unstable in the presence of oxygen or air or when exposed to ultra-violet light. The addition of anti-oxidants and control of oxygen exposure, however, allows for their use in food processing procedures. The bioavailability of iron, and the presence of iron absorption enhancers or inhibitors in food, determine which foods can be fortified and which iron fortificant can be used. Processing and storage conditions are also important since the solubility of iron fortificants is related to storage time and influences the development of off-flavors, -odors and-colors. The solubility of iodine compounds, and resistance to sublimation, are important determinants of which iodine fortificant is used.

The concentration of fortificant in food vehicles is based on data for per capita consumption of the food vehicle by different social and economic groups, in different ecological regions, preferably broken down by age and physiological group. These data are important, and must be made available, because delivery of too little micronutrient will result in an ineffective program while too much, will not only be wasteful but, could exceed the upper safe limit.

A number of foods have been fortified with vitamin A in developing countries. On-going fortification programs comprise sugar and monosodium glutamate (MSG). Successful field trials have been completed using whole wheat, rice and tea. Fortified oil has proven viable in the laboratory but field trials have yet to be undertaken. Foods fortified with iron include wheat flour, corn flour, and rice. Iron-fortified maize meal, sugar, salt, reconstituted low fat milk, biscuits, fish sauce, and curry powder have undergone field trials but their fortification has not been undertaken on a large scale. Salt is the most common food to be fortified with iodine. Brick tea is also fortified with iodine, and sugar has been fortified under laboratory conditions. Vitamin-mineral multimixes added to wheat flour have successfully completed field trials. Double fortification of MSG with vitamin A and iron, and salt with iron and iodine are currently undergoing laboratory testing. Corn and wheat based blended foods provided through PL 480 Title II programs, routinely incorporate vitamin-mineral multimixes.

Quality assurance is essential to developing an effective, practical, and economical fortification program because it guarantees that food vehicles are both properly fortified and delivered to consumers at the required level of potency and quality. Unless manufacturing executives and the government agencies involved in food regulation commit themselves to quality assurance, it is unlikely that the goals of food fortification will be met. Program goals, however, must be clearly stated at the outset of the program and a proper monitoring and evaluation process incorporated as part of the fortification program. Few fortification programs to date have undergone extensive monitoring and evaluation. Indeed, it would appear that the failure to monitor and evaluate and therefore demonstrate the benefits of micronutrient interventions is one of the key reasons why donors and developing country governments are so cautious about food fortification.

The costs incurred in food fortification are only the additional cost of fortifying the food vehicle; thus, the value of the food is not included. In general,

the operational and control costs in food fortification are small when compared to the recurrent costs of micronutrients. Vitamin A is particularly expensive. It costs approximately US$47.00-66.00 per kg. The cost of iron fortificants varies widely (US$2.00-19.00 per kg of iron) and is related to both the bioavailability and stability of the compound. Even so, supplying 1 million people with the raw iron ingredient costs between US$50.00 and US$460.00. Iodine compounds cost approximately US$30.00 per kg or US$8.00 per 1 million people for raw iodine. Economic analyses for the returns on fortification with vitamin A, iron, and iodine have shown that fortification is cost-effective in all cases.

The cost of a food fortification program can be borne by the government or passed on to consumers by increasing the price of food. Because the economic groups most vulnerable to micronutrient deficiencies are those least able to afford food price increases, it is essential to consider how to share the costs of fortification. Targeting fortified food to the most nutritionally deprived group, while spreading the fortificant cost across society, may be one option. A common industry response to cost of production increases is to reduce slightly the volume of packaged foods but maintain the current prices. This strategy may be appropriate in some instances.

A major constraint to food fortification is the demand the programs make on foreign exchange. It is imperative, then, to consider the feasibility of manufacturing fortificants and/or fortified food at the local or regional level. At the same time, the food industry needs to be given an incentive to fortify food. Thus, alternative ways of subsidizing food fortification, especially during the start-up years, have to be explored. Temporary support for subsidizing fortified food could come from donor institutions.

Without strong lobbying, governments are unlikely to adopt food fortification. The awareness of implications for development and the political will to initiate food fortification efforts do not, by and large, exist. Indeed, there may be misperceptions that the needed technology either does not exist or is too complex or expensive. Furthermore, governments often point to the need for legislation to ensure compliance and the need to tap the social concerns of the food industry. None of these claims may be true. The fact that a large number of foods in developed countries are fortified and have been fortified for a long time is testimony to well-developed technologies. Relatively minor modifications may be needed to fortify foods in developing countries. The technology needed in food fortification is not complex because essentially only measuring devices, feeders and mixers are required to add the fortificant during processing. Furthermore, legislation for compliance does not always ensure that fortification takes place. Indeed, free market competition and industrial support are more important than legislation in terms of stimulating food industry compliance. Finally, market forces and profit, not social concerns, tend to motivate the food industry, although social responsibility may become an important factor in building a positive corporate image.

To generate the political will to implement food fortification programs, it will be necessary to impress upon policy makers that micronutrient deficiencies are very real health problems with major economic consequences. Once this is recognized, the challenge will be to get top-level commitment from donors, national governments, and food industries to initiate and sustain actions that will directly address micronutrient deficiencies. When possible and when proven necessary, multi-prevention programs should be strongly advocated, because they are better than piecemeal approaches from both a nutritional and economic perspective.

I. INTRODUCTION

Micronutrient malnutrition is a widespread problem throughout the world and has both health and economic consequences. The most extreme effect is increased mortality, but other outcomes include blindness, poor cognitive development, reduced growth, lower worker productivity, higher morbidity, and adverse pregnancy outcomes.

Since the early 1980s, an immense amount of effort and resources have been devoted to identifying the extent and severity of micronutrient deficiencies in developing countries. Programs implemented to combat these deficiencies, which include nutrition education, supplementation, and food fortification, have met with varying levels of success. While nutrition education is recognized as being an important component in combating nutritional deficiencies, it alone cannot eradicate the problem. Supplementation programs, which depend on an effective health care delivery system, have tended to end up as pharmaceutical programs directed at specific age and physiological groups, rather than to sectors of society. Food fortification programs, on the other hand, are better suited to combating micronutrient deficiencies because they depend on people's participation in the market economy. They can also be targeted or untargeted depending on the magnitude of the micronutrient deficiency.

Most programs implemented to combat micronutrient deficiencies in developing countries have focused on single nutrients rather than on combinations of nutrients. The fact that there are separate international consultative groups for anaemia, vitamin A and iodine reinforces the single nutrient focus or vertical approach to dealing with micronutrient deficiencies. However, the vertical approach to combating widespread nutritional deficiencies is no longer recognized as the most efficient use of limited resources. Given this, and the need for mass prevention and control of micronutrient deficiencies, food fortification has increasingly gained renewed importance. In fact, the resurgent interest in food fortification has led to research in the application of existing technologies to develop more stable and biologically available micronutrient forms that can be added to food either singly or as multi-mixes.

Before discussing the rationale for food fortification, it is important to note that food fortification is used for two purposes. First, it can restore nutrients lost during food processing by enriching a food with the depleted nutrient. Second, it can increase the level of specific nutrient(s) in a food. In both cases, fortification increases the intake of a specific nutrient previously identified as inadequate.

In many developing countries, rural populations are largely dependent on subsistence foods; their diet is simple and monotonous. The urban poor are in a different and perhaps more precarious situation because they are unable to produce food for home consumption. Therefore, they must participate in the market economy. The situation is exacerbated by the rapidly increasing number of rural-to-urban migrants whose survival depends on their success in securing low-paid work. This scenario is presently more evident in Latin America and Asia but is rapidly emerging in Africa (Solomons and Gross, 1987; Viteri, 1987; Popkin and Bisgrove, 1988). The quality and quantity of the diet of the poor is generally limited. Therefore, micronutrient deficiencies, in particular, iron, vitamin A, and, to a lesser extent, iodine, often occur simultaneously in the same areas of a country. The aetiology of iodine deficiency is different to that of other micronutrients, because it results from geological rather than social and economic conditions.

Regardless of where people live, their diet is typically based on one or two cereals, tubers, or pulses as the staple. If the household has any livestock, it may also consume some dairy products. Fruit, unless gathered locally, is often a luxury, as are many vegetables. It is this dietary and economic context that must be considered if the objective is to improve micronutrient intake and status among the ultra poor (Lipton, 1983). Many processed foods are beyond the means of the poor, much less the ultra poor. Thus, a food fortification program needs to focus on fortifying foods which undergo minimal

processing, for example cereals, rather than highly processed foods which are inaccessible to the poor and ultra poor.

To ensure that the most vulnerable members of the population benefit from food fortification, the food vehicle(s) must be a staple food consumed throughout the year by a large proportion of the population, with relatively little inter- and intra-individual variation. In addition, the food must pass through central processing points where specified micronutrients can be added under controlled conditions. The level of fortification must be such that it contributes significantly to nutritional requirements while still remaining within the safe upper limit. Furthermore, the fortificant must not alter the organoleptic properties (taste, smell, look, texture), physical structure, or shelf life of the food vehicle(s). Control and monitoring procedures must be built into the manufacturing procedures to ensure that fortification levels are adequate; in some cases, legislation may be necessary to ensure compliance.

One **advantage of food fortification** is that it is socially acceptable. It does not require the active participation of the consumer nor any change in buying, cooking, or eating habits. Furthermore, fortification maintains a food's organoleptic properties. Because the food to be fortified is already marketed and has a widespread distribution system, it can be introduced quickly. And the benefits of fortification are readily visible. Legislation for compliance is possible and relatively easy to monitor. Fortification is the least costly intervention for a government, and is the most effective way of eliminating dietary micronutrient deficiencies. Finally, food fortification is sustainable (INACG, 1981; Bauernfeind and Arroyave, 1986; Venkatesh Mannar, 1987; Arroyave, 1987).

The **disadvantage of food fortification** is that it relies on a centrally processed and marketed food vehicle; thus, only those who consume the food vehicle may benefit. In other words, fortification is less likely to benefit people who consume locally produced, unprocessed food. In addition, fortified food reaches nontargeted as well as targeted individuals and may not be the most economical way to reach the target group. If the cost of fortification is passed on to only target group consumers, purchasing patterns among the intended beneficiaries may change adversely. Furthermore, fortification incurs recurring costs. In addition, political will, legislation, and enforcement mechanisms are necessary to ensure program success (Bauernfeind and Arroyave, 1986; Arroyave, 1987).

This report reviews the literature on food fortification with respect to vitamin A, iron, and iodine. No attempt has been made to discuss fortification from the food industry's perspective, which is not to say that this topic is any less important. Chapter II describes how fortification levels are determined as well as the different fortificants available. The third chapter summarizes some of the issues (fortificant used, potency, stability, trial results, technical and distributional problems, constraints, and cost) related to fortifying different foods. Chapter IV describes quality control and assurance while Chapter V outlines how to monitor and evaluate food fortification programs. The sixth chapter discusses the economic aspects and sustainability of food fortification programs. Chapter VII identifies political and legal dimensions. Finally, the last chapter puts forward suggestions for future directions.

II. VITAMIN A, IRON, IODINE, AND MULTIPLE NUTRIENT FORTIFICATION

Vitamin A, iron, and iodine deficiencies are the three most serious micronutrient deficiencies in developing countries. Largely because of food fortification programs, micronutrient deficiencies do not exist in developed countries. Food fortification is, however, technically easier to implement in developed countries because of the high dependency on processed food by all income groups. Consequently, a wide variety of processed foods can be fortified with different micronutrients. In developing countries, the challenge is not only to find suitable food vehicles for fortification but also to identify appropriate micronutrient compounds that remain both stable and biologically available after their addition to food and after they undergo normal food storage and preparation procedures. Given the enormity of the food fortification task and the absence of data on the extent and severity of other micronutrient deficiencies, food fortification in developing countries has tended to focus on those micronutrients whose deficiencies are most widespread and debilitating, namely, vitamin A, iron, and iodine.

Determining the level of fortification

Vitamin A

In food composition tables, the unit for vitamin A is generally the international unit (IU). However, vitamin A levels are conventionally expressed as micrograms (µg) of retinol. Because the vitamin A activity of carotenoid is lower than that of retinol, the retinol equivalent (RE) has been established to take into account dietary sources of both retinol and carotenoids. The relationship between the different units of vitamin A is shown in Table 1; and the FAO/WHO-recommended daily intakes (RDI) for vitamin A are presented in Table 2.

There is essentially no risk of vitamin A deficiency or toxicity when dietary intake from food totals 10,000 IU vitamin A/day. However, significantly higher levels of retinol intake just before or soon after conception may have teratogenic consequences. For this reason, WHO (1982) and IVACG (1980) recommend that daily supplements of 3,000 RE (10,000 IU) vitamin A can be given safely anytime during pregnancy.[1]

Given that a population's diet usually includes some vitamin A, fortification is generally used as a means of making up the deficit between intakes and requirements. With few exceptions, a food fortified with vitamin A should not be considered as the sole source. Often, however, the information available on vitamin A intake is inadequate. In these situations, the fortified food should provide the critical intake level or at least one-half of the RDI (IVACG, 1988). The limiting factor is the RDI for the groups most vulnerable to deficiency and/or toxicity (young children and/or pregnant women). Thus, for fortification to be effective yet remain within the upper safe limit, it must meet half the RDIs for children aged three to five years.

The concentration of fortificant to be used in the food vehicle should be based on data for the per capita consumption of the food vehicle by different social and economic groups in different ecological regions, preferably disaggregated by age and physiological group. These data are important because delivery of too little vitamin A results in an ineffective program while too much vitamin A is not only wasteful but can exceed the upper safe limit.

1 Vitamin A supplementation during pregnancy, however, should be considered only for women whose intakes are known to be inadequate.

Once the minimum and maximum intake levels of the food vehicle have been ascertained, a simple mathematical calculation determines the safe range of vitamin A fortification as shown in Table 3.

The safe range of fortification is between 8 and 6 IU/100 g vitamin A as ingested. Other factors, including losses during storage and cooking, also need to be taken into account when determining fortification levels.

Iron

Young children aged six to 18 months, preschool-age children, women, and adolescent girls are most vulnerable to iron deficiency anaemia (INACG, 1990; Gillespie *et al.*, 1991). Table 4 presents the RDI for the different age groups. Determining a measure of "safe intake" for minerals is problematic because of the substances' different reactivities in various food substrates (Clydesdale, 1991).

Nevertheless, a mineral safety index (MSI) has been proposed:

$$MSI = MTD/RDI,$$

where MTD is the minimum toxic dose as obtained from the literature and the RDI is the highest value for a nonpregnant and nonlactating adult. The estimated adult oral MTD for iron is 100 mg, thus, the MSI would be 2 or 4 depending on whether the iron availability in the diet was low or intermediate, respectively.

TABLE 1: Vitamin A Units

Unit	Equivalent Unit
1 retinol equivalent (RE)	1 µg retinol
	6 µg beta-carotene
	12 µg other provitamin A carotenoid
	3.33 IU vitamin A activity from retinol
	10 IU vitamin A activity from beta-carotene
1 international unit (IU)	0.3 µg retinol
	0.6 µg beta-carotene
	1.2 µg other provitamin A sources
1 µg retinol	1.0 µg RE
1 µg beta-carotene	0.167 µg RE
1 µg other provitamin A carotenoid	0.084 µg RE

Source: FAO/WHO (1988).

Iodine

Fortification with iodine should ensure that each individual receives at least 100 µg iodine per day from the fortified food. To take into account storage and transport losses, programs should aim to provide a daily intake of about 150 µg per person.

Types of fortificants

Vitamin A

Mammals are unable to synthesize vitamin A in the body and must receive dietary vitamin A in the form of retinol or carotene. Retinol or preformed vitamin A is found in foods of animal origin usually as a retinol ester. Carotenoid or provitamin A is found in plant material particularly in green leafy vegetables and yellow vegetables and fruit. The predominant carotenoid is beta-carotene. Both retinol and carotene can be commercially produced; the former as retinol, retinol acetate, and retinol palmitate, and the latter as beta-carotene and beta-apo-8'-carotenal (Bauernfeind and Arroyave, 1986). Pure vitamin A and carotenoid structures are fairly stable when heated to a modest temperature in an inert atmosphere and in the dark, but are unstable in the presence of oxygen or air, or when exposed to ultraviolet light. Vitamin A is quite stable in an alkaline environment although trace elements can accelerate its oxidation (Bauernfeind, 1978). With the addition of antioxidants and the control of oxygen exposure, several pure vitamin A and carotene structures, which remain stable during food processing procedures, have been developed for use in food fortification (Appendix 1).

The color of both the fortified food and the food vehicle determine which vitamin A structure is used in fortification. If vitamin A activity alone is important, then one of the vitamin A esters is used. If both the color and vitamin A activity of the fortified food are important, then one or a mixture of the carotene-containing structures is used. The vitamin A structure to be used also depends on whether the food vehicle is an oil- or fat-based food, a water-based food, or a dry-based food to be dispersed in water prior to consumption.

TABLE 2: Recommended Daily Intakes of Vitamin A

	Basal requirement		Safe intake level		Critical intake level	
	RE	IU	RE	IU	RE	IU
CHILDREN (age in years)						
0 to 1	180	600	350	1165	175	585
1 to 6	200	665	400	1330	200	670
6 to 10	250	835	400	1330	200	670
10 to 12	300	1000	500	1665	250	835
12 to 15	350	1165	600	200	300	1000
15 to 18 boys	400	1330	600	200	300	1000
15 to 18 girls	330	1100	500	1665	250	835
ADULTS						
Men	300	1000	600	2000	300	1000
Women	290	900	500	1665	250	835
Pregnant women	370	1230	600	2000	300	1005
Lactating women	450	1500	850	2830	425	1415

Source: FAO/WHO (1988).

Iron

A diet that contains too little iron and/or poor bioavailability of iron leads to iron deficiency anaemia. Iron is present in tissue foods as heme-iron and in plant materials as non heme- or inorganic iron. Between 20 and 30 percent of heme-iron is absorbed, although less than 5 percent of non heme-iron is absorbed (INACG, 1979; FAO, 1988). Adding ascorbate; removing iron absorption inhibitors in food, e.g., chlorogenic acid (coffee), calcium phosphate (cow milk and soya), egg yolk, polyphenols (cocoa, coffee, tea, pulses, and cereals), pyhtates (coffee, bran, cereals, legumes), and some dietary fibers (cereals); or increasing the intake of foods containing ascorbate or other acids (fruits and some vegetables) and heme-iron (meat, fish, and poultry but not dairy products) improves the absorption of non-heme-iron (DeMaeyer, 1989; Cook, 1990). Non-heme-iron is the primary source of iron for the poor in developing countries. Thus, in addition to the low bioavailability of iron, poor people's diets generally lack absorption-enhancing compounds (Finch and Cook, 1984). Factors that affect iron absorption are, therefore, critical in deciding which food vehicle to use in fortification.

Only two iron compounds, whose bioavailability is both acceptable and relatively independent of meal composition, can be used in food fortification. These are sodium ferric ethylenediaminetetraacetic acid (EDTA) and haemoglobin. EDTA is often used in technological processes that involve both foods and drugs. Its potential use as a fortificant has to be considered in terms of its maximum Accepted Daily Intake, which though a possible constraint in developed countries, is not generally a problem in developing countries. Haemoglobin, although readily absorbed, has a low iron content and strong color. The latter is an organoleptic constraint in food fortification (Hurrell *et al.*, 1989). It also requires a continuous supply of animal blood.

Many iron compounds can be added to food (Appendix 2), however, those that are more readily absorbed tend to produce undesirable changes in the food vehicle, namely, discoloration and off-flavors. INACG (1977), Cook and Reusser (1983), and Bauernfeind (1991) point out that ferrous salts may oxidize to form yellow green or black ferric oxide. In addition, ferrous salts react with sulphur or phenolic compounds as well as with tannins to produce blue-black colors. Because iron is a pro-oxidant, it may catalyze the development of oxidative reactions causing off-colors, -odors, and -flavors, even in the absence of oxidation enzymes. High-density iron compounds such as reduced iron powders may require special measures to achieve a

TABLE 3
Determining Safe Level of Vitamin A Fortification

Estimated intake of food vehicle	Appropriate level of fortification (IU/100 g) to provide vitamin A intake	
Max=X g	Min (670 IU)	Max (10,000 IU)
Min=Y g	670/Y=C	10,000/Y=D
	670/X=A	10,000/X=B

TABLE 4
Recommended Daily Intake for Iron (mg/day)

	Iron availability in diet		
	Low (5%)	Medium (10%)	High (15%)
Children:			
0.25-1	21	11	7
1-2	12	6	4
2-6	14	7	5
6-12	23	12	8
Boys 12-16	36	18	12
Girls 12-16	40	20	13
Men 16+	23	11	8
Women menstruating	48	24	16
Women post-menopausal	19	9	6
Women lactating	26	13	9

Source: FAO/WHO (1988).

stable and uniform distribution within the fortified food. The color and flavor of iron compounds themselves may be undesirable and carry through to the food, and may be more noticeable in beverages. Furthermore, the solubility characteristics of the iron compound may not be compatible with the food vehicle.

The type of iron fortificant selected for use is dependent on the food processing, storage, and distribution conditions (Cook and Reusser, 1983). In general, the solubility of the fortificant is inversely related to storage time. The more soluble the compound is, the better its bioavailability; but the greater the compound's chemical reactivity, the higher the risk of rancidity. Soluble iron compounds, therefore, are used to fortify foods with a short shelf life. Phosphate compounds (ferric orthophosphate and sodium pyrophosphate) are organoleptically more acceptable but have low bioavailability. Indeed, because of their poor bioavailability, the relative cost of these iron compounds is high. Elemental iron powders are used extensively in wheat flour fortification in developed countries. Although relatively inexpensive, these high-density iron compounds may separate in some food vehicles, and the finely powdered iron is flammable. Cost, too, is a limiting factor in food fortification. The more insoluble the compound the greater its cost. The addition of ascorbate to increase iron absorption is difficult because ascorbate is relatively unstable; it is also expensive.

Iodine

Both iodide and iodate compounds have been used in iodine fortification. Of the two compounds, potassium iodide is more soluble and is therefore needed in smaller quantities. It is more unstable under conditions of moisture, high temperatures, sunlight, excessive aeration, and when in the presence of salt impurities. It is also less expensive. However, because potassium iodate is much more stable and resistant to sublimation, and also has fewer requirements for stabilizing and drying agents, it is the preferred fortificant in most situations (Bauernfeind, 1991).

Multiple nutrient premixes

Food fortification can also be done using a micronutrient multimix. Premixes of vitamin A may include water soluble vitamins (e.g., folate, ascorbate) and minerals (e.g., iron, iodine). In addition to vitamin A, micronutrient multimixes for cereals[2] are often comprised of thiamin (vitamin B1), riboflavin (vitamin B2), niacin, and iron. The concentration of each vitamin and mineral in a micronutrient multimix depends on the naturally occurring level of the micronutrients in the food vehicle after milling and processing (examples of ATOCHEM and ROCHE cereal fortification multimixes are shown in Appendix 3).

Multipurpose multinutrient mixes are preferable to single nutrient fortification for a number of reasons (Mora, 1992). First, given that micronutrient deficiencies tend to coexist, it may be more cost-effective and appealing to policy makers to fortify a number of foods with a multi-nutrient mix rather than a single nutrient. A multiple focus would also preclude exacerbation of other micronutrient deficiencies as a result of alleviating a single deficiency. Second, if several commonly consumed foods are fortified, the total cost of fortifying a particular food may decline because less fortificant would be added to that food thus permit-

2 Primarily wheat, although trials are underway for rice.

ting more foods to be fortified. It would also allay fears that fortification would increase consumption of some foods, e.g., sugar. Third, fortification of several commodities may be potentially more acceptable to the food industry by allowing fortification costs to be shared by a number of food industries. It could also promote competition between the food industries. The food industry might even take on some responsibility for educating the consumer in situations where choices are available. Finally, fortification of a number of foods could increase public awareness of micronutrient deficiencies and sensitize the food industry to the importance of food fortification.

III. FOODS FORTIFIED WITH VITAMIN A, IRON, IODINE, AND PREMIXES

Developing countries offer some good examples of the potential use of specific commodities as vehicles for vitamin A fortification (Table 5). These commodities include sugar in Guatemala; MSG in the Philippines and Indonesia; whole wheat in Bangladesh; rice in the Philippines; and tea in India and Pakistan. Oil has yet to undergo field trials in Brazil. A less successful commodity is salt, which did not prove economically feasible.

Foods that can be fortified with iron include wheat and corn flour (PL 480 commodities) and infant formulae; rice in the Philippines; sugar in Guatemala; salt in India, Indonesia, and Thailand; and reconstituted low fat milk and biscuits in Chile. Water has also been fortified with iron. Foods that are colored and have strong tastes are particularly suitable for iron fortification because they permit the use of more reactive iron compounds. Examples include fish sauce in Thailand; curry powder in South Africa; and beverages such as "Kool Aid" in Egypt.

The most common food vehicle for iodine is salt (water has also been fortified with iodine). Brick tea (West China) and sweets (Middle East) have apparently been successfully fortified. In some developed countries, bread and milk have been inadvertently fortified with iodine through the addition of iodate as a bread conditioner and the use of an iodide compound to treat foot rot in cattle. Sugar has apparently been successfully fortified with iodine in Sudan.

Multimixes that include vitamin A and iron have been successfully added to wheat flour/bread in Jordan and India.

Fortificants are generally added to a food vehicle during the final stages of processing. Appendix 4 presents flow diagrams that show the stage at which fortificants are added in the production of fortified tea, rice, and flour.

The remainder of this section summarizes some of the important issues related to food fortification. Only foods for mass consumption are included; infant formulae and water are excluded.

TABLE 5
Foods Fortified with Micronutrients in Developing Countries

	Vitamin A	Iron	Iodine	Multi-mix
ON-GOING	Sugar	Wheat flour Corn flour Infant formulae Rice	Salt Brick tea Water Bread Milk	
EXPERIMENTAL	Whole wheat Rice Tea *Oil *Salt MSG	Sugar Salt Milk Biscuits Water Fish sauce Curry powder Maize meal "Kool-Aid" *MSG *Salt	*Sugar *Salt	Wheat flour Corn meal Wheat flour noodles

* Laboratory stage only.

Fortification with vitamin A

Sugar

Fortification of sugar with vitamin A has been successfully implemented in Guatemala, Costa Rica, Honduras, El Salvador, and Panama (Arroyave, 1972; Arroyave *et al.*, 1979; Arroyave *et al.*, 1981; Mejia and Arroyave, 1982; McKigney, 1983; Dary, 1991; McKigney *et al.*, 1992). Only Guatemala, Honduras, and El Salvador are currently fortifying sugar.

- **Fortificant:** Premix comprising one part retinol palmitate beadlets Type 250 CWS, nine parts white sugar, peroxide-free peanut oil, and stabilizer. The fortificant, which is a pale yellow color, is added to sugar during the final stages of processing.

- **Potency**: Premix 50,000-55,000 IU vitamin A/g.

- **Dilution**: 1:1000 of premix to white sugar yielding 50 IU vitamin A/g sugar. Sugar consumption by the most at-risk groups was 20 gm/day. This level of fortification would meet the Central American RDI for children (300 µg vitamin A).

- **Stability**: Nine percent decline in potency of fortified sugar at room temperature (18-32°C) after nine months, although recently tested samples in Guatemala show greater losses (McKigney *et al.*, 1992). Organoleptic characteristics of unfortified sugar maintained.

- **Results of field trials**:

  A three-fold increase in the average daily intake of RE. Among children under six-years-old, an increase in serum retinol levels; a reduction in the prevalence of low or deficient serum retinol values; an increase in prevalence of the highest category of adequacy; improved iron nutriture; suggestion of a positive impact on clinical eye signs and child growth. Increased retinol levels in breast milk.

- **Technical and distribution problems**: Failure in timely delivery of premix resulted in some distribution of unfortified sugar. There was some variation in the vitamin A content of the fortified sugar.

- **Constraints**: Political and economic. Sugar manufacturers were responsible for absorbing the cost of fortification, primarily because of the relatively low cost of sugar fortification. Due, in part, to inadequate monitoring, the fortification program in Panama was suspended by the sugar industry soon after implementation. In Guatemala, the decline in the world price of sugar and simultaneous increase in the cost of the fortificant caused manufacturers to temporarily suspend the fortification program during the 1980s.[3].

- **Cost**: Guatemala

  1979 prices

  — US$0.0029/kg fortified sugar

  — US$0.07 per person per year

  1991 prices

  — US$0.0066/kg fortified sugar

  — US$0.30 per person per year.

The current consumer price of sugar is US$0.42/kg. Thus, fortification represents 1.6 percent of the consumer price of sugar.

Monosodium glutamate

Fortification of MSG with vitamin A has been tried in the Philippines (Solon *et al.*, 1985; Latham and Solon, 1986) and Indonesia (McKigney, 1983; Murphy *et al.*, 1987, Muhilal *et al.*, 1988a; 1988b). The fortification program in the Phillipines used dry vitamin A palmitate Type 250 SD but experienced organoleptic problems (color, size, density), variability in vitamin A content and loss of vitamin A activity. Indonesia has made progress in overcoming some of the technical problems associated

3 The Costa Rica sugar fortification program was discontinued in the late 1970s after it was shown that dietary vitamin A intake and serum retinol levels of pre-school-age children had increased significantly to satisfactory levels.

with fortifying MSG with vitamin A and has conducted field trials using fortified MSG. Poor households tend to buy MSG in small packets of 5 g or less whereas better-off households buy larger amounts. Fortification of small packets of MSG would thus target the lower social and economic groups.

- **Fortificant**: Dry vitamin A palmitate Type 250 CWS dispersed in an edible carbohydrate, stabilized with antioxidants, and coated with a white pigment. The fortificant, known as "white" vitamin A, is miscible in both hot and cold water.

- **Potency**: "White" vitamin A 175,000 IU vitamin A/g.

- **Dilution**: 17.1 kg "white" vitamin A mixed with 982.9 kg MSG to provide 3,000 IU vitamin A/g MSG. Daily MSG consumption levels of adults and children are in the order of 0.4 g and 0.2 g, respectively. Thus, fortified MSG provides on average a maximum of 1,200 and 600 IU vitamin A per day to children and adults, respectively. These levels are close to the FAO/WHO (1988) critical intake levels.

- **Stability**: "White" vitamin A is sensitive to oxygen, high temperatures, moisture, and light. It compares favorably with uncoated vitamin A and retains more than one-half of its potency when stored for over 18 months at 25°C and for over seven months under moist dark conditions. There is evidence that the white coating doubles the storage life of "white" vitamin A under light conditions.

  Under controlled conditions, the fortified MSG retains one-half of its potency for over two years of storage at temperatures up to 35°C, but the loss of vitamin A activity is high when the fortified MSG is exposed directly to light. Precautions also need to be taken to ensure that fortified MSG is not exposed to moisture. To avoid physical separation of "white" vitamin A from MSG, agglomeration of "white" vitamin A into clusters with particle sizes similar to that of MSG is necessary.

  In field trials, fortified MSG retained over 90 percent of its vitamin A activity after two months, 80 percent after six months and just under 60 percent after 11 months.

- **Field trial results**:

  Among children under five-years-old, an improvement in serum retinol levels; a reduction in the prevalence of low and deficient serum retinol levels; a reduction in the level of xerophthalmia; an improvement in growth; an increase in haemoglobin levels; a 45 percent reduction in the mortality rate.

  Increased retinol levels in breast milk.

- **Technical and distribution problems**: Loss of "white" vitamin A integrity after exposure to marketing conditions. Large variation in the vitamin A content of the fortified MSG.

- **Constraints**: Indonesian policy requires consensus before taking action. The Consumer's Union and some MSG manufacturers resisted the use of MSG as the food vehicle. Controversy developed over the safety of MSG as a food and thus over fortifying a food whose consumption perhaps should not be encouraged. Manufacturers of MSG were not satisfied that the technology produced a sufficiently white product.

- **Cost**: Feasibility study indicated that MSG fortification would cost US$0.06 per child per year. Overall program cost is estimated to be US$5 million per year. It is likely the government of Indonesia will require fortification of MSG in packages below a certain size, with the cost spread over all MSG irrespective of package size. Gradually, however, the cost will be passed on to the consumer through annual reductions in the level of government subsidy. Only about one-third of the MSG will be fortified, therefore, the increase in price will be relatively small. Because price parity will be maintained, consumers will not switch to unfortified MSG.

Fortification of MSG with both vitamin A and iron has been laboratory tested in the Philippines (Bauernfeind, 1991). The double fortification appears feasible as long as the MSG is a milled or fine mesh crystalline product. Micronized ferric orthophosphate and zinc stearate coated with ferrous sulphate have been added to MSG along with stabi-

lized vitamin A palmitate Type 250 SD. Sachets comprising 2.4 g fortified MSG contained 15,000 IU vitamin A and 50 mg iron. Both products were found to have favorable color, taste, bioavailability, and particle size characteristics. Storage trials indicated that the iron did not influence vitamin A activity. Large-scale production trials and field testing of the product need to be carried out.

Whole wheat[4]

Fortification of wheat with vitamin A has been considered in Bangladesh (Darton-Hill, 1988; Crowley *et al.*, 1989). Wheat, the least preferred staple, is generally eaten by the very poor. Wheat aid (Title II) goes to the particularly disadvantaged through programs targeted to those most in need. The mixing of synthetic vitamin A powder with wheat flour was considered but rejected as inappropriate. The reason is that Bangladeshi households tend to buy locally milled whole wheat grain in the market. Thus, whole wheat fortification was considered.

- **Fortificant**: Premix (known as vitamin A wheat concentrate) of concentrated vitamin A attached to wheat grains.
- **Potency**: Not stated.
- **Dilution**: 1:400 of the premix to regular wheat.
- **Stability**: Not stated.
- **Results of field trials**: Not stated.
- **Technical and distribution problems**: Not determined.
- **Constraints**: With no explanation, the government of Bangladesh did not approve the project, which was to have demonstrated the technical feasibility of fortification and confirm its nutritional impact.
- **Cost**: Not stated.

Rice

Both the Dominican Republic (Emodi and Scialpi, 1976) and the Philippines (Florentino and Pedro, 1990; Murphy *et al.*, 1992) have attempted to fortify rice with vitamin A (Rubin, Emodi and Scialpi, 1977). Rice fortification, however, requires an approach that differs from other food vehicles. The reason is that rice is consumed as a whole grain that is picked over for irregular kernels then washed before cooking. In addition, cooking times vary by culture. Thus, the fortificant has to be resistant to both washing and cooking. Initially, rice was fortified by applying a coating that included vitamin A to rice grains. The vitamin A-coated rice grains constituted the premix. Technically, the fortification process was viable, but the product was unacceptable to the Philippine authorities because washing losses ranged from 10 to 20 percent. More recently, a synthetic rice grain comprising vitamin A has been developed as the fortificant and is undergoing field testing.

- **Fortificant**: Premix of rice flour (made from broken rice grains) fortified with retinol palmitate 250 SD in an acacia matrix with antioxidants, preservatives and a small amount of lipids. By using a pasta extruder, the premix is formulated into grains similar in appearance to rice.
- **Potency**: Premix 2,000 - 2,500 IU vitamin A/g.
- **Dilution**: 1:199 premix fortified rice to regular rice. Estimated to provide 13 IU vitamin A/g fortified rice.
- **Stability**: 100 percent retention of vitamin A activity in both the premix and synthetic grains after washing tests. Cooking retention of vitamin A varies enormously (46 to 94 percent) depending on the lipids and antioxidants used to formulate the synthetic grains. In the Philippines, a 50 percent cooking stability is the minimum criterion for acceptability. Combinations of more saturated oils (peanut, coconut), tocopherols, and ascorbate are recommended for

4 Appendix 5 summarizes the technical feasibility of fortifying cereal grain-based products.

adequate vitamin A preservation in the synthetic rice premix.

- **Field trial results**: Not determined.

- **Technical and distribution problems**: Formulation of simulated kernels is easy, but production can be a problem. Soft kernels leach in the washing water, while excessively hard kernels which will not be digested, may be detected in cooked rice, picked out, and discarded.

- **Constraints**: Not determined.

- **Cost**: Not stated.

Tea

Both India (Brooke and Cort, 1972) and Pakistan (Fuller *et al.*, 1974; Crowley *et al.*, 1989) considered the fortification of tea. Both tea dust (smallest tea particles) and tea leaves were successfully fortified in India. Pakistan showed interest in fortifying tea leaves.

- **Fortificant**: Tea dust is fortified by dry mixing dust with fine-powdered vitamin A palmitate 250 SD. Tea leaves are fortified by using emulsions of vitamin A palmitate and acetate in an acacia and 50 percent dextrin (or sucrose) solution with BHT and dl-alpha-tocopherol as antioxidants and sodium benzoate as a preservative. Vitamin A concentration 400,000 IU/g or 500,000 IU/g.

- **Potency**: 125 IU vitamin A/g fortified dry tea.

- **Dilution**: One 150 ml cup of tea brewed from 3 g dry tea supplies 375 IU vitamin A/cup of tea. Three cups of tea a day provide 1,125 IU, which is equivalent to the current average intake of vitamin A in India (more than the critical intake level for nonlactating adults) and approximately 38 percent of the RDI in Pakistan. Two cups of tea a day provide at least 75 percent of the critical intake level for all children.

- **Stability**: Fortified tea dust retained 85 percent of its vitamin A activity after one year of storage at room temperature. Fortified tea leaves sprayed with vitamin A emulsion diluted in water and dextrin showed unsatisfactory stability (20 to 85 percent retention depending on storage conditions), but vitamin A emulsions diluted in sucrose solution retained 90 to 98 percent of their vitamin A activity when stored for up to a year at 37°C. Vitamin A palmitate in both the powdered and sucrose-diluted emulsion forms showed 100 percent vitamin A activity after one hour of boiling.

- **Field trial results**: Not disclosed.

- **Technical and distribution problems**: None; commercial-scale trial demonstrated feasibility of fortification during processing in individual or blending plants. Organoleptic characteristics of unfortified tea maintained. Shipping tests showed no apparent signs of vitamin A segregation in tea fortified with the sucrose-diluted emulsion.

- **Constraints**: Absence of support from major tea blending companies (Lipton and Brooke Bond). Funding (USAID) withheld until completion of studies on food consumption patterns and nutritional status. Studies never completed; project lost momentum. Government of Pakistan, in conjunction with a minor local tea blending company, undertook trials of fortified tea leaves in a limited marketing area, but the results were not disclosed.

- **Cost**: Estimated total manufacturing cost of fortifying at 250 IU vitamin A/g in Pakistan was US$0.015/kg (1974 prices), of which the ingredients accounted for 94.7 percent, maintenance and depreciation 2.4 percent, quality control 1.5 percent, and labor 1.2 percent.

Oil

Fortification of soybean oil is currently under trial in Brazil (Favaro *et al.*, 1990). Vegetable oil consumption, in particular soybean oil, is increasing rapidly throughout the country, especially among the lower social and economic sectors. The reason is that soybean oil costs less than other oils and fats. Vegetable oil processing is centralized and controlled by large companies and cooperatives, thus

facilitating large-scale fortification with vitamin A. Commercial vegetable oils are traditionally packed and sealed in metal cans and thus are protected from light in storage.

- **Fortificant:** Retinol palmitate and antioxidants.
- **Potency**: 1,700,000 IU vitamin A/g.
- **Dilution**: Fortified soybean oil provides 200 IU vitamin A/g. Assumption that daily consumption of oil among the poor in southern Brazil is 15 - 30 g; thus, fortified oil can contribute up to 6,000 IU vitamin A per day.
- **Stability**: Fortified oil retained all its vitamin A activity for six months irrespective of whether or not it was stored in sealed cans and in the dark. After nine months, fortified oil stored in sealed cans in the dark, retained 98.5 percent of its vitamin A activity. After 18 months, however, this same oil registered only 41 percent of its original vitamin A activity. The vitamin A activity of fortified oil stored in open cans began to deteriorate after six months; oil stored in the dark retained 33 percent of its activity, but oil stored in the light had a negligible amount of vitamin A after 18 months.

  Vitamin A was uniformly dissolved and dispersed throughout the cans, and there were no changes in the oil's organoleptic properties.

  When normal household cooking procedures are followed, the vitamin A activity of rice cooked with oil remained at 99 percent and at approximately 90 percent for beans cooked with oil (boiled or pressure cooked). Repeated use of oil in frying, however, destroyed the vitamin A. Indeed, after four repeated fryings one-half of the oil's vitamin A activity had been lost.
- **Field trial results**: Not undertaken.
- **Technical and distribution problems**: Not determined.
- **Constraints**: Oil consumption data are lacking and purchasing patterns are not documented.
- **Cost**: Not stated.

Salt

Fortification of salt with vitamin A has been tried under laboratory conditions (Bauernfeind and Arroyave 1986; Crowley *et al.*, 1989; Bauernfeind, 1991).

- **Fortificant**: Dry vitamin A palmitate Type 250 SD protected by a lipid.
- **Potency**: Not stated.
- **Dilution**: Not stated.
- **Stability**: Protection of vitamin A activity was considerable up to a moisture level of about 2 percent.
- **Field trial results**. Administration of salt fortified with 440 IU vitamin A/g over a six month period was found to be effective in improving vitamin A status among preschool-age children.
- **Technical and distribution problems**: Salt is hygroscopic, which means that it must either contain a desiccant or be packaged in a moisture-resistant package to prevent it from absorbing moisture. Impurities in the salt and nonuniform crystals also destabilize vitamin A.
- **Constraints**: Unless salt is available at low cost to all throughout the country, fortification may not be feasible on a commercial scale.
- **Cost**: Not stated.

Fortification with iron

Wheat flour

Whole grain cereals are difficult to fortify with soluble iron compounds because the fortificants are susceptible to fat oxidation during storage, thereby reducing the cereal's shelf life. However, low extraction flours, which contain less fat, phytic acid, and fiber, are good food vehicles (Cook and Reusser, 1983; Arroyave, 1992).

- **Fortificant:** Reduced iron powders when long shelf life is expected. Ferrous sulphate when short shelf life is expected.
- **Potency:** Not stated.

- **Dilution:** Not stated.
- **Stability:** Good.
- **Field trial results:** Evidence in developed countries suggests that iron-fortified flour has reduced and prevented anaemia.
- **Technical and distributional problems:** Elemental iron may segregate on pneumatic conveying systems and may be extracted by magnets used to remove contaminants during milling.
- **Constraints:** Most of the wheat in developing countries is imported. Consumption generally favors higher-income groups.
- **Cost:** Not stated.

Rice

Discussions are under way in the Philippines to fortify rice with iron (and other micronutrients) (Florentino and Pedro, 1990). The fortification method needs to account for micronutrient losses that can occur when Filipinos pick out unacceptable "objects" from their rice and wash the rice two or three times before cooking. There are two possible ways to fortify rice. The first is to use simulated rice kernels (see fortification of rice with vitamin A). The second is to use a rinse-resistant premix that is coated onto the surface of ordinary rice kernels.

- **Fortificant:** Anhydrous ferrous sulphate suspension is sprayed onto polished rice. The solvent evaporates and leaves a relatively insoluble coating on the rice kernel. The fortified kernel is then encapsulated with a coating material to prevent discoloration and off-flavors and to minimize the degree to which the fortificant is washed off in cold water during the precooking rinsings. The coating, which is insoluble in cold water, breaks down during cooking to release the nutrients.
- **Potency:** 14 g anhydrous ferrous sulphate yields about 448 mg iron/100 g premix.
- **Dilution:** 1:200 premix to ordinary milled rice. After taking into account iron losses due to rinsing and storage, the premix provides 2 mg iron/100 g enriched rice (in addition to the 1 mg iron already present in the rice).
- **Stability:** Not stated.
- **Field trial results:** The color of the fortified rice kernels was hardly distinguishable from that of ordinary rice kernels. The color of the fortified kernels did, however, change from a creamy white to a light beige after 20 weeks of storage at room temperature. There was a 9 percent loss of iron after a standard rinsing and washing test that involved two water changes.
- **Technical and distribution problems:** Not determined.
- **Constraints:** Millers may be reluctant to implement the program if they see it as a way in which the government can monitor their throughput of rice and thus tax both them and the producers. Indeed, this was the reason for the collapse of the legislated rice fortification program in the 1950s.

  Under the auspices of the National Food Authority, the government procures, mills, and distributes rice for sale to the public at a controlled price. About 10 percent of the total population, largely represented by lower-income groups, consumes the fortified rice. Targeting fortified rice only to this group is a possible option.

  Between 10 and 15 percent of the population home pound their rice rather than pay for milling services. For this reason, it has been proposed that the premix should be available for sale in retail stores and perhaps health centers.
- **Cost:** Not stated.

Sugar

Iron added to sugar is well absorbed, especially if added to citrus drinks. However, a high proportion of the sugar consumed by adults is added to tea and coffee, which inhibit iron absorption. Sugar fortification with iron has been tried in Guatemala (Zoller *et al.*, 1980; Cook and Reusser, 1983; Viteri in Levin, 1986; Molina, 1991).

- **Fortificant:** Ferric-sodium-EDTA.
- **Potency:** Not stated.
- **Dilution:** 13 mg of iron as ferric-sodium-EDTA/100 g sugar. Average sugar consumption was 40 g/day; thus, the fortified sugar provided more than 5 mg iron/day (mean absorption was just over 6 percent).
- **Stability:** At a concentration of 1 mg iron/g, sugar fortification does not affect the color or taste of sugar and greatly **retards** (though does not eliminate) the discoloration that takes place when the fortificant is directly added to tea. No unfavorable interactions when sugar is fortified simultaneously with vitamin A and iron.
- **Field trial results:** Incidence of anaemia was reduced substantially.
- **Technical and distribution problems:** Noticeable discoloration when coffee or tea are prepared with iron-fortified sugar.
- **Constraints:** Cost of fortificant.
- **Cost:** Fortifying sugar to increase an adult woman's iron intake by 5 mg a day (13 mg iron/100 g sugar) adds 1 to 2 percent to the cost of sugar or approximately US$0.10 per person per year.

Salt

Laboratories in India have carried out most of the recent work on iron fortification of salt. The government has passed legislation that authorizes the production of iodized salt only. Work is now focused on multinutrient fortification of salt (Zoller *et al.*, 1980; Anon, 1983; Levin, 1986; Mannar, 1990; Bauernfeind, 1991).

- **Fortificant:** Ferrous sulphate with sodium acid pyrophosphate as a coordinating agent and sodium acid sulphate as an absorption enhancer. Fortificant made from either 3,500 ppm ferrous phosphate and 5,000 ppm sodium acid sulphate, or 3,200 ppm ferrous sulphate, 2,200 ppm orthophosphoric acid (OPA) (or sodium orthophosphate (SOP)) and 5,000 ppm sodium hydrogen sulphate. The latter fortificant is less costly than the former.
- **Potency:** 1 mg iron/g salt.
- **Dilution:** 3.5 g fortificant per kg salt, which provides 10 to 15 mg iron per adult per day assuming an absorption rate of 5 percent and an average intake of 15 g salt per day. This is just over one-third of the Indian RDI.
- **Stability:** Not stated.
- **Field trial results:** Favorable acceptance of fortified salt once people became familiar with crushed salt. Significant improvement in haemoglobin levels and a reduction of anaemia with both types of fortificants. The largest rises in haemoglobin levels were among people with the worst anaemia.
- **Technical and distribution problems:** The salt used in fortification should have a minimum purity of 99 percent (dry basis), a maximum moisture content of 2 percent and a maximum magnesium chloride level of 0.1 percent. The salt also needs to be fine-grained and of uniform size. All salt in India must be iodized, and studies of salt fortified with both iron and iodine are currently underway. The iron salt in an acid medium, which was developed for iron fortification, quickly decomposes the potassium iodate (the preferred iodine compound because of its better stability) in iodized salt to elemental iodine, which, in turn, vaporizes quickly. A fortificant containing 0.04 g potassium iodate (40 ppm), 3.28 g ferrous sulphate (1,000 ppm Fe), and 10 g of a permitted food stabilizer per kg looks promising. The bioavailability of both the iron and iodine in the salt after prolonged periods of storage are reported to be good. A field trial has been undertaken to study the impact of iron-iodine fortified salt on anaemia and goiter control, but the results are still unknown. Consumer acceptance after storage and cooking (no discoloration or off-flavors) has not yet been documented. The technology for processing and fortifying salt with both minerals needs to be refined.
- **Constraints:** Cost.

- **Cost:** US$25.00/ton for the iron phosphate formulation and US$16.00/ton for the iron sulphate formulation, each of which is equivalent to US$0.05/kg salt. Iron fortification adds between 50 and 80 percent to the cost of the salt and costs approximately US$0.18 to US$0.20 per person per year. Fortification of salt with both iron and iodine adds approximately 50 percent to the retail price of salt. Neither producers, nor consumers would be able to pay the added increment.

Milk

Chile has introduced some novel ways of fortifying foods with iron (Walter, 1990) by acidifying iron-fortified milk and adding bovine haemoglobin to wheat biscuits.

- **Fortificant:** Ferrous sulphate.
- **Potency:** Not stated.
- **Dilution:** 15 mg ferrous sulphate/l reconstituted low fat milk.
- **Stability:** Not stated.
- **Field trial results:** Significant but inadequate reduction in anemia (from 27 to 10 percent) among children aged three to 15 months. The low bioavailability of the iron was believed to have limited the decline in anemia levels. When, however, ascorbate was added (100 mg/l) to enhance iron absorption, anemia in the children was virtually eradicated. Trials in a feeding program also showed the positive impacts of iron-fortified milk in reducing anemia in infants.
- **Technical and distribution problems:** Not stated.
- **Constraints:** Except for young children, household members did not find the acidified milk palatable. Furthermore, given that the popular National Supplementary Feeding Program (NSFP) distributes milk to mothers after they bring their infants for growth monitoring/EPI and other primary health care activities, program implementers were concerned that issuance of acidified milk would adversely affect the health program for mothers and infants.

  The fact that only some milk manufacturers had the facilities to acidify milk and pack it in tins was viewed as unfairly restricting those who could bid to supply milk to the NSFP.
- **Cost:** The acidification process and the need to pack the milk in tin cans rather than in polyethylene bags significantly increased the cost of fortification.

Fish sauce

Thailand has successfully completed field trials on the use of fish sauce as a vehicle for iron fortification (Garby and Areekul, 1973; Cook and Reusser, 1983; Lynch, 1990). Aside from its use as a condiment, fish sauce often substitutes for solid salt.

- **Fortificant:** Ferric-sodium-EDTA.
- **Potency:** Not stated.
- **Dilution:** 1 mg iron/ml fish sauce. Mean absorption was 8 percent for meals that contained fish sauce. Average daily consumption of fish sauce was between 10 to 20 mls, which could provide an additional 0.8 to 1.2 mg of absorbed iron.
- **Stability:** Good.
- **Field trial results:** Significant improvement in hematocrit values among 25 to 35 percent of those receiving the supplement.
- **Technical and distribution problems:** Fish sauce is not consumed throughout the country, although its consumption is progressively increasing. Fish sauce is produced by hundreds of small local companies and distributed through local stores and street vendors.
- **Constraints:** Too many producers.
- **Cost:** Thailand completed its field trials in the early 1970s when fish sauce was sold in 750 ml bottles at a cost of US$0.1-0.5 per bottle. The addition of iron was expected to increase the cost of the fish sauce by 10 to 20 percent, which was equivalent to 0.3 to 1.0 percent of a Thai farmer's average monthly income.

Curry powder

The fortification of curry powder with iron was initiated after Asian South Africans were discovered to be iron deficient anaemic even as black South Africans evidenced an iron overload. Curry powder is widely used by poor Asian households but rarely used by the black population (Lamparelli *et al.*, 1987; Ballot *et al.* in Lynch, 1990).

- **Fortificant:** Ferric-sodium-EDTA.
- **Potency:** 10 mg ferric-sodium-EDTA/g masala curry powder. Mean bioavailability of iron was 10 percent.
- **Dilution:** 1.4 mg iron/g masala curry powder. Average masala curry powder consumption was 5.5 gm per day, which would increase iron availability by 0.8 mg per day.
- **Stability:** Not stated.
- **Field trial results:** After two years, field trials revealed a significant improvement in the iron status of women, with the greatest benefit occurring among the most anaemic individuals. No excessive iron accumulation was observed among individuals with normal iron status at the beginning of the trial.
- **Technical and distribution problems:** No commercial supply of food-grade masala curry powder.
- **Constraints:** Cost and the absence of a commercial supply of food-grade masala curry powder.
- **Cost:** Not stated.

Other foods

Wheat biscuits have been successfully fortified with bovine haemoglobin in Chile (Cook and Reusser, 1983; Walter, 1990). Indeed, the fortified biscuits were used as part of the national school lunch program (for children aged six to 18 years). Each child received three 10 g biscuits every day, which provided 5 mg heme-iron and about 1 mg absorbed iron daily. Although the program resulted in significantly improved haemoglobin levels and iron stores, none of the children was anaemic at the outset; the program was subsequently limited to one province. Two other constraints were cost and supplies. The program cost US$0.54 per child per six month school year, and 16 tons of dried haemoglobin or 125,000 l whole blood were required each month to maintain the program.

Wheat flour noodles are currently under consideration for iron and other micronutrient fortification in Indonesia. The main constraint is the lack of expertise in this technical area (Karyadi, 1990)

Maize meal can be readily fortified with iron without any technical problems (Cook and Reusser, 1983). Dry milled maize meal fortified with reduced iron (88 mg/kg maize meal) was stable after 56 days of accelerated storage. To date, maize meal has not been considered as a food vehicle in developing countries because a considerable amount of the maize consumed is processed at the home. However, given the increasing numbers of urban migrants dependent on processed food, it may be appropriate to consider maize meal as a primary vehicle for iron in countries where maize is a staple food.

Fortification with iodine

Salt

There are a number of ways in which salt can be iodized. Methods include dry mixing (premix of iodate with anticaking agent made in a ratio of 1:9; adding a premix to powdered salt in a ratio of 1:10 through drip feeding (for salt crystals); spray mixing (for coarse salt powder); and submersion followed by drying. The method selected for use depends on the location and type of salt. Where the salt is impure, the humidity high, and the packing materials not moisture-resistant, the spray mixing method is best. A batch-type system has been developed for small manufacturers in India that do not have a continuous spray mixing plant (Venkatesh Mannar, 1987; Venkatesh Mannar, 1988; Dunn and van der Haar, 1990).

- **Fortificant:** Potassium iodide, potassium iodate, or calcium iodate.
- **Potency and dilution:** Level of iodination is fixed by individual countries and varies by such factors as the level of salt consumption (usually between 5 and 10 gm per person per day) and

climate. In Africa, salt consumption is often relatively low (about 5 mg per person per day) while iodine losses are high; thus, it has been recommended that iodine be added at a level of 100 mg potassium iodate/kg salt; 168.6 mg potassium iodate provides 100 mg iodine.

- **Stability:** Potassium iodide is unstable in impure salt even though it is less costly than other fortificants and is needed in smaller quantities. Potassium iodate is more stable so the need for stabilizing and drying agents is lower.

- **Field trial results:** Significant reduction in goiter and cretinism.

- **Technical and distribution problems:** Packing is critical. Iodized salt stored in jute bags loses 75 percent of its potency because of moisture absorption and leaching. Fortified salt should be packed in moisture-resistant bags.

- **Constraints:** Logistics and transport of iodized salt to remote areas.

- **Cost:** The cost of fortified salt depends on the method of fortification. The drip feeding submersion processes are less expensive than either the spray drying or dry mixing of iodate with salt because of lower capital and operating costs. For an iodine level on the order of 40 ppm, the cost is about US$12.00 per ton. The general cost guide is US$0.07 per person per year. The retail price of salt for the domestic market is usually US$0.25 to US$1.00 per kg, although the cost of iodination may increase the retail price of salt by 2 to 20 percent.

Other foods

Brick tea is fortified with iodine in Tibet and West China. Trials to fortify sweets with iodine have been carried out in the Middle East. Milk was inadvertently fortified with iodine when an iodide compound was used to eliminate foot rot in cattle (Dunn, personal communication). Sugar has apparently been successfully fortified with iodine in Sudan, and there is interest in implementing a fortification program, despite the fact that there are no data on sugar consumption. Even though Sudan rations and controls its sugar distribution, a huge black market for sugar flourishes, leading to both a sugar shortage in western Sudan where iodine deficiency disorder (IDD) is endemic and a sugar over-supply in Khartoum and neighboring provinces where IDD is not a problem.

Fortification with vitamin-mineral premix

Wheat flour

By definition, flour with a low extraction rate already has a low micronutrient content because milling removes the nutrients near the surface of the wheat grain. Milling also removes some of the fiber and phytates that inhibit iron absorption. For these reasons, white flour is a suitable food vehicle for fortification (Arroyave, 1992). Fortification of flour with niacin, thiamine (B1), riboflavin (B2), and iron is carried out in many developed countries. Trials on wheat flour fortified with the above micronutrient multimix in addition to vitamin A, pyridoxine (B6), folate, calcium, magnesium, and zinc have shown that organoleptic properties of bread are maintained (Cort *et al.*, 1976; Rubin *et al.*, 1977).

- **Fortificant**: Multivitamin-iron premix contains dry vitamin A palmitate Type 250 SD (22.7 percent), thiamine (2.5 percent), riboflavin (1.4 percent), niacin (17.8 percent), pyridoxine (1.8 percent), folate (0.3 percent), reduced iron (29.6 percent), vitamin E (22.3 percent), and starch (1.7 percent). Mineral premix contains calcium (78.7 percent), magnesium (11.6 percent), zinc (0.4 percent), and starch (9.3 percent).

- **Potency**: Vitamin-iron premix 51,500 IU vitamin A/g, 20.45 mg thiamine/g, 12.7 mg riboflavin/g, 169 mg niacin/g, 14.1 mg free base pyridoxine/g, 2.1 mg folate/g, 282 mg iron/g, and 106 IU vitamin E/g. Mineral premix 300 mg calcium/g, 67 mg magnesium/g, and 3 mg zinc/g.

- **Dilution**: 31 g vitamin-iron premix and 660 g mineral premix per 100 kg flour provides 15,965 IU vitamin and 87 mg iron per kg of flour.

- **Stability**: Excellent stability of vitamin A (100 percent), pyridoxine (99 percent), folate (96 percent), vitamin E (95 percent), thiamine (95 per-

cent), and riboflavin (98 percent) in vitamin-iron premix after six months at room temperature.

Excellent stability of vitamins (all over 95 percent) in the fortified flour after six months at room temperature even when minerals were included. Organoleptic properties of fortified flour were the same as for unfortified flour.

Fortified bread retained its thiamine, riboflavin, pyridoxine, and niacin activity. However, bread made with fortified flour, which included magnesium and calcium, showed lower vitamin A activity and, to a lesser extent, reduced folate activity. (Fortification trials in Jordan showed that vitamin A activity in wheat flour declined insignificantly during storage. Destruction of vitamin A was also negligible (about 2 percent) during the baking of Arabic bread. Bread baking trials conducted in India were also successful. The flour was fortified with a premix containing iron, vitamin B1, vitamin B2, and vitamin A (8000 IU/kg flour)).

- **Results of field trials**: Not undertaken.
- **Technical and distribution problems**: After one week of storage, bread made with both the vitamin-iron and mineral premixes developed an off-flavor that was attributed to magnesium. This was not the case with freshly baked bread. In addition, bread made with both premixes was darker, had a poorer texture, and required greater proving time, indicating further problems with the use of magnesium (and calcium) in fortification.
- **Constraints**: Not stated.
- **Cost**: Not stated.

Corn meal

Yellow corn meal has been fortified with a vitamin-iron and mineral premix (Cort *et al.*, 1976).

- **Fortificant:** Multivitamin-iron premix containing dry vitamin A palmitate Type 250 SD (22.7 percent), thiamine (2.5 percent), riboflavin (1.4 percent), niacin (17.8 percent), pyridoxine (1.8 percent), folate (0.3 percent), reduced iron (29.6 percent), vitamin E (22.3 percent), and starch (1.7 percent). Mineral premix contains calcium (78.7 percent), magnesium (11.6 percent), zinc (0.4 percent), and starch (9.3 percent).
- **Potency**: Vitamin-iron premix 51,500 IU vitamin A/g, 20.45 mg thiamine/g, 12.7 mg riboflavin/g, 169 mg niacin/g, 14.1 mg free base pyridoxine/g, 2.1 mg folate/g, 282 mg iron/g, and 106 IU vitamin E/g. Mineral premix 300 mg calcium/g, 67 mg magnesium/g, and 3 mg zinc/g.
- **Dilution**: 31 g vitamin-iron premix and 660 g mineral premix per 100 kg flour provide 15,965 IU vitamin and 87 mg iron per kg of flour.
- **Stability**: Good stability of thiamine (100 percent), pyridoxine (100 percent), vitamin E (100 percent), folate (97 percent), and vitamin A (90 percent) after six months at room temperature. After 12 weeks at 45°C (equivalent to two and one-half years at room temperature), vitamin A potency fell to 67 percent, while pyridoxine, folate, and vitamin E retained over 95 percent of their potency.
- **Results of field trials**: Not undertaken.
- **Technical and distribution problems**: Not stated.
- **Constraints**: Not stated.
- **Cost**: Not stated.

IV. QUALITY ASSURANCE AND CONTROL

Quality assurance and control ensures that the manufactured food is safe, unadulterated, properly labeled, and meets all company as well as local and national government regulations. An effective quality assurance system should include the following:

- testing all ingredients against reference standards, i.e., ingredient inspection and control.
- identifying quality criteria and chemical, microbiological, and physical hazards, i.e., manufacturing control. Establishing and monitoring the critical control points involved in manufacturing fortified food and documenting any action taken to alter the manufacturing process.
- establishing good distribution control to ensure that the fortified food is unadulterated, properly labeled, and packaged to minimize micronutrient losses.

The implementation of a quality assurance program involves eight steps (Wilson, 1988), as follows:

- deciding on the specifications for both the fortificant and food vehicle in terms of particle size, color, potency, and acceptable ranges of fortificant, and target food vehicle fortification levels.
- routinely undertaking safety analyses of fortified foods for chemical, microbiological, and physical contaminants.
- imposing quality controls on the fortificant, the food vehicle, and the fortified food to ensure that all specifications are met. Quality control activities include random sampling and testing of the fortificants, the food vehicle, and the fortified food for potency, particle size, color, packaging integrity, net weight, adulteration, and storage conditions, including temperature, light, moisture, and oxygen.
- identifying and regulating the critical control points that might adversely affect fortified food, (i.e., quality control of the physical environment), by controlling for damage from shipping/transport, industrial processing, storage (thus requiring inventory control), retailing (thus requiring stock rotation), and the consumer (thus requiring periodic sampling to verify potency).
- putting in place a recall strategy and system so that in the event of a recall, a manufacturer can trace or identify the product (and thus the ingredients) by its code.
- periodically auditing the system to ensure that manufacturers adhere to the above stages, and that fortified foods continue to meet manufacturing specifications as they advance through the food marketing chain.
- enabling the manufacturer to respond to consumer and customer complaints and to correct any safety or regulatory deficiencies discovered as a result of any complaints.
- documenting all aspects of the quality assurance system and making the documentation available to those responsible for the fortified food.

Theoretically, all food manufacturers have a quality assurance system in place. Fortification requires modifying this process, which, with the possible exception of the micronutrient assays, should not incur major costs or disruption to on-going procedures. Vitamin A assays generally require HPLC which is both complex to use and expensive. Iron assays are relatively simple to perform because iron is highly reactive. The difficulty with iron assays is not so much knowing how much iron is in the fortified food, but how much of the iron is biologically available, especially if the food is con-

taminated with nonfortificant iron. A salt-iodine laboratory is estimated to cost between US$2,000 and US$3,000 (Bailey, 1992). Simple field techniques, however, can be developed. For example, the INCAP Guatemala sugar fortification program developed a rapid, semiquantitative colorimetric test for determining the vitamin A content of fortified sugar (Arroyave *et al.*, 1979). Iron assay field tests also exist. Spot testing of salt for iodine content is possible with simple starch-iodine field tests that cost US$2.00 per kit (Bailey, 1992).

The development, refinement, and implementation of a sound quality assurance system is instrumental to developing an effective, practical, and economical fortification program. This not only will guarantee that food vehicles are properly fortified, but that they are delivered to consumers at the required levels of potency and quality. Unless manufacturing executives and government agencies involved in food regulation commit themselves to quality assurance, it is unlikely that the objectives of food fortification will be met. Indeed, a recent evaluation of the Guatemalan sugar fortification program found that, while the quality control for the premix was adequate, the quality control for determining the efficacy of the fortification process was very weak. Only one sample of sugar for every 6,000 bags (100 lbs each) of sugar was analyzed for vitamin A content. Over 90 percent of the samples contained vitamin A, but only 30 percent were fortified within the legal limit because proper homogenization of the vitamin A premix was not achieved (McKigney *et al.*, 1992). The absence of an effective quality control system to regulate the production of fortified sugar resulted in continued underfortification four years after the program was restarted.

V. MONITORING AND EVALUATION

The goal of food fortification is to *increase the intake of a micronutrient(s)*, thereby *improving the micronutrient(s) status* of a population and preventing irreversible functional damage. The purpose of an evaluation is to monitor the progress of a program to ensure that the prestated objectives are met. Progress toward objectives cannot be measured unless program goals are clearly stated, and the necessary baseline biochemical, clinical and dietary data are collected and made available. IVACG (1988) has suggested that the goal of vitamin A food fortification programs should be to reduce:

- the proportion of the population with *intakes* below the critical level (i.e., one-half the safe RDI level) to less than 10 percent;
- the prevalence of *serum retinol levels* under 20 µg/100 ml and under 10 µg/100 ml to less than 15 percent and 5 percent respectively; and,
- the prevalence of *clinical eyesigns* to the extent that Bitot's spots with conjunctival xerosis do not exceed 2 percent, corneal xerosis/ulceration and/or keratomalacia are less than 0.01 percent, and corneal scarring is less than 0.1 percent.

INACG (1977) suggests that intervention goals may be expressed as a proportion of the population with haemoglobin concentrations below a certain level or as an accepted frequency distribution of haemoglobin concentrations within physiologic groups. Each country must set its own minimum standards because not all anaemias are the result of iron deficiency. For example, folate deficiency, vitamin B12 deficiencies, helminths, and parasites also cause anaemia.

ICCIDD (Pandav *et al.*, 1987) state that the goal of iodine fortification should be to reduce:

- the prevalence of *goiter* to less than 10 percent; and,
- the incidence of *neonatal hypothyroidism* to less than 0.05 percent by a defined time period, by introducing programs that will ensure the availability of a minimum of 150 µg of iodine per person per day.

Because the monitoring and evaluation process tracks the extent to which goals are being met, periodic biochemical, clinical, and dietary intake assays need to be undertaken and compared with the specific intermediate targets as set out by the program designers. There may be, however, other external factors that influence micronutrient status, e.g., an overall improvement in social and economic conditions, that could result in an overall improvement in dietary intake. It is important that externalities are included in monitoring and evaluation efforts because they may confound the interpretation of a cause-effect relationship between reducing micronutrient deficiencies and food fortification. As part of the monitoring and evaluation process, the critical control points in the fortification process need to be reviewed to ensure that, among other things, the fortified food contains sufficient micronutrients to increase intake levels and improve biological status; is an effective means of increasing intake; flows effectively through the proper marketing and distribution channels; and benefits those most in need. Any ineffective or malfunctioning component needs to be identified and corrected.

Few fortification programs implemented to date have undergone extensive monitoring and evaluation. Exceptions include the Guatemalan sugar fortification program (Arroyave *et al.*, 1979; McKigney *et al.*, 1992), the Philippine MSG program (Popkin *et al.*, 1980), and iron programs in Kenya, Mexico and Indonesia (Levin, 1986). Venkatesh Mannar (1988) pointed out that most IDD programs suffer from serious shortcomings in their efforts to evaluate their progress and impact. The main difficulties include poor definition of methods for IDD control and surveillance, defective sampling in prevalence surveys, unspecified frequency for repeated evaluations, different classification systems for goiter, inadequate manpower

and training, and insufficient resources for carrying out control and evaluation activities. Furthermore, many programs lack laboratory facilities and funds for checking the iodine levels in salt and evaluating the resultant impact on a population's health status. Similar shortcomings could no doubt be found in other fortification programs.

In sum, it would appear that the failure to monitor and evaluate micronutrient interventions may be an important reason that donors and developing country governments are so cautious about supporting food fortification. In other words, there is insufficient evidence to convince them that micronutrient fortification is viable.

VI. ECONOMIC ASPECTS AND SUSTAINABILITY

Economic aspects

The economic impact of any intervention can be assessed by performing cost-effectiveness and/or cost-benefit analyses.[5]

Costs

The costs incurred in food fortification include the fortificant(s); transport of fortificant(s); equipment (feeders, sprayers, dryers); equipment maintenance; production labor; quality assurance, including assays; any special packaging of the fortified product; monitoring and evaluation; and enforcement and legislation. Because the cost is only the additional cost of fortifying the food vehicle, the value of the food vehicle is not included. In general, the operational and control costs are small compared with the recurrent costs of the micronutrient(s) (Arroyave *et al.*, 1979; Crowley, 1990). The cost of a fortification program can be presented as either the total cost per year or the cost per kg of fortified food per year. Both recurrent and outlay costs after amortization should be used.

Among the micronutrients, vitamin A, in particular, is expensive. Liquid vitamin A palmitate (1,000,000 IU vitamin A/g) and dry vitamin A palmitate (510,000 IU vitamin A/g) currently cost US$46.00 and US$47.00 per kg, respectively (Gmunder, personal communication). Using a RDI of 850 µg vitamin A per person, this is equivalent to US$41,000 per one million people. In the Guatemala vitamin A fortification program, retinol palmitate accounted for 89 percent of the total cost (Arroyave *et al.*, 1979). Crowley *et al.* (1989) estimated that vitamin A alone would account for 85 percent of the cost of fortified wheat flour in Sri Lanka. While the cost of vitamin A, compared with the cost of other nutrients as well as other program components, may be considered expensive, the overall cost of vitamin A fortification can be relatively inexpensive, especially when compared with the costs of vitamin A deficiency, and the cost of other interventions.

The cost of iron fortificants varies depending on the source of the iron, the percent of iron in the fortificant, its bioavailability, and its functionality (color and stability). See Table 6. Using a RDI of 12 mg per person, the cost ranges from US$50.00 to US$460.00 per one million people. Fortifying salt with iron in India added about 20 percent to the cost of the salt, while fortifying sugar with iron in Guatemala added only 1 to 2 percent to the cost of sugar (Working Group on Fortification of Salt with Iron, Cook and Reusser in Levin, 1986). More recently, it was noted at the XII INACG (1990) meeting that the costs of iron fortificants are significant and increasing rapidly. However, no data were presented as to how much iron fortificants contribute to overall fortification costs.

The potassium iodide and potassium iodate used in iodine fortification cost US$30.00/kg (Dunn and van der Haar, 1990; Lund, 1991). At the recommended fortification level (150 µg iodine), raw ingredients cost a total of US$8.00 per one million people. To provide 15 to 40 ppm iodine, the additional cost (1988 prices) would be US$0.75 to US$2.00 per ton of salt. The average cost of iodizing a ton of salt is US$7.50 (range US$3.95 to US$12.50); with packing US$11.50 (range US$7.95 to US$16.50). This is equivalent to US$0.004 to US$0.016 per kg or to US$0.02 to

5 *Cost* refers to all the resources required to deliver the micronutrients to the target population. *Cost-effectiveness* refers to the efficiency of the delivery system in eliminating the deficiency among those with deficits, and/or alleviating any adverse consequences (increased morbidity, blindness, high worker absence, low worker productivity, etc.) associated with the deficit over a given period of time. *Cost-benefit* analysis is a method of ascertaining whether the intervention is both feasible and the best option given available resources (Levin *et al.*, 1991).

US$0.06 per person per year, which represents 2 to 20 percent the retail price of salt.

Cost-effectiveness

Cost-effectiveness may be measured in terms of the delivery system or biological cost-effectiveness (Arroyave *et al.*, 1979; IVACG, 1984; Levin *et al.*, 1991). The **delivery system cost-effectiveness** includes:

(1) the cost per person per year; and,

(2) the cost per unit of nutrient utilized.

Biological cost-effectiveness includes:

(3) the cost per protected person per year where protection is defined as a reduction in the number of the targeted population who fall below the critical level, whether measured in terms of intake, serum levels or clinical signs of deficiency;

(4) the discounted healthy life year gained;

(5) the cost per life saved; and,

(6) the cost per unit of economic productivity gained.

Levin *et al.* (1991) indicate that adjustments for leakage are necessary in (1) and (2). This is because not all participants are at risk of deficiency; therefore, the cost per at-risk person is greater than the cost per recipient. For example, if only one-third of the population is at risk of micronutrient deficiency, then the cost for each at-risk person is three times the cost per person. Levin *et al.* also point out that, if leakage is high, targeting will not necessarily make a program more cost-effective, if the costs of activities needed to achieve targeting are high.

In order to measure (4), (5), and (6), the prevalence rates for the deficiencies are needed as well as the age distribution of the population; the demographics of economically active populations; the excess mortality due to micronutrient deficiencies; the disabilities due to micronutrient deficiencies (partial and total blindness, anaemia, cretinism, goiter); the coverage and effectiveness of the program; the discount rate; the life expectancy; and the cost per capita. The annual wage rate is needed to calculate (6). The expense of obtaining the data needed and other demands on the scarce expertise available to conduct these analyses make this type of cost-effective analysis unpractical for many developing countries. Although not usually expected to be a problem, consumer compliance can be a problem with fortified food and must be taken into account when determining the effectiveness of a program. Levin *et al.* (1991) point out that when a commodity is available in the market, as both a fortified and unfortified food, consumer compliance may become a problem. Ecuador, for example, had to mount a social marketing campaign to promote the use of iodized salt because of the availability of local unfortified salt. In addition, storage losses or losses due to environmental degradation will adversely affect the potency of the fortified food and thus the effectiveness of a fortification program. Table 7 shows Levin *et al.*'s calculations for the returns on fortification of iron, iodine, and vitamin A compared to supplementation. The table shows that fortification is cost-effective in all cases.

Cost-benefit

Cost-benefit analysis looks at a program's private and social costs and benefits. The private

TABLE 6
Costs of Iron Sources Used in Fortification

	Fe %	1990 cost $/kg	Cost $/kg Fe	Bioavailbility	Color	Stability
Hydrogen reduced iron	98	1.94	2.00	Fair-	Black	Good
Electrolytic iron	98	4.71	4.8	Fair+	Black	Good
Ferrous sulphate	32	2.35	7.3	Good	Tan	Fair
Ferric orthophosphate	28	2.73	9.8	Poor	White	Excel.
Ferrous fumarate	33	2.94	8.9	Good	Red	Fair?
Iron EDTA	13	2.4	18.5	Excel.	Off-white	Good?

Source: INACG (1990).

cost is primarily the increase (if any) in the price of the fortified food. The social costs include any food price increase resulting from the program, as well as the program's operating and maintenance costs. Clearly, the economies of scale *vis a vis* equipment costs, the discounted rate of return time frame, fluctuations in the foreign exchange (which determine fortificant costs), fluctuations in the price of the food vehicle, and inflation also have to be taken into account.

The private benefit from food fortification comes from the additional income earned over a lifetime as a result of completely eliminating the deficiency(s), which, in turn, reduces an individual's risk of dying; greater morbidity; lower productivity; lower educational attainment; reproductive disorders; and physical growth retardation. The social benefits are the savings in public health care; reduced absenteeism; increased worker productivity; tax revenue gains that would accrue from the increased income earned over an individual's lifetime; improved school performance; and reduced expenditures on special services for the disadvantaged (Popkin *et al.*, 1980; Levin *et al.*, 1991).

Because of the dearth of data in developing countries, it is particularly difficult to measure and quantify the benefits of food fortification. Nevertheless, Levin (1986) has shown that the benefits of iron fortification, even under a conservative set of conditions (haemoglobin change of 5 percent and a work output elasticity of 1), varied from 5 times the cost in Indonesia to 30 and 49 times the cost in Kenya and Mexico, respectively. Popkin *et al.*, (1980) found that the benefits of vitamin A fortification in the Philippines ranges from six to 21 times the cost. Tilden and Gross (1988), however, suggest that over a 20-year time frame fortification may be the least cost-effective (i.e. most expensive) vitamin A intervention, while dietary modification may be the most cost-effective (i.e. least expensive) with supplementation falling in between. An important reason for using such estimates with caution is differences due to country-specific conditions.

It is universally true, however, that increasing the intake of a micronutrient(s) results in tissue repletion and reduces the risk of specific tissue malfunctions and/or damage caused by the micronutrient(s) deficiency. Furthermore, fortification is as cost-effective or more cost-effective than other interventions in the near term. It also improves the general health of individuals, although it is difficult to isolate the beneficial effects of a particular program on improved health given the complex multiple causes of poor health in developing countries.

Sustainability

The cost of a food fortification program can be borne by a government or passed on to the consumer

TABLE 7
Returns on Nutrition Investments

	Cost/life saved (US$)	Discounted value ($) of productivity gained per program $	Cost per discounted healthy life year gained ($)
IRON			
Supplement pregnant women	800	24.7	12.8
Fortification	2000	84.1	4.4
IODINE			
Supplement women of child bearing age only	1250	13.8	18.9
Supplement all under 60 yrs	4650	[illegible]	37.0
Fortification	1000	28	7.5
VITAMIN A			
Supplement under 5 yrs only	50	146.0	1.4
Fortification	154	47.5	4.2

Source: Levin *et al.*, (1991).

by increasing the price of the fortified food. It is important, however, to know how consumers are likely to respond to a price increase. The price elasticity of the food vehicle, i.e., the percent increase/decrease in consumption for each percent increase in the price of the food vehicle, and cross-elasticities of inter-changeable foods, i.e., the percent increase/decrease in consumption of one food when the price of an inter-changeable food rises, are important to understanding consumer behavior.

Invariably, the economic groups most vulnerable to micronutrient deficiencies are those least able to afford food price increases. Thus, consideration needs to be given as to how to better share the cost of food fortification. Targeting fortified food to the most nutritionally deprived groups, while spreading costs across society, would not only appear more "socially acceptable" but also more feasible than either increasing fortified food prices or instituting untargeted fortification. This has been considered for MSG in Indonesia (Muhilal et al., 1988a; 1988b). Crowley (1990) suggested that one option for Sri Lanka was to fortify only the wheat flour distributed to the tea estates where nutritional deficiencies are more widespread than elsewhere. The estimated cost of $61,200 per year was less than 8 percent of the generalized fortification program.

In order to keep costs down, improve targeting, and enhance the feasibility of fortification programs, more attention should be given to fortifying foods that selectively reach low income or high risk groups. This includes food distributed through ration shops, work programs, school feeding programs, and MCH clinics. INCAP, for example, has developed a fortified biscuit for school children in Guatemala. The biscuits are made in about 100 bakeries throughout the country by using flour provided by WFP and sugar purchased by the community. Together, the biscuits and a beverage supply 330 Kcal and 11 g protein and a significant proportion of RDIs of micronutrients per day during the 180-day school year.

An important aspect of food fortification is the source of the food vehicle, particularly if that source is food aid programs. Many of the PL 480 Title II commodities provided by the U.S. Agency for International Development are fortified with thiamine, riboflavin, niacin, iron, vitamin C, and vitamin A at a level of 2,000 IU/100 g. However, not all donors provide fortified food even though the food must be fortified in their own country (as was evident with the food aid arriving in Sudan during 1986-90). Donors should ensure that donated food aid, which can be fortified with micronutrients, is fortified before shipment to developing countries.

Probably the most important factor determining the sustainability of a food fortification intervention is that of foreign exchange. If governments perceive that an alternative to food fortification exists that does not incur foreign exchange, they are more likely to show interest in the alternative. Such is the case with supplements, which are generally not purchased. Many countries are currently dependent on UNICEF to provide high dose vitamin A capsules for children and iron supplements for women. The decision to use supplements is made jointly by each UNICEF office and the host-country ministry of health. Vitamin A capsules (200,000 IU vitamin A), for example, are procured commercially from Western European pharmaceutical companies at a cost of US$0.02 each (plus 10 to 15 percent for sea freight) and are financed from each country's UNICEF health budget. One argument often put forward for the use of high dose vitamin A supplements is that they are inexpensive. Too often, however, it is assumed that the health care delivery system does not incur any additional costs in issuing vitamin A capsules because vitamin A is no different from any other pharmaceutical, and thus, the costs associated with it are borne by existing programs. This assumption is questionable given the costs of training health care personnel about vitamin A deficiency; setting up and monitoring both prevention and treatment programs; and monitoring capsule storage, especially where proper storage facilities do not exist. Indeed, Keusch and Scrimshaw (1986) state that a high-dose vitamin A distribution program may cost between US$1.64 and US$2.20 per individual. Such programs also assume that the health care delivery system works both efficiently and effectively and provides as large a coverage as fortification.

West and Sommer (1987) calculate that universal vitamin A capsule distribution has to achieve at least 65 percent coverage before it has a favorable impact on vitamin A deficiency among pre-school children. The evidence to date suggests that this target, with few exceptions, has not been met (Cohen, 1987; Muhilal, 1988a; West and Sommer 1987). Gillespie *et al.* (1991) also note that iron supplements have failed to achieve high coverage or have a major impact on reducing levels of iron

deficiency anaemia. The current emphasis on the use of pharmaceuticals may act as a disincentive for governments to work toward mass *prevention* of micronutrient deficiencies. It also assumes that children under the age of five years and women are the only groups at high risk of vitamin A deficiency and anaemia, which may not be the case.

To ease the foreign exchange burden, governments need to consider the local or regional production of fortificants. In particular, the chemical, food and pharmaceutical industries should address the production of fortificants as outgrowths of (or using by-products from) other industries and investigate how to determine or create demand for fortificants. Alternative ways of subsidizing food fortification also have to be explored. Bailey (1992) doubts that permanent subsidies for salt iodination programs should be implemented, although he acknowledges that temporary help may be needed, particularly for importers of iodized salt who will face a price increase of 10 percent or more. Eventually, the cost could be recovered through price increases, however, in the interim, temporary support could come from donor institutions such as the World Bank. The same argument could be made for the importation of fortificants.

In countries where foods are fortified locally by a number of companies, it may be necessary to provide tax incentives in the early stages of the program to cover the additional costs of fortification. Ultimately the consumer will have to pay, but payment schemes might take different forms. For example, manufacturers could reduce the amount of the fortified food in a packet but maintain the price (as was considered for MSG in the Philippines), or program managers could target fortified foods and increase the price of the food vehicle irrespective of whether it is fortified, thereby maintaining price parity (as is considered for MSG in Indonesia). In fact, the production costs incurred from fortification result in only a small increase in the price of the fortified food. Indeed, the price increases are insignificant compared with inflation.

Governments are often concerned about fortifying a single imported food commodity lest it lead to dependence on both the commodity and the micronutrient(s). While this concern may be justifiable, it underlines the importance of considering multicommodity fortification.

VII. POLITICAL AND LEGAL DIMENSIONS

Without strong lobbying, governments are unlikely to adopt food fortification. The awareness of implications for development and the political will to initiate food fortification efforts do not, by and large, exist. Indeed, there may be misperceptions that the needed technology either does not exist or is too complex or expensive. Furthermore, governments often point to the need for legislation to ensure compliance, and that the social concerns of the food industry may be tapped. None of these claims may be true. The fact that a large number of foods in developed countries are fortified and have been fortified for a long time is testimony to well-developed technologies. Relatively minor modifications may be needed to fortify foods in developing countries. The technology needed in food fortification is not complex because essentially only measuring devices, feeders and mixers are required to add the fortificant during processing. Cereal feeders, for example, are estimated to cost between US$1500-5000 per cereal plant (Mora, 1992).

It is generally assumed that food fortification compliance will only take place if governments enact legislation. Regulation or legislation, however, was not sufficient to ensure fortification of sugar with vitamin A in Panama or rice with B vitamins and iron in the Philippines. Indeed, it would appear that if policy makers were adequately informed, food fortification could be implemented without legislation. Some form of regulation may play an important role, however. Control is needed to ensure that imported unfortified food (e.g., non-iodinated salt) does not leak into and displace fortified food. Bailey (1992) suggests that a regulation which does not have to go to parliament or the head of state for signature is preferable to legislation. The regulation needs to be based on an existing law such as a public health or food and drug law, which does not exist in many countries, certainly in the African context. Some countries have followed other strategies. For example, the Rwanda Ministry of Commerce issued an administrative instruction to the Bank of Rwanda directing the bank to give foreign exchange only for salt that conforms to stated specifications.

Legislation that mandates fortification works only when a formal system of laws, fines, and procedures for dealing with defaulters is in place. In other words, legislation must be supported by an inspection force with effective backup, including legal and judicial pursuit. The inspection force needs clearly defined procedures for sampling fortified food as well as well-established standards and quick semiquantitative analytical methods for assaying the micronutrient content of fortified food. The location of the inspection force depends on the country. For example, in Morocco, the inspection force comes under the Fraud Prevention Group of the Department of Agriculture; in Guatemala, it comes under the Ministry of Health. Other countries may use the Ministry of Commerce or the Ministry of Industry. Clearly, when fortified food is imported, the import/export control group must be involved in setting the standards for the importation of the fortified food.

It may be that food industry ethics are more important than legislation in motivating food fortification. To implement a fortification program, the food sector needs to be motivated to comply and penalties must be enforced for non compliance. In countries where food adulteration is common and consumers accept tampering as the norm, it may be difficult to enforce legislation. Consumer unions, however, whose mandate is to ensure that the public receives good-quality food, can play an important role in ensuring that the food sector complies with food legislation. The reason is that the food industry, like any other industry, responds to factors which affect its market share. Among the most notable factors is corporate image, which is determined by advertising and public relations. In many developing countries, consumer unions are either weak or do not exist; the result is little public will to enforce legislation. Even where consumer unions do exist, it will be necessary to inform them of the importance

of food fortification and thereby gain their active support in both informing consumers about the importance of food fortification and lobbying the government and food industry to fortify food. Whatever the scenario, unless there is the political will to prevent and control micronutrient deficiencies through food fortification, a discussion of the roles of legislation and food industry ethics is academic.

VIII. FUTURE DIRECTIONS

Several documents consulted for this report alluded to the fact that micronutrient deficiencies are not perceived as major health problems by many policy makers and health officials (no doubt because micronutrient deficiencies are not overtly disabling until they reach an advanced stage). The challenge, therefore, is to secure top-level commitment from donors, national governments, and the food industries to initiate and sustain actions that directly address micronutrient deficiencies. Multiprevention programs would appear to be more appealing than piecemeal approaches from both a nutritional and economic perspective. The synergism between vitamin A and iron metabolism is a good example. The following are some of the issues related to food fortification that need to be considered.

- Foods that are widely consumed, even by children, with little day to day variation in intake, and that pass through a central processing point, need to be identified in countries where micronutrient deficiencies are recognized problems. *Simple but informative dietary surveys are needed to identify foods that could be viable food vehicles.* This includes condiments and snack foods. The objective is to determine the optimum level of fortification that does not produce any toxic effects.

- More attention should be given to multiprevalence deficiencies in nutrition surveys. This would be facilitated if there were more *simple field methods for screening micronutrient deficiencies*, and that are suitable for use by semi-skilled personnel.

- Continued support for the *use of micronutrient multimixes*, particularly those that incorporate both iron and vitamin A, is essential.

- Food fortificants represent a major cost in fortification. Indeed, it is highly probable that governments would find it politically more expedient to use the limited foreign exchange allocated to food imports on food alone, rather than on fortificants and food. For this reason, it would be useful to *explore the possibilities of fortificant production, particularly iron, iodine, and preparation of multimixes, at a national or regional level.*

- The evidence to date suggests that operational and political issues rather than technical matters have been the major obstacles to implementing national food fortification programs. Clearly, governments that generally do not have funds available to pay for recurring costs need to be convinced that the cost of not fortifying food far exceeds the cost of fortifying food. *More detailed studies of the economics of food fortification and other ongoing micronutrient intervention strategies* are needed. Incentives for the food industry that minimize price differentials between fortified and unfortified foods need to be explored. Incentives include interest-free loans for purchasing fortification equipment, a free supply of fortificants, subsidizing the cost of the fortificant, subsidizing the cost of transporting subsidized food, and so on.

- Commercial companies are often sensitive to activities that could jeopardize the market for their product (as happened with tea in Bangladesh). To better convince companies that their fortified product will be accepted, *data on consumer behavior in terms of acceptable organoleptic properties and price levels are needed in countries where field trials have been promising.* This information will indicate if social marketing is necessary or helpful in implementing fortification programs.

- Vitamin A assays require sophisticated laboratory equipment (HPLC) that many developing countries do not have. *A simple quantitative test to determine the vitamin A content in fortified food is needed.* The availability of such a test would reduce the costs of the fortification program. Tests would be conducted by less skilled personnel in facilities that

come under the purview of the quality assurance system.

- There is a need for a *comprehensive and detailed review of the status of micronutrient fortification programs currently underway in developing countries.*

- There is a need for a *comprehensive review of countries that have enacted food enrichment and/or fortification legislation.* Mora (1992) has obtained this information for Latin America from Hoffman-La Roche (Appendix 6).

- The *potential role of the Food Quality Standards Service of the FAO (Codex Alimentarius) should be explored as a means of encouraging and advocating food fortification.*

- PL 480 programs reach a large and important target group in many countries. The choice of vehicles for vitamin A fortification among PL 480 Title II commodities should be re-examined, and recommendations on raising iron levels should be implemented as soon as possible. The *potential impact and public sector costs of fortifying PL 480 Title III food aid should be investigated.*

- *Field trials for fortified foods that have proven to be viable in a controlled environment should be considered* in countries where consumption levels of the food vehicle are known (e.g., tea).

- *Information modules on food fortification for donors, government officials, and the food industry should be developed.*

- Food fortification does not have to depend on high technology. Locally available sources of vitamin A can be used to fortify meals. It may be possible to maximize seasonal excesses of vitamin A by sun-drying vitamin A-rich fruits and vegetables for use as condiments or food flavorants. Proper *ethnographic studies on the uses and cooking practices associated with potential fortificants are needed as are studies on the micronutrient bioavailability of locally processed foods under different storage conditions.*

- All *clinical and dietary vitamin A surveys should be expanded to include other micronutrients.* Ethnographic data on other relevant food-related issues should be collected as part of these surveys (although such information may be compiled by relying on focus groups or other less formal survey techniques).

APPENDIX 1

Vitamin A Used in Food Fortification

Type and name	Potency (in millions of IU/g)	Other ingredients	Usage
LIQUID PRODUCTS			
1. Vitamin A palmitate	1.65-1.8	Edible antioxidant; no oil dilutent	Where maximum concentration is required; with stabilizers
2. Vitamin A palmitate	1.65-1.8	No antioxidants; no oil dilutent	Where maximum concentration is required; no stabilizers
3. Vitamin A palmitate Type PIMO/BH	1.0	Edible oil; edible antioxidants	Recommended for general use; with stabilizers
4. Vitamin A acetate or vitamin A palmitate	1.0	Edible oil dilutent; no antioxidant	For specific uses
5. Vitamin A palmitate emulsion	0.5	Emulsifiers; anti-oxidants; preservative	Fortification of cereals, milk products; potato flakes & food products that require specific processing techniques
DRY PRODUCTS			
1. Vitamin A palmitate beadlets, Type 500	0.5	Gelatin; carbohydrate; tricalcium phosphate; antioxidant; preservatives	For products not dispersed in cold water where high resistance to moisture and heat required, e.g. extruded foods
2. Vitamin A palmitate beadlets, Type 250-CWS	0.25	Gum acacia; carbohydrates; modified food starch antioxidants	Water dispersable; for dry products to be reconstituted before use, e.g. sugar
3. Vitamin A palmitate beadlets, Type 250-S	0.25	Gelatin; dextrose; modified food starch; coconut oil; sorbitol; sodium citrate; antioxidants	Water dispersable; free flowing beadlets to help meet the stringent flavour needs of milk-base products and other beverages
4. Vitamin A palmitate beadlets, Type 250-T tochoperol; preservative	0.25	Acacia; carbohydrate; modified starch; alpha-	Water dispersable fine beadlet product for pre-mixes
5. Vitamin A palmitate Type 250-SD	0.25	Acacia; lactose; coconut oil; preservatives	For product use where very fine particle size is desired, i.e flour corn meal, vitamin pre-mixes, dry milk, sugar, beverage powders.

Source: Bauernfeind and Arroyave (1986).

Appendix 1, continued

Some Application Forms of Carotenoid Vitamin A Precursors

FORM	DESCRIPTION	USES	STOCK SOLUTION
30% β-Carotene liquid suspension	■ Micronized β-carotene suspension in food-grade vegetable oil: pourable at 75 F (24 C) and above: semisolid at 40-60 F (4-16 C): no added antioxidants: dissolves readily in warm oil	For coloring fat and oil products, margarine , process cheese, frozen and dried egg yolk, winter butter (continuous process), and other fat-base foods	1.5 gm of suspension to 450 ml of warm vegetable oil, with stirring to dissolve. 1 ml = 1 mg β-carotene
24% β-Carotene semi-solid suspension	■ Micronized β-carotene in hydrogenated vegetable oil: semisolid at 70-90 (21-32 C): pourable at 100 F (38 C) and above: no added antioxidants: dissolves readily in warm oil	For coloring fat and oil products, margarine, and other fat-base foods	2 gm of suspension to 480 ml of warm vegetable oil, with stirring to dissolve. 1 ml = 1 mg β-carotene
22% β-Carotene HS liquid suspension	■ Micronized β carotene suspension in food-grade vegetable oil: pourable at 75 F and above: semisolid at 40-60 F: stabilized with added antioxidants: dissolves readily in warm oil	For coloring popping oil, heat-stressed cooking oils, for fat-base foods where greater carotene stability is required	2 gm of suspension to 440 ml of warm vegetable oil, with stirring to dissolve. 1 ml = 1 mg β-carotene
3.6% β-Carotene liquid emulsion	■ β-Carotene in orange oil and brominated vegetable oil emulsified in a hydrolyzed protein base: pourable at 75 F: specific gravity, oil phase 1.053 ± 0.003 (12.5 to 13.6° Brix): stabilized with added antioxidants	Especially designed for coloring orange-flavored drinks and fruit juice blends: adjusted for specific gravity in clear glass or opaque containers	3 gm of emulsion to 108 ml of water, with stirring to disperse. 1 ml = 1 mg β-carotene
Dry β-Carotene beadlets 10%	■ Colloidal β-carotene in a gelatin-carbohydrate matrix: stabilized with added antioxidants: readily dispersible, with stirring in warm water, 130 F (54 C)	For coloring water-base foods and beverages for dry products to be reconstituted in warm water	1 gm of beadlets to 96 ml of warm water, with stirring to disperse. 1 ml = mg β-carotene
Dry β-Carotene beadlets 2.4%	■ β-Carotene in vegetable oil emulsified in a gelatin-carbohydrate matrix: stabilized with added antioxidants:readily dispersible in water (75 F)	For coloring juice drinks, dry beverage bases, beverages, and other water-base liquid or dry foods to be reconstituted in water	4 gm of beadlets to 100 ml of warm water, with stirring to disperse. 1 ml = 1 mg β-carotene
Dry β-Carotene powder 1% CWS	■ β-Carotene in dry powder form: in dextrin, acacia carbohydrate, ascorbate and tocopherol as antioxidants: readily dispersible in water	For coloring dairy products, baked goods, sauces, icings, puddings, etc.	10 gm of powder to 100 ml of warm water, with stirring to disperse. 1 ml = 1 mg β-carotene
β-Carotene blend with vitamin A (and D)	■ Micronized β-carotene suspension in vegetable oil with added dissolved vitamin A (and D)	For simultaneous coloring and vitamin A fortification of margarine, mellorine, etc.	
20% Apo-carotenal liquid suspension	■ Micronized apo-carotenal suspension in food-grade vegetable oil: pourable at 75 F: no added antioxidants: dissolves readily in warm oil: semisolid at 40-60 F	For coloring fat and oil products, salad dressing, processed cheese, and other fat-base foods	1 gm of suspension to 200 ml of warm vegetable oil, with stirring to dissolve. 1 ml = 1 mg apo-carotenal
Carotenal solution 2%	■ Apo-carotenal dissolved in a food-grade modified vegetable oil composition: 1.4% apo-carotenal plus 0.6% β-carotene	For coloring process cheese, salad dressings, and other fat-base products	5 gm of solution to 100 ml of vegetable oil, with stirring to dilute. 1 ml = 1 mg apo-carotenal
Carotenal solution #73	■ Apo-carotenal and β-carotene dissolved in a food-grade modified vegetable oil composition: stabilized with added antioxidant	For coloring process cheese, salad dressings, and other fat-base products	5 gm of solution to 100 ml oil, with stirring to dilute. 1 ml = 0.7 mg apo-carotenal and 0.3 mg β-carotene
Carotenal solution 4%	■ Apo-carotenal dissolved in a food-grade modified vegetable oil composition with dl-a-tocopherol	For coloring process cheese, salad dressings, and other fat-base products: dry spice and breading mixes	5 gm of solution to 200 ml of vegetable oil, with stirring to dilute 1 ml = 1 mg apo-carotenal

Adapted from Klaeui and Bauernfeind (1981)

APPENDIX 2

Table of Commercially Available Iron Compounds

			Common Vehicles						
KEY: G = Good, F = Fair, P = Poor - = Information not available R = Recommended, V = Variable NR = Not Recommended Relative Cost Factor $\frac{100}{\%\ \text{iron}}$ x Bioavailability factor in humans Bioavailability factor G = 1, F = 2, P = 3	% Iron Content	Bioavailability in Humans	Bioavailability in Animals	Processed Cereals	Salt	Sugar	Infant Foods/Milks	Beverages	Relative Cost Factor
Freely water soluble									
Ferrous sulfate · 7H O	20	G	G	V	V	R	R	R	5.0
Ferrous gluconate	12	G	G	V	V	R	R	R	8.3
Ferrous lactate	19	G	G		NR	NR	V	R	5.3
Ferric ammonium citrate	18	G	G	V	NR	NR	R	V	5.5
Ferric ammonium sulfate	14		G						
Ferric choline citrate	14		G		NR	NR			
Slowly soluble									
Dried ferrous sulfate	33	G	G	V	V	R	V	R	3.0
Ferric glycerophosphate	15	G	G		NR	NR	V	V	6.6
Ferric citrate	17	P	F	V	V	R	V	R	17.6
Ferric sulfate	22	P	G	NR	NR	NR	NR	NR	13.6
Ferric saccharate	3.35	F	G	R				R	5.7/6.6
Ferric chloride	34	F	G	NR	NR	NR	NR	NR	5.9
Poorly soluble									
Ferrous fumarate	33	G	G	R	R	NR	NR	NR	3.0
Ferrous succinate	35	G	G	R			NR	NR	2.8
Ferrous tartrate	22	F	F						9.0
Ferrous citrate	24	F	F	V	V		V	R	8.4
Almost insoluble or insoluble									
Ferric pyrophosphate	25	P	P	R	R	R	NR	NR	12.0
Ferric orthophosphate	28	P	P	R	R	R	NR	V	10.7
Sodium iron pyrophosphate	15	P	P	NR	NR	NR	NR	NR	20.0
Reduced elemental iron									
a. Reduced by hydrogen (10-45 µm)	96	F	F	V	NR	NR	NR	NR	2.1
b. Reduced by carbon monoxide	96	F	F	V	NR	NR	NR	NR	2.1
c. Carbonyl iron	98	F	F	V	NR	NR	NR	NR	2.1
d. Reduced by electrolysis - 20 µm	97	F	F	V	NR	NR	NR	NR	2.1
Ferric oxide	70	P	P	NR	NR	NR	NR	NR	4.2
Ferric hydroxide	62	P	P	NR	NR	NR	NR	NR	4.8
Ferrous carbonate	35	P	P	NR	NR	NR	NR	NR	8.5
Iron Complex Compounds									
Sodium Ferric EDTA	13	G	G	R		R	V	V	7.7

To determine equivalent costs on a bioavailability basis, multiply the relative cost factor by the available price per kilo of iron compound. Current local costs per kilo should be used when available.

SOURCE: IVACG (1990)

APPENDIX 3

Composition of ATOCHEM N-Richment-A Cereal Fortification Premixes

	Fortification level per kg		
	Corn/Sorgum	Wheat flour	Bulgar
Thiamin (vitamin B_1)	4.9 mg	5.7 mg	3.3 mg
Riboflavin (vitamin B_2)	2.6 mg	4.0 mg	2.2 mg
Niacin	31 mg	46 mg	—
Iron	26 mg	37 mg	11 mg
Vitamin A	23540 IU	23540 IU	23540 IU

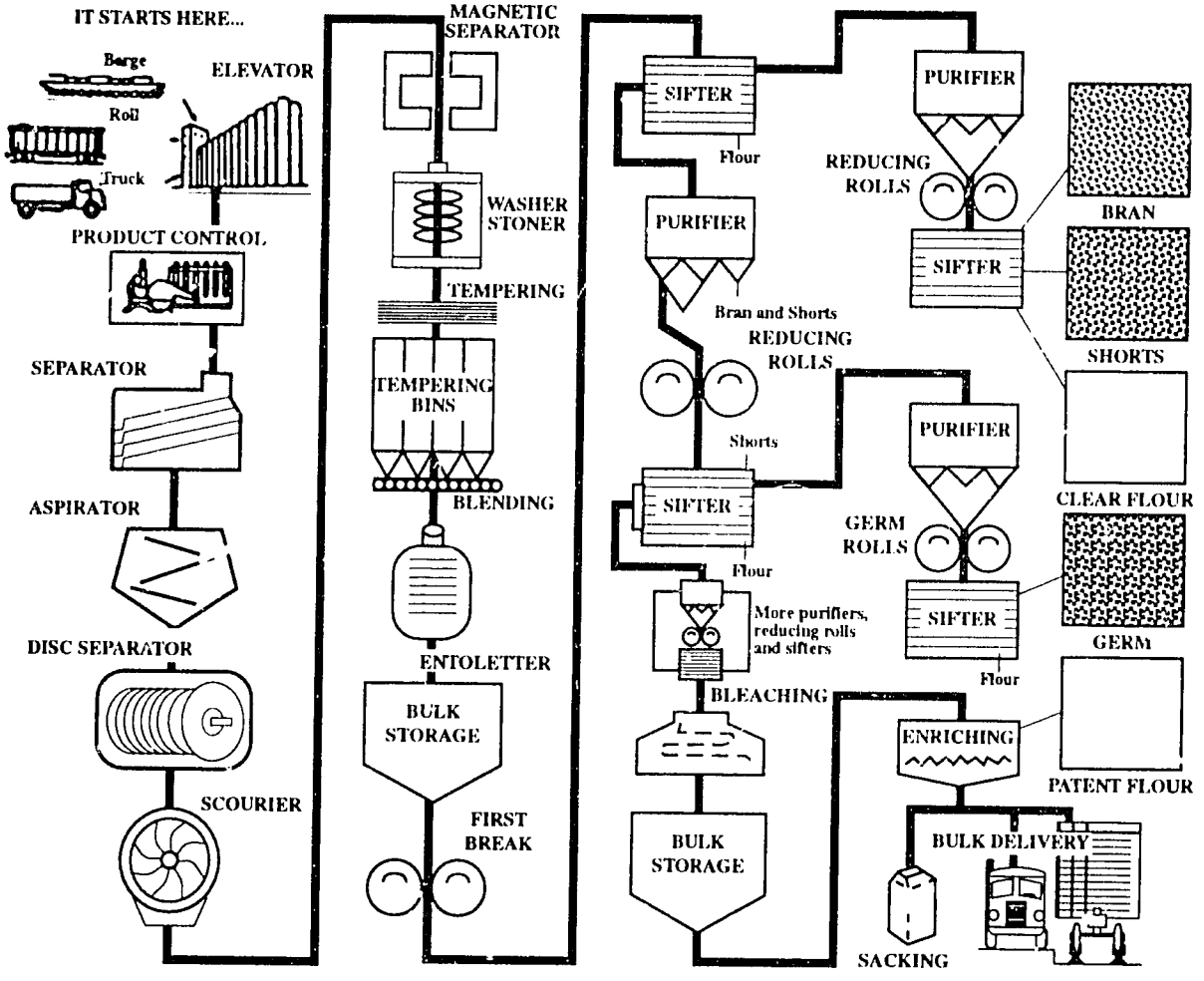
Composition of ROCHE Rovifarin 955 Fortification Premix

	Fortification level kg/flour
Thiamin (vitamin B_1)	4.45 mg
Riboflavin (vitamin B_2)	2.65 mg
Niacin	35.62 mg
Iron	29.28 mg

Composition of ROCHE Precision Premix

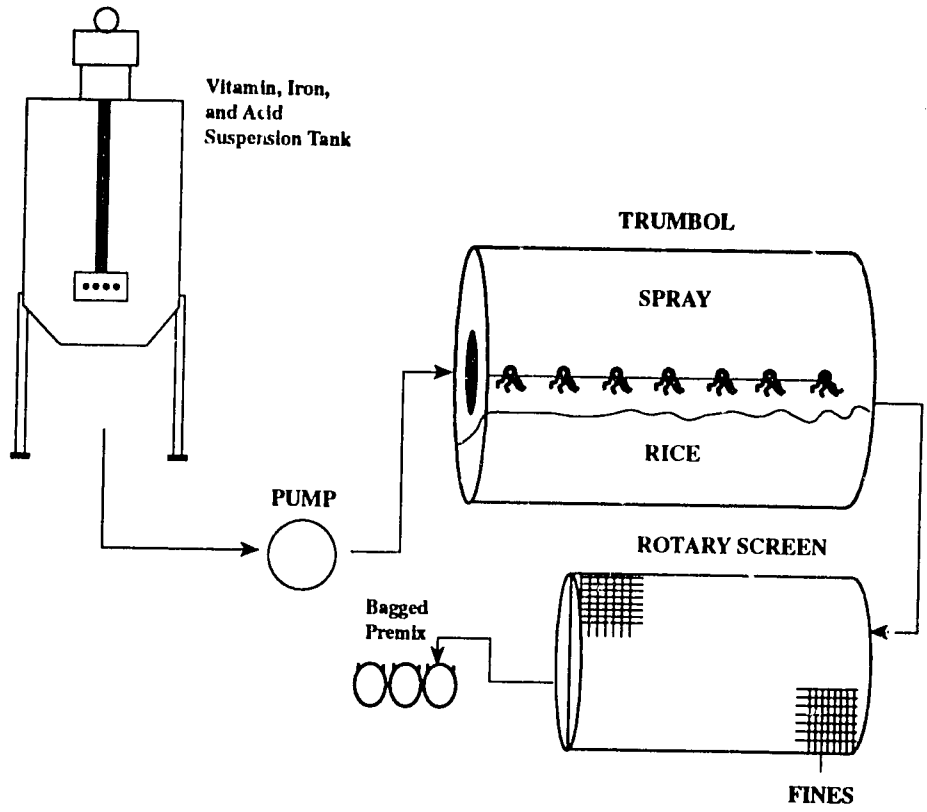
DESCRIPTION	USDA	USDA W/O MINERALS
Ascorbic Acid F.P.	78.0000 mg	78.00 mg
Niacinamide	22.0000 mg	22.00 mg
Pyridoxine Hydrochloride	2.7800 mg	2.78 mg
Riboflavin, Type S	1.9600 mg	1.96 mg
Thiamine Mononitrate	1.7300 mg	1.73 mg
Vitamin B_{12} 1.0% SD (spray dried)	0.7000 mg	0.70 mg
Vitamin A 250 SD (spray dried)	24.0000 mg	24.00 mg
Vitamin E 50% CWS/F	69.0000 mg	69.00 mg
Folic Acid	0.4800 mg	0.48 mg
Vitamin D_3 100 SD (spray dried)	4.8000 mg	4.80 mg
D-Calcium Pantothenate SD (spray dried)	12.5400 mg	12.54 mg
Biotin	0.3600 mg	0.36 mg
Di-Cal Phosphate anhydrous	0 mg	0 mg
Copper Gluconate	15.7000 mg	—
Iron Electrolytic	19.1000 mg	—
Potassium Iodide	0.2430 mg	—
Zinc oxide	20.0000 mg	—

APPENDIX 4a



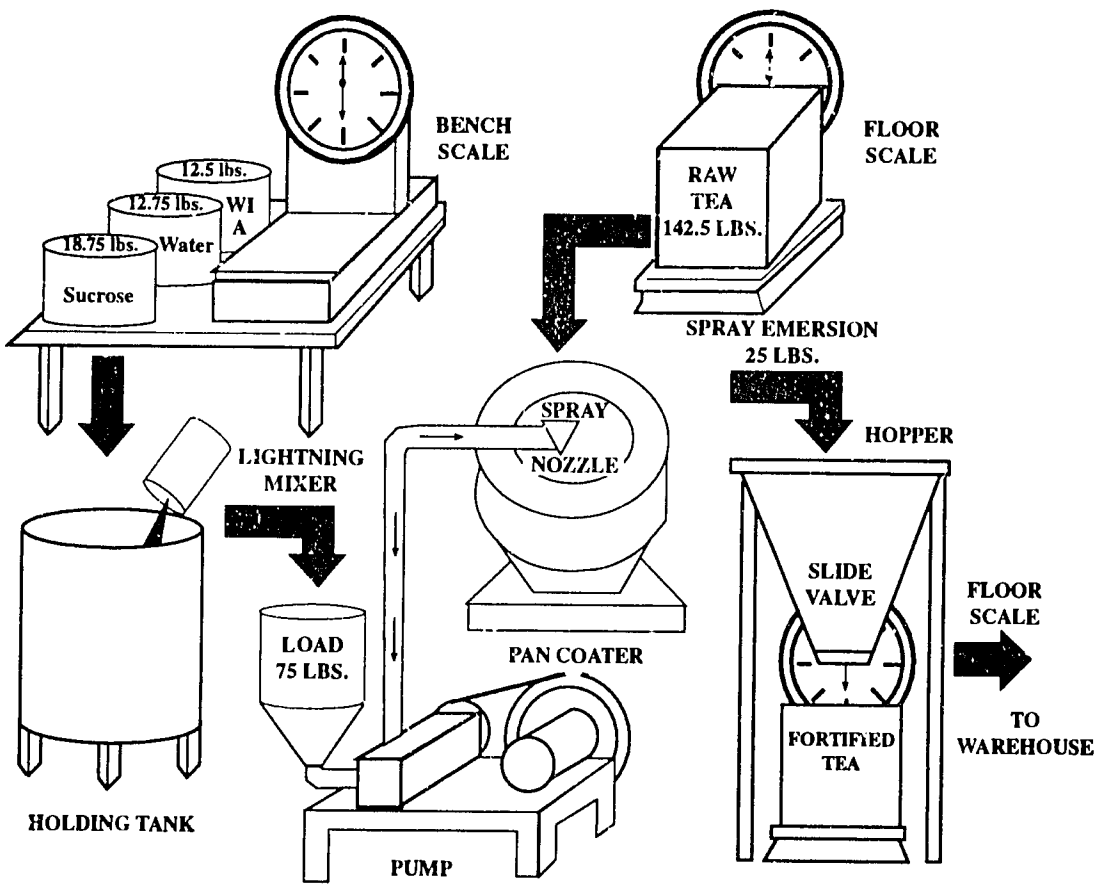
SIMPLIFIED FLOW CHART FOR FLOUR MILLING

APPENDIX 4b



PRODUCTION OF VITAMIN-ENRICHED RICE PREMIX

APPENDIX 4c



DIAGRAMMATIC FLOW SHEET FOR FORTIFICATION OF TEA WITH VITAMIN A

APPENDIX 5

TECHNICAL FEASIBILITY OF FORTIFYING CEREAL-GRAIN BASED PRODUCTS AS RECOMMENDED

Source: Bauernfeind and Lachance (1991)

	VITAMIN A	THIAMIN	RIBOFLAVIN	NIACIN	VITAMIN B	FOLIC ACID	IRON (1)	CALCIUM	MAGNESIUM	ZINC	Key: A = appears to be technically feasible B = insufficient data to evaluate technical feasibility C = not technically feasible at this time D = no data submitted for committee review
Flour Extended Shelf-Life	A	A	A	A	B	B	A	A	B	B	Consumer acceptance problems indicated from preliminary results of extended storage studies at elevated temperatures and humidities
Industrial (short shelf-life)	A	A	A	A	A	A	A	A	A	A	
Farina	A	A	A	A	A	A	A	A	A	A	Consumer acceptance problems indicated from preliminary results of extended storage studies at elevated temperatures and humidities
Corn Flour	A	A	A	A	A	A	A	A	A	A	
Meal	A	A	A	A	A	A	A	A	A	A	
Grits	A	A	A	A	A	A	A	C	A	A	Calcium addition should be no more than 300 µg/lb
Rice	A	A	A	A	A	A	A	C	C	A	Addition of riboflavin may cause consumer acceptance problem. Ferric orthophosphate recommended as iron source. Calcium and magnesium addition might be possible by change in enrichment process to use of "synthetic kernel" technique
Bread	A	A	A	A	A	A	A	A	A	A	Nutrient additions adjusted for less nutrients inherent in flour
Soft Sweet Goods Cakes	A	A	A	A	A	A	A	A	A	A	
All Others	D	D	D	D	D	D	D	D	D	D	Would appear to be feasible based on results obtained on bread, cake. Confirmation through testing suggested
Cookies & Crackers	A	A	A	A	A	A	A	A	A	A	Iron used at 40 mg/lb
Pasta	A	A	A	A	A	A	B	B	A	A	Iron used at 40 mg/lb
Refrigerated Doughs	A	A	A	D	D	A	D	D	D	D	
Frozen Products Unbaked	D	A	A	A	D	D	A	A	D	D	
Baked	D	A	A	A	D	D	A	A	D	D	
Prepared Mixes	D	A	A	A	D	D	A	D	D	D	

(1) Based on level of 16.5 mg/lb rather than NAS proposal of 40 mg/lb

APPENDIX 6

Latin American and Caribbean Countries where Food Fortification is Legislated

Country	Food	Micronutrient	Level
Argentina	Milk	Vitamin A	2,500 IU/l (max)
		Vitamin D	400 IU/l (max)
Brasil	Margarine	Vitamin A	15,000-50,000 IU/kg
		Vitamin D	500-2,000 IU (optional)
	Skim milk (for complementary food)	Vitamin A	1,500-2,500 IU/100 g
		Vitamin D	200-240 IU/100g
Chile	Margarine	Vitamin A	30,000 IU/kg
		Vitamin D	3,000 IU/kg (optional)
		Linoleic acid	70 g/kg
	Wheat flour	Vitamin B1	6.3 mg/kg
		B2	1.3 mg/kg
		B6	13.0 mg/kg
		Iron	30.0 mg/kg
	Pastas	Vitamin B1	9.0 mg/kg (optional)
		B2	3.0 mg/kg
		B6	57.0 mg/kg
		Iron	30.0 mg/kg
Colombia	Margarine	Vitamin A	3,180-7950 IU/kg
		Vitamin D	120-300 IU/kg
Honduras	Sugar	Vitamin A	50,000 IU/kg
El Salvador	Wheat flour	Vitamin B1	2.0 mg/lb
		B2	1.2 mg/lb
		B6	13.0 mg/lb
		Iron	500.0 mg/lb
		Calcium	500.0 mg/lb
Guatemala	Sugar	Vitamin A	50,000 IU/kg
	Wheat flour	Vitamin B1	4.41-5.50 mg/lb
		B2	2.65-3.30 mg/lb
		B6	35.20-44.00 mg/lb
		Iron	28.70-36.60 mg/lb
		Calcium	1,100.00-1,375.00 mg/lb
		Vitamin D	1,102-2205 IU/kg (optional)
Mexico	Semi-skimmed ultra -pasteurised milk	Vitamin A	4,000 IU/l
		Vitamin D	400 IU/l
	Semi-skimmed pasteurised milk	Vitamin A	4,000 IU/l
		Vitamin D	400 IU/l
	Evaporated milk whole and skimmed	Vitamin A	4,000 IU/l
		Vitamin D	400 IU/l
	Margarine	Vitamin A	20,000 IU/kg
		Vitamin D	2,000 IU/kg (optional)
Panama	Sugar	Vitamin A	50,000 IU/kg
Venezuela	Milk powder	Vitamin A	4,000 IU/l
		Vitamin D	400 IU/l

Source: Hoffman-La Roche, Brasil, in Mora (1992).

REFERENCES

Anonymous. 1983. Use of iron fortified salt to combat anemia: the Indian experience. *Nut. Rev.*, 41:10, 302-303.

Arroyave, G. 1972. Distribution of vitamin A to population groups. In *Proceedings of the western hemisphere nutrition congress III*. Futura, New York.

Arroyave, G. 1987. Alternative strategies with emphasis on food fortification. In *Delivery of oral doses of vitamin A to prevent vitamin A deficiency and nutritional blindness - a state of the art review*. (Eds) K.P. West and A. Sommer. ACC/SCN State of the Art Review Series. Nutrition Policy Discussion Paper No. 2. Rome.

Arroyave, G. 1992. Food nutrification with emphasis on the addition of micronutrients to wheat flour. VITAL/ISTI, Washington, DC.

Arroyave, G., J.R. Aguilar, M. Flores, and M.A. Guzman. 1979. Evaluation of sugar fortification with vitamin A at the national level. PAHO, Washington, DC.

Arroyave, G., L.A. Mejia and J.R. Aguilar. 1981. The effect of vitamin A fortification of sugar on the serum levels of preschool Guatemalan children: a longitudinal evaluation. *Am. J. Clin. Nut.*, 34: 41-49.

Bailey, K. 1992. Notes on salt iodation in Africa. Unpublished.

Bauernfeind, J.C. 1978. The technology of vitamin A. Hoffmann-La Roche, Inc., New Jersey.

Bauernfeind, J.C. 1991. Foods considered for nutrient addition: condiments. In *Nutrient additions to food*. (Eds) J.C. Bauernfeind and P.A. Lachance. Food and Nutrition Press, Trumbell, CT.

Bauernfeind, J.C. and G. Arroyave. 1986. Control of vitamin A deficiency by the nutrification approach. In *Vitamin A deficiency and its control*. (Ed) J.C. Bauernfeind. Açademic Press, London.

Brooke, C.L. and W.M. Cort. 1972. Vitamin A fortification of tea. *Food Technol.*, 26:6, 50-52.

Clydesdale, F.M. 1991. Mineral additives. In *Nutrient additions to food*. (Eds) J.C. Bauernfeind and P.A. Lachance. Food and Nutrition Press, Trumbell, CT.

Cohen, N., H. Rahman, M. Mitra, J. Sprague, S. Islam, and E. Leemhuis de Regt. 1987. Impact of massive doses of vitamin A on nutritional blindness in Bangladesh. *Am. J. Clin. Nut.*, 45: 970-976.

Cook, J.D. 1990. Adaptation in iron metabolism. *Am. J. Clin. Nut.*, 51: 301-308.

Cook, J.D. and M.F. Reusser. 1983. Iron fortification: an update. *Am. J. Clin. Nut.*, 38: 648-659.

Cort, W.M., B. Borenstein, J.H. Harley, M. Oseada, and J. Scheiner. 1976. Nutrient stability of fortified cereal products. *Food Technol.*, 30:4 52-62.

Crowley, P.R., F.F. Barrett, R.P. Weil, D.A. Fellers, and N.M. Blocker. 1989. Final Report: Food technology for development project. OICD/USDA, Washington, DC.

Crowley, P.R. 1990. Fortification of wheat flour with vitamins and minerals: Sri Lanka trip report. USDA/OICD, Washington, DC.

Darton-Hill, I. 1988. Vitamin A fortification of wheat: Bangladesh experience. HKI, New York.

Dary, M. 1991. Sugar fortification with vitamin A in Guatemala. XXIII IVACG meeting. Ecuador.

DeMaeyer, E. 1989. Preventing and controlling iron deficiency anaemia through primary health care. WHO, Geneva.

Dann, J.T. and F. van der Haar. 1990. A practical guide to the correction of iodine deficiency. ICCIDD.

Emodi, A. and L. Scialpi. 1976. Rice fortification for the Dominican Republic. Unpublished report, Hoffman-La Roche, New Jersey.

FAO/WHO. 1988. Requirements of vitamin A, iron, folate and vitamin B12. FAO Food and Nutrition Series No. 32. Rome.

Favaro, R., J.F. Ferreira, I.D. Desai and J.E. Dutra de Oloveira. 1990. Studies on the fortification of refined soybean oil with all-trans-retinyl palmitate in Brazil: stability during cooking and storage. University of San Paulo Medical School and University of British Columbia.

Finch, C.A. and J.D. Cook. 1984. Iron deficiency. *Am. J. Clin. Nut.*, 39: 471-477.

Florentino, R.F. and M.R. Pedro. 1990. Rice fortification in the Philippines. In *Combating iron deficiency anemia through food fortification technology*. INACG, Washington, DC.

Fuller, C.E., J.H. Nelson, D.E. Smith, P.R. Crowley, J.L. Swanson and F.B. Wells. 1974. A technology for the fortification of tea with vitamin A. *Proc. IV Int. Congress Food Sci. and Technol.* V: 180-189.

Garby, L., and S. Areekul. 1973. Iron supplementation in Thai fish sauce. *Annals Trop. Med. Parasit.*24, 68:4, 467-476.

Gillespie, S., J. Kevaney, and J. Mason. 1991. Controlling iron deficiency. ACC/SCN State-of-the-Art Series Nutrition Policy Discussion Paper No. 9. Geveva.

Hurrell, R.F., D.E. Furniss, J. Burri, P. Whittaker, S.R. Lynch, and J.D. Cook. 1989. Iron fortification of infant cereals: a proposal for the use of ferrous fumarate or ferrous succinate. *Am. J. Clin. Nut.*, 49: 1274-1282.

INACG. 1977. Guidelines for the eradication of iron deficiency anaemia. Washington, DC.

INACG. 1979. Iron deficiency in infancy and childhood. Washington, DC.

INACG. 1981. Iron deficiency in women. Washington, DC.

INACG. 1990. Combating iron deficiency anemia through food fortification technology. Washington, DC.

IVAGC. 1980. The safe use of vitamin A. Washington, DC.

IVACG. 1984. Periodic, large oral doses of vitamin A for the prevention of vitamin A deficiency and xerophthalmia: a summary of experiences. Washington, DC.

IVACG. 1988. Guidelines for the eradication of vitamin A deficiency and xerophthalmia. Washington, DC.

Karyodi, D. 1990. Iron fortification cost issues. In *Combating iron deficiency anemia through food fortification technology*. INACG, Washington, DC.

Keusch, G.T. and N. Scrimshaw. 1986. *Rev Infec. Dis.*, 8: 273-287.

Lamparelli, R.D., A.P. MacPhail, T.H. Bothwell, D. Ballot, M.D. Danilewitz, B.J. Macfarlane, F. Mayet, and R.D. Baynes. 1987. Curry powder as a vehicle for iron fortification: effects on iron absorption. *Am. J. Clin. Nut.*, 46: 335-340.

Latham, M.C. and F.S. Solon. 1986. Vitamin A deficiency control in the Philippines. In *Vitamin A deficiency and its control*. (Ed) J.C. Bauernfeind. Academic Press, London.

Levin, H.M. 1986. A benefit-cost analysis of nutritional programs for anemia reduction. *Research Observer* (World Bank), 1:2 219-245.

Levin, H.M., E. Pollitt, R. Galloway, and J. McGuire. 1991. Micronutrient deficiency disorders. In *Disease control priorities in developing countries*. (Eds) D.T. Jamison and W.H. Mosley. Oxford University Press, New York.

Lipton, M. (1983). *Poverty, undernutrition and hunger*. World Bank Staff Working Paper No 597. Washington, DC.

Lund, B.B. 1991. Engineering aspects of nutrifying foods. In *Nutrient additions to food*. (Eds) J.C. Bauernfeind and P.A. Lachance. Food and Nutrition Press, Trumbell, CT.

Lynch, S.R. 1990. Iron fortification of condiments and sugar. In *Combating iron deficiency anemia through food fortification technology*. INACG. Washington, DC.

McKigney, J.I. 1983. Interventions for the prevention of vitamin A deficiency: a summary of experiences. In *Nutrition intervention strategies in national development*. Academic Press, New York.

McKigney, J.I., *et al.*, 1992. Evaluation of interventions for the control of vitamin A deficiency in Guatemala. VITAL/ISTI, Washington, DC.

Mejia, L.A. and G. Arroyave. 1982. The effect of vitamin A fortification of sugar on iron metabolism in preschool children in Guatemala. *Am. J. Clin. Nut.*, 36: 87-93.

Molina, M.R. 1991. Foods considered for nutrient addition: sugars. In *Nutrient additions to food*. (Eds) J.C. Bauernfeind and P.A. Lachance. Food and Nutrition Press, Trumbell, CT.

Mora, J.O. 1992. Trip report San Paulo, Apr 26-May 2, 1992. VITAL, Washington, DC.

Muhilal, A. Murdiana, I. Azis, S. Saidin, A.B. Jahari, and D. Karyadi. 1988a. Vitamin A fortified monosodium glutamate and vitamin A status: a controlled field trial. *Am. J. Clin. Nut.*, 48: 1265-1270.

Muhilal, D. Permeisih, Y.R. Idjradinata, Muherdiyantiningsih, and D. Karyadi. 1988b. Vitamin A fortified monosodium glutamate and health, growth, and survival of children: a controlled field trial. *Am. J. Clin. Nut.*, 48: 1271-1276.

Murphy, P., K.W. Hsu, A. Fratzke, and C. Hauck. 1987. Fortification of monosodium glutamate with "white" vitamin A in Indonesia. Dept. Food Technol., Iowa State University.

Murphy, P., B. Smith, C. Hauck, and K. O'Connor. 1992. Stabilization of vitamin A in a synthetic rice premix. *J. Food Sci.*, 57:2 437-439.

Panday, C.S., R.C. Carriere, N. Kochupillai, T. Ma, and L.M. Nath. 1987. The planning and management of IDD control programs. In *The prevention and control of iodine deficiency disorders*. (Eds) B.S. Hetzel, J.T. Dunn and J.B. Stanbury. Elserver Press, Amsterdam.

Popkin, B.M. and E.Z. Bisgrove. 1988. Urbanization and nutrition in low-income countries. *Food and Nut. Bull.*, 10:1, 3-23.

Popkin, B.M., F.L. Solon, T. Fernandez, and M.C. Latham. 1980. Benefit-cost analysis in the nutrition area: a project in the Philippines. *Soc. Sci. & Med.*, 14C: 207-216.

Rubin, S.H., A. Emodi and L. Scialpi. 1977. Micronutrient additions to cereal grain products. *Cereal Chem.*, 54:4 895-904.

Solomons, N.W. and R. Gross. 1987. Urban nutrition in the tropics: a call for increased attention to the metropolitan population in the developing world. *Food and Nut. Bull.*, 9:4, 1-2.

Solon, F.S., M.C. Latham, R. Guirriec, R. Florentino, D.F. Williamson and J. Aguilar. 1985. Fortification of MSG with vitamin A: the Philippine experience. *Food Technol.*, 39:11 71-77.

Tilden, R.L. and R.N. Grosse. 1988. Vitamin A cost-effectiveness model. Dept. Pop. Plan. and Int. Health, School of Public Health, University of Michigan.

Venkatesh Mannar, M.G. 1987. Control of iodine deficiency disorders by iodination of salt: strategy for developing countries. In *The prevention and control of iodine deficiency disorders*. (Eds) B.S. Hetzel, J.T. Dunn and J.B. Stanbury. Elserver Press, Amsterdam.

Venkatesh Mannar, M.G. 1988. Salt iodination. Part 2: iodination technique. *IDD Newsletter*, 4:4, 11-16.

Venkatesh Mannar, M.G. 1990. Fortification of salt with iron - a status report. In *Combating iron deficiency anemia through food fortification technology*. INACG. Washington, DC.

Viteri, F.E. 1987. Nutrition-related health consequences of urbanization. *Food and Nut. Bull.*, 9:4, 33-41.

Walter, T. 1990. Combating iron deficiency: Chile: A case study. In *Combating iron deficiency anemia through food fortification technology*. INACG. Washington, DC.

West, K.P. and A. Sommer. 1987. Delivery of oral doses of vitamin A to prevent vitamin A deficiency and nutritional blindness. A state-of-the-art review. ACC/SCN Nutrition Policy Discussion Paper No. 2. Rome.

WHO. 1982. Control of vitamin A deficiency and xerophthalmia. Technical Report Series No. 672. Geneva.

WHO. 1991. National strategies for control of micronutrient deficiencies (CMM). Gereva.

Wilson, L.A. 1988. Proposed quality assurance guidelines for the fortification of MSG with white vitamin A in Indonesia project. Dept. Food Tech., Iowa State University.

Zoller, J.M., I. Wolinsky, C.A. Paden, J.C. Hoskin, K.C. Lewis, D.R. Lineback, and R.D. McCarthy. 1980. Fortification of non-staple food items with iron. *Food Technology*, 34:1, 38-47.