PN-ACD-290

Fortification Basics

Choosing a Vehicle

Rationale

Fortification of foods with vitamins and minerals can be an effective way to combat micronutrient deficiencies in developing countries One of the key processes in developing a fortification program (Table 1) is choosing a suitable food vehicle This can be a challenge especially in countries with large rural populations a small food industry with limited technology and limited access and low consumption of processed foods Some foods that are suitable for fortification such as commercial infant foods (many of which are fortified), processed fruit juices and processed milks are generally consumed by middle or high income groups who are not always at greatest risk of micronutrient deficiencies Some staple foods, such as rice are generally processed in many plants, making it difficult to transfer appropriate technology and to implement quality control Examples of foods used in fortification programs in developing countries are listed in Table 2

Selecting an appropriate vehicle and having an effective fortification program that provides a significant amount (programs have used 33% to 50%) of the recommended daily intake of micronutrient(s) for those at greatest risk of deficiency, reduces the need to provide supplements in pharmaceutical forms on a widespread basis

Criteria for vehicle selection

The success of a fortification program depends in part, on the selection of the right food vehicle This requires knowledge of food intake patterns that show who is eating what foods among the groups at greatest risk of deficiency The selection of a vehicle should be based on several key factors

- it must be centrally processed so that quality control can be effectively implemented
- it must be consumed regularly and in predictable amounts and be affordable by the target population
- the stability and bioavailability of the micronutrients added to the food must remain high under standard local conditions of storage and use
- the fortified food should not undergo changes in color taste, or appearance as a result of adding the micronutrients
- the addition of micronutrients should be economically feasible through an industrial process
- the added nutrient should supply optimal amounts without

Table 1
Development of a Fortification Program

Determining the prevalence of micronutrient deficiency

Choosing a suitable food vehicle
- Food production and consumption data for potential food vehicles segregated by socio economic and age groups and geographic area
- Marketing and distribution patterns for food vehicle

Determining the level of fortificant to be added

Developing a quality assurance system

Monitoring and evaluating the fortification program

Legislating and enforcing laws to ensure fortification of foods

Table 2
Some Foods Considered in Food Fortification Programs in Developing Countries

Food	Intervention	Countries	Fortificant
Sugar	Program (Mandatory)	Guatemala El Salvador Honduras	Vitamin A
MSG	Experimental	Philippines Indonesia	Vitamin A
Salt	Program (Mandatory)	Numerous	Iodine
Corn flour	Program (Mandatory)	Venezuela	Vitamin A Iron Thiamin Niacin Riboflavin
Wheat flour	Program (Mandatory)	Chile Peru Honduras El Salvador Guatemala Venezuela Panama Costa Rica Nigeria	Thiamin Niacin Riboflavin Iron and in some countries Folic Acid
	Experimental	Philippines	Vitamin A Iron

Table 2 (continued)

Margarine	Program (Mandatory)	Brazil Chile Colombia Mexico Peru Honduras Ecuador Panama	Vitamins A&D
Oil	Experimental Voluntary	Brazil Chile	Vitamin A Vitamins A&E
Ghee	Program (Voluntary)	Pakistan	Vitamin A
Noodles	Program (Voluntary)	Thailand	Vitamin A Iron B Complex
Milk	Program (Mandatory)	Argentina Brazil Mexico Honduras Guatemala Malaysia	Vitamins A&D

Table 3
Per Capita Wheat Consumption, and Percent of Daily Energy Intake from Wheat in Selected Countries

Country	Consumption (g/person/day)	% of daily energy intake
Pakistan	318	45
Turkey	484	44
Syria	490	44
Chile	372	42
Egypt	397	35
Greece	371	28
Argentina	344	28
Uruguay	269	26
Bolivia	159	20
South Africa	191	18
Peru	136	17

FAO 1991 Food Balance Sheets 1984 1986 Rome

Table 4
Per Capita Corn Consumption, and Percent of Daily Energy Intake from Corn in Selected Countries

Country	Consumption (g/person/day)	% of daily energy intake
Bolivia	97	16
Brazil	90	10
Egypt	151	16
Guatemala	319	48
Honduras	258	41
India	21	3
Indonesia	74	8
Nepal	116	18
Philippines	132	15
South Africa	308	30
Venezuela	122	14
Zambia	477	68

FAO 1991 Food Balance Sheets 1984 1986 Rome

a risk of excessive intake or toxic effects

Food vehicles

Foods that have been successfully fortified in developing countries include

- **Sugar** Vitamin A fortification of sugar has been implemented in Guatemala Honduras and El Salvador and is being considered in Ecuador Nicaragua Philippines Uganda and Zambia
- **Wheat flour** Fortification of wheat flour with thiamin riboflavin niacin and iron has been successfully used for a long time Studies conducted in the U S showed good stability of vitamin A added to wheat flour Efficacy trials on wheat flour fortification with vitamin A and wheat flour with iron are currently underway in the Philippines and Sri Lanka respectively
- **Corn flour** In Venezuela precooked corn flour is fortified with vitamin A, thiamin riboflavin niacin and iron
- **Salt** Salt is fortified with iodine in many countries throughout the world Work is currently underway to test the efficacy of salt that is fortified with both iodine and iron
- **Fats and oils** Fats and oils may serve as good vehicles for vitamin A because vitamin A is fat soluble Vegetable ghee (hydrogenated vegetable oil) is fortified in India and Pakistan

  Margarine is fortified with vitamin A in about 24 countries including Brazil Chile Colombia Mexico Indonesia and many others Trials on vitamin A fortified soybean oil are underway in Brazil
- **Milk** Milk has been successfully fortified with vitamins A and D for many years One of the latest successful experiences in fluid milk fortification with iron occurred in Argentina

To identify a good food vehicle data are needed on food production imports and exports Foods that are locally produced or home grown and not centrally processed such as rice in Asia are not effective vehicles for delivering micronutrients because it is difficult to make the fortificant available to the many thousands of small producers/processors

Similarly non-staple foods may not be effective in reducing the prevalence of micronutrient deficiencies because they are generally not consumed by the target populations

Finally the role of imported foods should be considered Leakage of non-fortified foods across international borders may dilute the effect of a fortification program Where food regulations exist imported foods must comply with the local food regulations

Consumption patterns

Information on consumption patterns is necessary to identify

an appropriate vehicle for fortification For example worldwide consumption patterns of wheat corn, oil, and sugar presented in tables 3 4, 5 and 6, respectively show that these foods are potentially good vehicles for fortification Unless the food is eaten in predictable amounts on a regular basis by the target population the program will not be effective Knowledge of consumption levels are also needed to determine how much micronutrient(s) can be safely added to the food vehicle

Differences in foods consumed by urban versus rural populations exist and must be considered before choosing a fortification vehicle For example urban populations in Brazil consume a wide variety of foods (Figure 1) that are not typically consumed by the rural populations (Figure 2)

The choice of a vehicle should ideally be based on consumption data for children under 5 years of age and pregnant women, who are most vulnerable to micronutrient deficiencies because of their increased requirements for growth and development Where possible consumption data should be segregated by different social and economic groups and also by different geographic/ecological regions

Marketing and distribution

The marketing and distribution plans for the food vehicle need to be known to ensure that the fortified foods reach the most isolated populations who are the most vulnerable to micronutrient deficiencies

Marketing patterns may vary from country to country Fortified products such as sugar, salt and cereal flours generally pass through a series of distribution points between wholesalers and retailers before being sold to consumers Involving both the private and public sector in the marketing and monitoring of fortified foods will increase the likelihood of the program being effective

Food producers and processors should be encouraged to make appropriate nutritional claims, in accordance with local regulations, for a properly fortified product to provide adequate information to the consumer This should be done through product labeling and appropriate advertising and promotion of the fortified food

Stability of micronutrients in fortified food

Micronutrient losses can occur at each point in the distribution chain if storage conditions are not optimal Exposing fortified food to light air heat and humidity may result in losses of some micronutrients and their potency

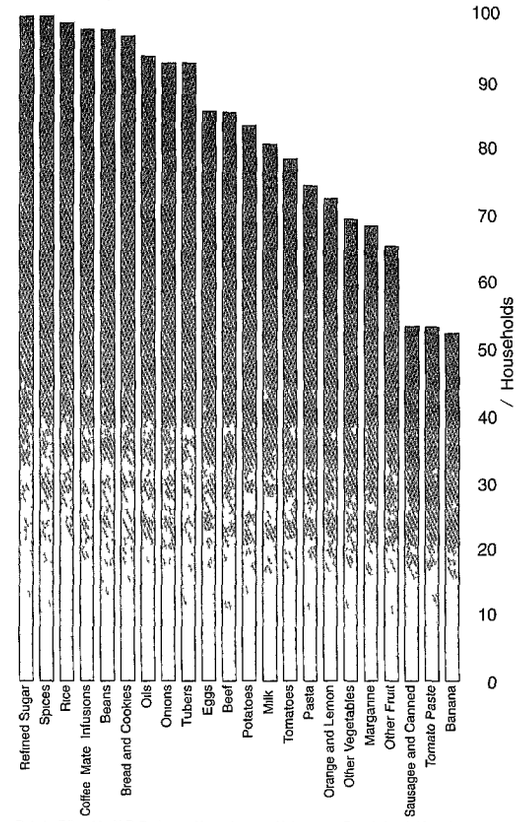
Micronutrient losses can also occur at the household level during storage and food preparation Thus data are needed on ambient storage conditions at different points in the distribution chain and at the household level before deciding on the type and form of fortificants that can be added to improve micronutrient status

Table 5
Per Capita Vegetable Oil Consumption, and Percent of Daily Energy Intake from Vegetable Oils in Selected Countries

Country	Consumption (g/person/day)	% daily energy intake
Brazil	33	9
Mexico	27	9
Costa Rica	30	9
Central Africa	35	11
Congo	12	5
Gambia	34	12
India	31	11
Indonesia	16	7
Nepal	17	6
Philippines	12	4

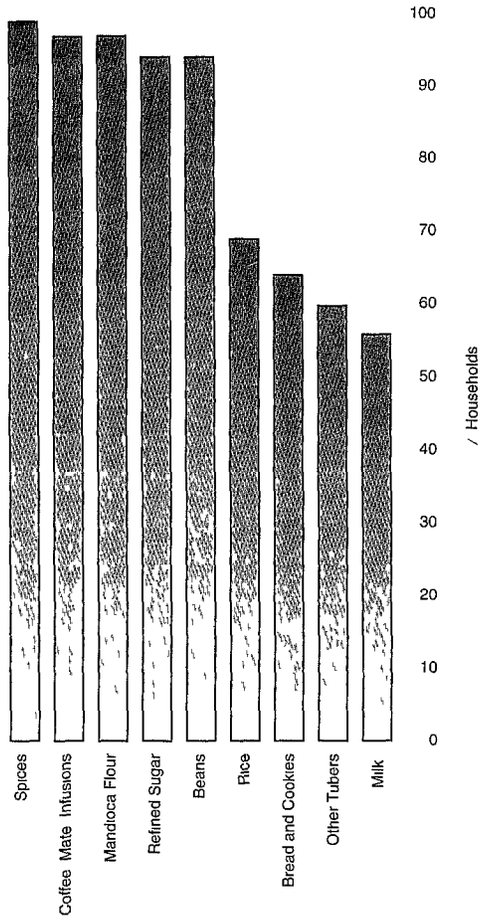
FAO 1991 Food Balance Sheets 1984 1986 Rome

Figure 1
Typical Foods Consumed by Households with Children Under 5 Years of Age in Urban Sao Paulo, Brazil



Batista Filho M N P Barbosa Alimentaçao e Nutriçao no Brasil 1974 1984 Instituto Nacional de Alimentaçao e Nutriçao Brasil 1989
Fresh and Pasteurized

Figure 2
Typical Foods Consumed by Households with Children Under 5 Years of Age in Rural Northeast Brazil



Batista Filho M N P Barbosa Alimentaçao e Nutriçao no Brasil 1974 1984 Instituto Nacional de Alimentaçao e Nutriçao Brasil 1989
Fresh and Pasteurized

Table 6
Per Capita Sugar Consumption, and Percent of Daily Energy Intake from Sugar in Selected Countries

Country	Consumption (g/person/day)[1]	% of daily energy intake[2]
Brazil	127	17
Peru	88	14
Guatemala	110	15
Honduras	85	12
India	42	5
Indonesia	42	5
Morocco	88	11
Mali	22	2
Egypt	80	10
Zambia	31	8
Cameroon	17	3
South Africa	100	15

[1] International Sugar Association 1995
[2] FAO 1991 Food Balance Sheets 1984 1986 Rome

Sensory characteristics

One of the advantages of fortification is that it can be achieved without changing the sensory properties of the food If consumers, however notice that there is a difference in the taste smell or texture of the food as a result of fortification they may not buy the fortified food Sensory characteristics can play an important role in determining the amount of micronutrient added to the food For example the amount of riboflavin (vitamin B_2) added to corn flour can be limited by the extent to which the change in color caused by the addition of riboflavin is acceptable to consumers

Data sources

Data on the production and availability of potential food vehicles can be obtained from government offices trade associations banks and other agencies

Data on food consumption and distribution are generally not easy to obtain from official sources However some food companies and marketing and advertising firms conduct research to obtain these data Many trade associations also gather and publish food consumption and distribution statistics which are normally available to the public Even though these data may be quite specific and specialized they can be used as a reference or indirectly to assess more general consumption patterns It is important to note that data may only be available at a per capita consumption level and not segregated by age groups

In some countries such as Bangladesh and the Philippines national dietary surveys are carried out regularly while in other countries dietary surveys are carried out on a limited basis Where consumption data do not exist crude intake levels can be calculated from the FAO Food Balance Sheets that are based on production export and import data These data however provide information at the per capita level only

Food consumption by different socioeconomic groups may also be derived from household budget surveys that most countries undertake when constructing their cost of living indices Again these data may be available on a per capita basis only

In conclusion a food fortification vehicle should be chosen based on key factors including consumption patterns marketing and distribution data, and economic and technical feasibility

OMNI Opportunities for Micronutrient Interventions
Roche
USAID
COD 51056

Fortification Basics

Oils and Margarine

Rationale

Oils and fats, along with carbohydrates and proteins are major components of the human diet Oils provide energy fat soluble vitamins (vitamins A D, and E) and essential fatty acids that are required for proper growth and development

The production of vegetable oils (canola corn, cottonseed, coconut, olive, palm, peanut, safflower, soybean, sunflower) is high throughout the world and consumption (Table 1) is increasing especially among the lower socioeconomic groups A higher consumption of vegetable oils over animal fats is preferable because vegetable oils contain much less saturated fat than animal fats (Figure 1) and they contain no cholesterol

Vegetable oils are suitable as vehicles for vitamins A D and E fortification, as the production and refining of the oils is a centralized process As vitamins A D and E are fat soluble, they can be uniformly distributed in oil The stability of vitamin A is greater in oils than in any other food and oil facilitates the absorption of vitamin A by the body Vegetable oils are consumed by almost everyone, thus, it is possible to improve people s access to fat soluble vitamins through fortification

Hydrogenation converts liquid vegetable oils into solid fats, such as margarine The vitamin A and D content in margarine is negligible However, fortification with these vitamins can make margarine an important source of these nutrients as well as a source of energy

Fortification with vitamin E may be important where the diet is high in polyunsaturated fatty acids (PUFA) PUFAs are long chain fatty acids with more than one double bond, which makes them susceptible to oxidation The process of oxidation of fat in oils is the same as in cells

- Food oils that are high in triglycerides can contain PUFAs which produce hydroperoxyacids on oxidation resulting in a rancid odor in food
- At the cellular level, oxidation results in the formation of free radicals which have been shown to be associated with cancer and cardiovascular diseases (CVD), hence antioxidants are thought to be anticarcinogenic and cardiovascular protective Technologies now exist to add water soluble micronutrients including vitamin C the B complex iron and calcium to margarine

Fortification Criteria

Fortification of vegetable oils and their derivatives (margarine mayonnaise etc) with vitamins A D and E is technologically feasible Crude vegetable oils are a rich source of vitamin E Processing crude oil however can result in the loss of this vitamin the extent of this loss is dependent on the processing method used Vitamin E can be added to refined oil as a nutrient or as an antioxidant Vitamin E antioxidants such as alpha (α) tocopherol prevent rancidity and protect other components in the oil susceptible to oxidation including vitamin A but it is not a good fortificant Alfa tocopheryl acetate in contrast is stable making it a good fortificant but it has no antioxidant activity

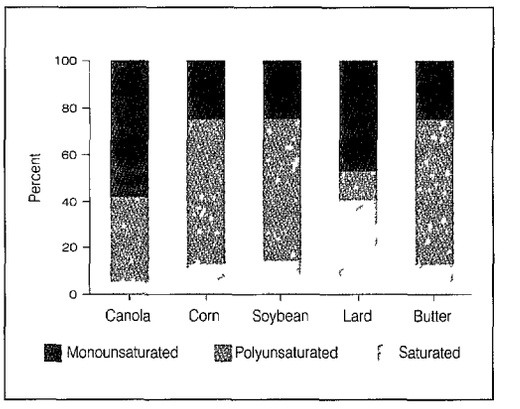
Table 2 shows that the range of vitamin A added to margarine in a number of countries varies between 3,180 and 45 000 IU/Kg while

Table 1
Per Capita Vegetable Oil Consumption, and Percent Daily Energy Intake from Vegetable Oils in Selected Countries

Country	Consumption (g / day)	% Energy intake
Argentina	33	9
Brazil	27	9
Mexico	30	9
Costa Rica	35	11
Central Africa	12	5
Congo	34	12
Gambia	31	11
India	16	7
Indonesia	17	6
Philippines	12	4

Source FAO 1991 Food Balance Sheets 1984 1986 Rome

Figure 1
Fatty Acid Content of Different Vegetable Oils and Animal Fats



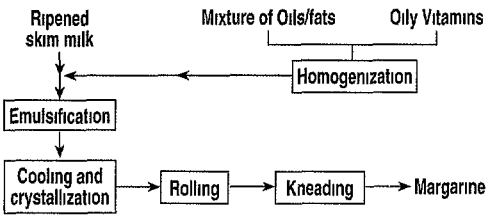
Source Giese J 1996 Fats Oils and Fat Replacers Food Technology 50 (4) 77 84

Table 2
Mandatory Fortification of Margarine with Vitamins A&D

Country	Vitamin A (IU/Kg)		Vitamin D (IU/Kg)	
Belgium	22 500	27 000	2 500	3 000
Brazil	15 000 -	50 000	500	2 000
Canada		≥ 33 000		≥ 5 300
Chile		30 000		3 000
Colombia	3 180	7 950	480	1 200
Denmark		25 200		
Ecuador	20 000	30 000	2 000	4 000
El Salvador		15 000		
Guatemala	15 000	50 000		
Honduras		35 000		1 500
India		≥ 30 000		
Indonesia	25 000	35 000	2 500	3 500
Malaysia	25 000	35 000	2 500	3 500
Mexico		20 000		2 000
Netherlands		≥ 20 000		≥ 3 000
Panama		20 000		1 500
Peru		30 000		3 000
Portugal		18 000		
Singapore		≥ 28 300		≥ 2 200
Sweden		≥ 30 000		≥ 3 000
Taiwan		≥ 45 000		
Turkey		20 000		1 000
U S A		33 000		2 080
UK	24 000	30 000	2 800	3 520

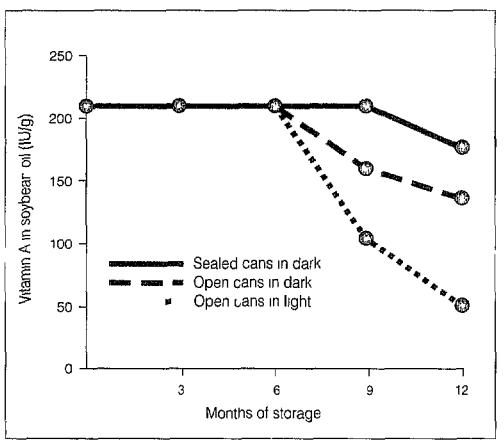
Source Raunhardt O and A Bowley Mandatory Food Enrichment Nutriview Supplement to 1/1996 Issue

Figure 2
Flow Chart of Fortified Margarine Manufacturing



Source O Brien A and D Robertson n d Vitamin Fortification of Foods (Specific Applications) The Technology of Vitamins in Foods In Micronutrient Fortification of Foods The Micronutrient Initiative Ontario Canada

Figure 3
Stability of Vitamin A Fortified Soybean Oil During Storage at 23°C Under Different Conditions



Source Favaro R J Ferreira I Desai and J Dutra de Oliveira 1991 Studies on Fortification of Refined Soybean Oil with All trans Retinyl Palmitate in Brazil Stability During Cooking and Storage J Food Comp Anal 4 237 244

that for cholecalciferol (vitamin D_3) varies between 480 and 5 300 IU/Kg A 15 g serving (1 tablespoon) of these margarines would provide between 4 and 51 percent of the recommended daily intake (RDI FAO/WHO 1988) for vitamin A and between 2 and 20 percent of the RDI for vitamin D for pre school children

As a nutrient it would be appropriate to fortify oil and margarine with vitamin E at a level of 65 to 190 mg/Kg The recommended daily intake for vitamin E increases with intake of PUFA At a ratio of 0 4 mg α tocopherol to 1 gm PUFA there is enough vitamin E in normal circumstances to counteract the level of PUFA normally being consumed to prevent oxidation At a level of 65 to 190 mg/Kg 1 tablespoon of oil or margarine/day would provide between 15 and 50 percent of the RDI for a child between 1 and 6 years old

The level of fat soluble vitamins in fortified oils and margarine depends on consumption patterns and nutritional requirements Clearly before determining the level of nutrient to add to oils and fats the use of and consumption patterns for oil by different socio economic and age groups need to be determined in order to ensure that the maximum safe level of intake for each nutrient is not exceeded

Technology

The most common commercial vitamin A and D_3 blend used contains 1 000 000 IU vitamin A palmitate (300 000 mg/g) and 100 000 IU vitamin D_3 (2 500 mg/g) in a liquid form stabilized with vitamin E (α tocopherol) or a BHA/BHT mixture The same vitamin A/D blend is also available with vitamin E fortificant (vitamin E acetate) as a custom-made premix

Fortification of vegetable oil

Oil fortification consists of adding appropriate amounts of vitamin A and D_3 concentrate to clarified degassed oil at 45-50°C The solubility of commercially available vitamin A and D_3 blends in vegetable oils is excellent

To ensure that the vitamins are uniformly distributed mixing takes place in vertical tanks that contain turbines or propeller agitators Edible antioxidants (BHA and/or BHT) or natural antioxidants (e g α-tocopherol or ascorbyl palmitate) may be added to protect both the vitamin A and the oil the stability of vitamin A in the oil depends greatly on the stability of the oil itself Vitamin A oxidizes faster and loses its activity in the presence of oxidized oils

To maintain vitamin A activity fortified oil needs to be packaged in light protected sealed containers Replacing the container headspace with inert gas will help retain the stability of both the oil and vitamin A prior to the container being opened but this is not usually a practical solution and adding an adequate micronutrient overage may be considered as an alternative

The production and fortification of margarine is carried out in a batch or continuous process The vitamin A and D_3 blend is premeasured according to the batch size of the margarine tanks and mixed with warm oil in a ratio of 1 5 until a uniform solution is obtained This premix is then incorporated into the margarine before the emulsifying process (Figure 2) ß Carotene is also added to margarine (15 to 20 g/ton of a 30% oily suspension) before the emulsification step to enhance the color as well as to contribute to the vitamin A content of the product ß-Carotene converts to vitamin A at a mean level of 555 IU/mg thus providing an additional 2 498 to 3,330 IU of vitamin A per kilogram at the above mentioned level

Stability of Micronutrients

Stability of vitamin A in storage

Studies conducted in Brazil showed that the stability of vitamin A in fortified soybean oil stored at room temperature (23°C) depends on the presence of oxygen and light (Figure 3) The stability of vitamin A in oil stored in sealed cans is excellent after 9 months However

if the oil is stored in open containers, where it is exposed to both oxygen and light the vitamin A becomes unstable after 6 months and just under 50 percent of the initial vitamin A remains after 9 months Stability studies in India showed almost 100 percent retention of vitamin A in fortified soybean oil after 5 months of storage in sealed cans

Vitamin A added to margarine is quite stable during the manufacturing process and during storage at home Table 3 shows that there were minimal losses of vitamin A in margarine after 6 months of storage at 5°C (refrigeration conditions) When the same margarine was stored at 23°C more than 85 percent of the initial vitamin A was retained after the same period of time

Stability of vitamin A during cooking

The stability of vitamin A in fortified soybean oil added to plain rice or kidney beans during cooking is good (Table 4) Boiling rice and pressure cooking kidney beans did not destroy the vitamin

Frying, however, can destroy vitamin A The amount lost depends on the number of times the same oil is used for frying foods (Figure 4) After the initial frying about 65 percent of the original vitamin A remained after 4 repeated fryings less than 40 percent of the original levels of vitamin A was retained, and after 12 consecutive fryings most of the vitamin A was lost Thus, how oil is used at the household level needs to be considered in determining whether oil can be a good vehicle for vitamin A

Vitamin A losses in margarine occur under extreme conditions Heating it to 160°C 180°C, or 200°C for one-half hour results in average vitamin A losses of 20, 35, and 50 percent, respectively Vitamin A, however survives the baking process in biscuits cakes and breads prepared with vitamin A fortified margarine between 80 and 100 percent of the added vitamin remains

Stability of vitamin D_3

The stability of Vitamin D_3 is similar to that of vitamin A, little or no loss is experienced during processing or storage

Stability of vitamin E

Vitamin E losses occur during prolonged heating, such as frying Furthermore the production of hydroperoxides during frying accelerates the degradation of vitamin E

Acceptability of Fortified Margarine and Oils

Fortifying margarine with vitamins A D and E does not alter its flavor making it an excellent carrier for these micronutrients Foods made with fortified soybean oil including mayonnaise fried beans, cooked rice, fried potatoes soup, wheat tortillas, and fried meat showed excellent acceptability among consumers who were not able to distinguish between products prepared with either vitamin A fortified or unfortified oil

Studies in humans have shown that the bioavailability of vitamin A in cooked foods made with fortified soybean oil is good (Figure 5)

Quality Control

Determination of vitamins A D and E in oil and margarine is done by HPLC This method is based on the separation of the specific vitamins from other substances that absorb radiant energy at an equal or similar wavelength to the specific vitamin It is accurate but the equipment is expensive and highly trained personnel are required

Measuring the amount of micronutrients to add and the process of their addition to oil or margarine, requires careful attention to ensure that the final fortified product is both homogeneous and standardized

Table 3
Retention of Vitamin A in Commercial Margarine

Brand	Initial Level (IU)	After 6 Month Storage at 5°C	After 6 Month Storage at 23°C
A	13 900	14 700	13 600
B	14 200	13 400	12 700
C	13 500	12 400	11 500
D	12 300	12 100	12 300
E	12 400	12 100	10 900

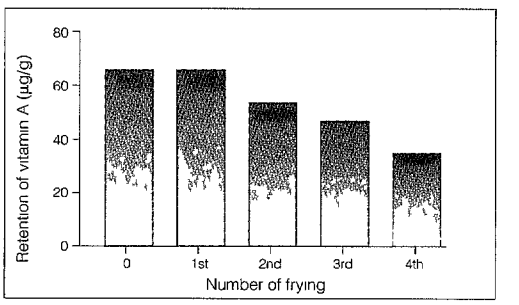
Source Bauernfeind J C 1978 The Technology of Vitamin A Hoffmann La Roche Basel Switzerland

Table 4
Stability of Vitamin A in Soybean Oil During Cooking

Food	Type of cooking	Amount of Vitamin A (µg/g) Before cooking	Amount of Vitamin A (µg/g) After cooking	Recovery (%)
White rice	Boiled	330	330	100
Kidney beans	Boiled	180	150	83
Kidney beans	Pressure cooked	120	120	100

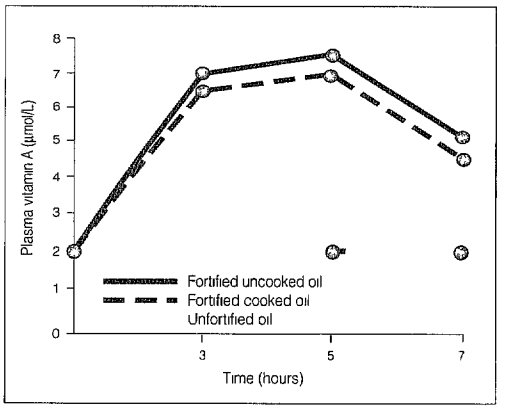
Source Favaro R J Ferreira I Desai and J Dutra de Oliveira 1991 Studies on Fortification of Refined Soybean Oil with All trans Retinyl Palmitate in Brazil Stability During Cooking and Storage J Food Comp Anal 4 237 244

Figure 4
Stability of Vitamin A in Fortified Soybean Oil After Repeated Fryings of Potatoes at 117-170°C



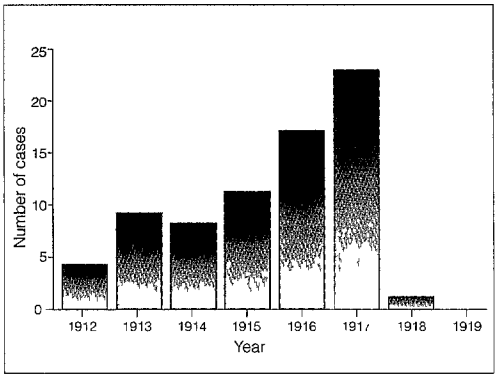
Source Favaro R J Ferreira I Desai and J Dutra de Oliveira 1991 Studies on Fortification of Refined Soybean Oil with All trans Retinyl Palmitate in Brazil Stability During Cooking and Storage J Food Comp Anal 4 237 244

Figure 5
Serum Retinol levels in Humans After Ingestion of Cooked and Uncooked Fortified Oil with Vitamin A



Source Dutra de Oliveira J E I Desai R M D Favaro and J F Ferreira 1994 Effect of Heat Treatment During Cooking on the Biological Value of Vitamin A Fortified Soybean Oil in Human Int J Food Sci Nutr 45 203 207

Figure 6
Distribution According to Year of Appearance of Xerophthalmia in 72 Patients Admitted to the Rigshospital, Copenhagen from 1912 to 1919



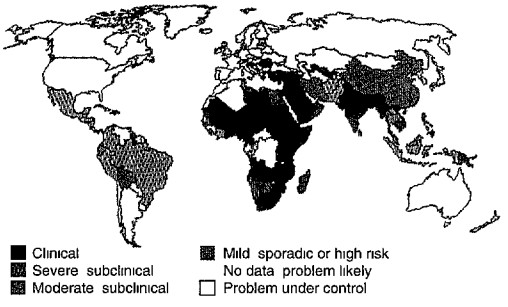
Source Bloch C E 1931 Effects of Deficiency in Vitamins in Infancy Am J Diseases of Children 42 271

Table 5
Vitamin A Deficiency in Newfoundland in 1944 and 1948

	1944	1948
Number of subjects	312	342
Percent of subjects with		
serum vitamin A < 20 µg/dl	48	2
serum vitamin A < 30 µg/dl	74	18
Mean serum vitamin A (µg/dl)	22	41

Source Aykroyd W R et al 1949 Medical Resurvey of Nutrition in Newfoundland 1948 Murray Printing Company 11 12

Countries Categorized by Degree of Public Health Importance of Vitamin A Deficiency



Source WHO XVII IVACG Meeting Guatemala 1996

Costs

The cost of fortification includes capital costs such as blending equipment (tanks propellers or agitators) and recurrent costs including those for the premix personnel and monitoring and evaluation

If margarine is fortified to provide 30 000 IU of vitamin A/Kg the cost of the fortificant would be in the order of US$ 0 0020/Kg when a vitamin A/D_3 blend is used The cost of vitamin A alone is around US$ 0 0017/Kg of product These estimates do not take in account the cost of new equipment and training of staff which are one-time costs and are likely to be small as well as the cost of quality control

Legislation

To ensure that a fortification program is successful an interdisciplinary task force with experts from the different, appropriate sectors should be set up The sectors include the vegetable oil industry and trade organizations, nutrition institutes universities the Ministry of Health regulatory institutions consumer associations and donors

A fortification plan should specify the type of micronutrients and levels to be added based on the consumption patterns of oil by different socioeconomic and age groups It must also define precautions and food safety conditions to be observed during production transportation, storage and sale of the products

History and Successful Interventions

The prevalence of xerophthalmia in Denmark declined drastically in 1918 and disappeared in 1919 (Figure 6) following the introduction of butter rationing (which made butter available at a low price and diminished consumption of non enriched margarine) at the end of 1917 Xerophthalmia reappeared in 1920 when butter rationing was discontinued thus eliminating access to an important source of natural vitamin A Such observations on the curative effects of milk fat but not of margarine eventually led to the enrichment of margarine with vitamin A

A successful intervention with vitamin A fortified margarine (45 IU vitamin A/g margarine) initiated in Newfoundland in 1944-45, led to a marked improvement in the vitamin A status as shown by biochemical measurements made in a sample of the population (Table 5)

Thirty years ago Pakistan agreed to fortify processed oil products with vitamin A at a level of 33 000 IU/kg Enforcement and monitoring has been weak as reflected in the levels of vitamin A in vegetable ghee, which were on average 15 000 IU/kg With an average vegetable ghee consumption of 30 g/person/day the ghee would provide about 30 24, and 15 percent of the RDI for infants children and pregnant women respectively

In the Philippines a collaborative effort between the public and private sectors resulted in the Star brand margarine being fortified with vitamin A 'Star margarine is fortified at a level of 25 µg RE/g (83 IU) and provides 95 percent of the RDI for children 1 to 10 years old when 15 grams/day (1 tablespoon) is consumed Other countries fortifying margarine with vitamins A and D are presented in Table 2

Sweden fortifies canola oil used in food aid programs with 15 mg vitamin A/g oil Canada has adopted an even higher level of 22 5 mg vitamin A/g canola oil used in food aid programs

Fortification Basics

Principles of Assay Procedures

Micronutrients added to foods are analyzed using various procedures depending on their nature and properties Some micronutrients can be detected using relatively simple colorimetric methods Where resources are available, more sophisticated methods such as high pressure liquid chromatography (HPLC) (Fig 1) which separates the compound of interest in a pre-treated food sample followed by spectrophotometric or fluorometric detection can also be used

Before starting a program for micronutrient analyses some essential elements need to be put in place

- A quality assurance system must be set up to ensure that the manufactured food is safe, unadulterated properly labeled, and meets all the company's specifications and government regulations (Table 1)
- Food samples must be representative and selected at random, with an adequate and reproducible sampling procedure
- Personnel must be trained in the assay method(s) that should have been previously identified or set-up
- Equipment required must be available on-site in working condition

Figure 1
HPLC Equipment

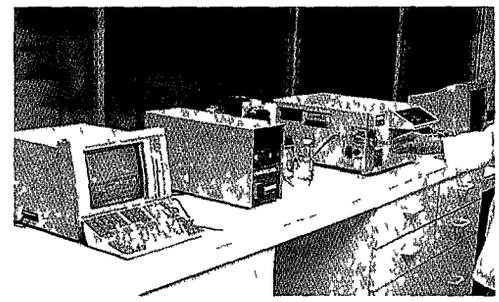


Table 1
Developing a Quality Assurance System

An effective quality assurance system includes

- *Ingredient inspection and control* testing all ingredients against reference standards
- *Manufacturing control* identifying quality criteria and chemical microbiological and physical hazards establishing and monitoring the critical control points involved in manufacturing fortified food
- *Distribution control* ensuring that the fortified food is unadulterated properly labeled and packaged to minimize micronutrient losses

Vitamin A assays

Vitamin A is one of the most unstable micronutrients Industrially produced vitamin A, like retinyl palmitate is more stable than naturally occurring vitamin A although it remains sensitive to air light moisture, heat and acid conditions

Vitamin A levels have been determined using colorimetric and spectrophotometric methods for a long time Currently HPLC is the method of choice (Table 2) The use of HPLC is preferred when samples have a significant amount of interfering substances such as other vitamins, minerals proteins, and carbohydrates

Semi-quantitative method
Colorimetric method

The colorimetric method involves adding a chromogenic reagent to a volume of solubilized fortified food sample The reagent reacts with retinol to produce a blue color whose intensity is proportional to the amount of retinol in the sample The intensity of the blue color is measured against a set of known standards (Fig 2) The formed blue color is very unstable and necessitates a fast and skillful worker Because this assay method is inexpensive and does not need sophisticated equipment it is used in many countries

Quantitative method
Spectrophotometric method

The sample is irradiated with UV light and its absorbance is measured The absorbance is proportional to the vitamin A content in the sample The spectrophotometric method can be used to monitor vitamin A levels in fortified products at the production level

Table 2
Vitamin A Assays and their Advantages and Limitations

Assay	Advantages	Limitations
Colorimetric	Simple Rapid Inexpensive	Semi quantitative Sample pretreatment Not applicable for field
Spectro photometric	Sensitive Rapid Inexpensive	Needs UV apparatus Sample pretreatment Not applicable for field
HPLC	Reliable High resolution No interferences Accurate	Expensive Training of personnel Sample pretreatment Not applicable for field

Figure 2
Semi - Quantitative Colorimetric Determination of Vitamin A in Sugar

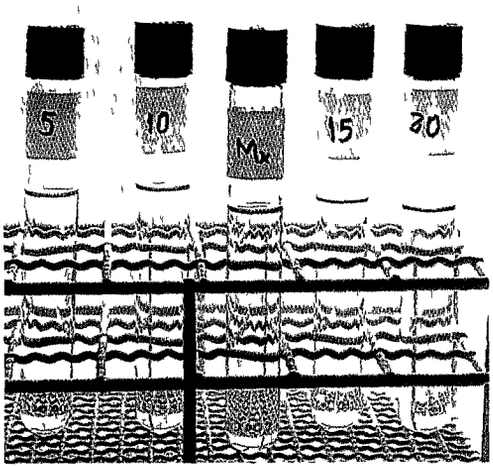


Figure 3
Vitamin A Determination by HPLC

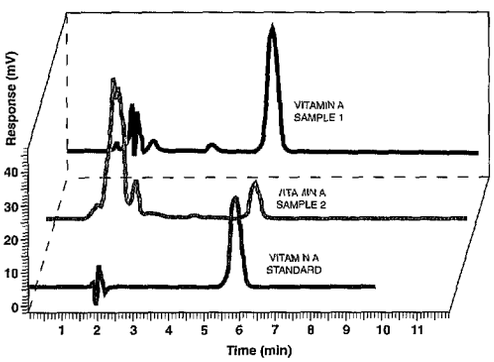
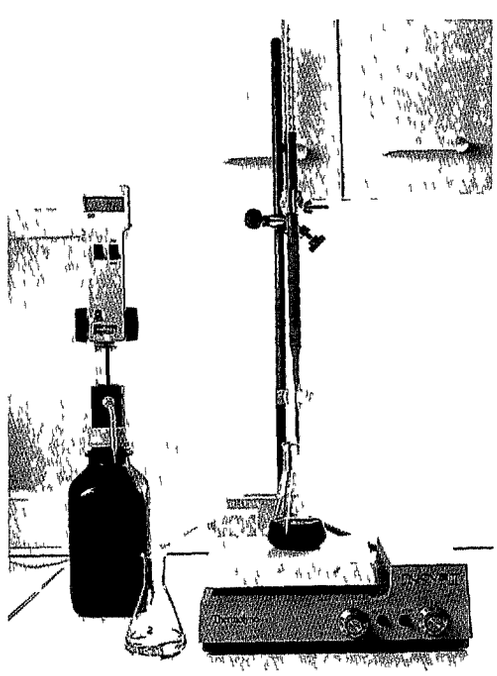


Figure 4
Titrimetric Determination of Vitamin C



HPLC method

In this method retinol is separated from other substances, which absorb radiant energy at equal or similar wavelengths to retinol using hexane Retinol is then detected using spectrophotometric or fluorometric techniques A typical HPLC chromatograph of retinol analysis is presented in Figure 3 The HPLC method is very reliable mainly because of its ability to effect rapid separation and the high resolution achieved High costs of equipment and time required do not permit several measurements per shift Highly trained personnel are also required

Vitamin B-complex assays

Thiamin (vitamin B_1) is analyzed quantitatively by fluorometric methods The method of choice is the thiochrome procedure which involves treatment of thiamin with an oxidizing agent (ferricyanide or hydrogen peroxide) to form a fluorescent compound (thiochrome) The intensity of fluorescence is proportional to the thiamin concentration

Riboflavin (vitamin B_2) is usually assayed fluorometrically by measuring its characteristic yellowish green fluorescence It can also be assessed microbiologically, using *Lactobacillus casei* where the growth of this riboflavin-dependent microorganism correlates with the amount of vitamin in the sample The growth response of the organism is measured either by titration or by measuring turbidity

Niacin is assayed semi-quantitatively with sulfanilic acid to yield a yellow color The intensity of the yellow color correlates with the amount of niacin present, which is measured against a set of standards Niacin can be quantitatively determined using microbiological assays (*Lactobacillus plantarum*) or colorimetric methods (cyanogen bromide as the color reagent) Microbiological assays are preferred over colorimetric methods for foods containing high levels of Maillard browning products (for example cocoa products) in order to minimize color interference

Microbiological assays for quantifying pyridoxine (vitamin B_6) and its isomers pyridoxal and pyridoxamine rely on the growth response of *Saccharomyces uvarum*

Microbiological assays are also used for quantitative determination of folic acid, pantothenic acid and vitamin B_{12} in foods The test organisms used in folate assays are *Streptococcus faecalis* or *Lactobacillus casei* *Saccharomyces carlbergensis* and *Lactobacillus plantarum* are common test organisms used in determining pantothenic acid because they do not grow in the absence of pantothenic acid Similarly vitamin B_{12} can be determined using microbiological assays with the test organism *Lactobacillus leichmannii*

High pressure liquid chromatography (HPLC) methods to determine most B-complex vitamins have been considered and evaluated but have not yet been validated as official methods by the Association of Official Analytical Chemists (AOAC) There is ongoing interest in developing and validating these methods Techniques also exist for simultaneous determination of all water-soluble vitamins by HPLC using UV/visible spectrophotometric detection

Vitamin C assays

Vitamin C can be quantitatively analyzed by either titrimetric or fluorometric methods The titrimetric method (Fig 4) involves the measurement of decolorization of 2 6-dichloroindophenol dye by ascorbic acid This method is not suitable for highly colored products (for example colored fruit juices) because of the difficulty of determining the endpoint during titration The fluorometric method involves oxidation of ascorbic acid to dehydroascorbic acid which reacts with phenylene diamine

to produce a fluorescent compound whose intensity is proportional to the vitamin C concentration

Vitamin D assays

Vitamin D is quantitatively determined using liquid chromatography After saponification and extraction of the sample purification is achieved by sequentially using alumina and silica columns

Vitamin E assays

Vitamin E levels can be determined spectrophotometrically although the HPLC method with fluorescence detection is preferred as it permits the measurement of different forms of vitamin E, thus, total vitamin E activity However, it is a sophisticated technique and requires trained personnel to execute the analysis

Iron assays

Qualitative method

This method is applicable for qualitative determination (presence or absence) of iron in enriched or iron-fortified flour Ferric iron added to flour reacts with a thiocyanate (KSCN) reagent to form a red colored complex A deeper red color will be formed with enriched and fortified flour compared with the untreated flour

Quantitative methods

Quantitative iron assays involve extraction and detection

Iron extraction Iron extraction can be done by dry or wet ashing

Dry ashing

The sample is dried overnight in a muffle furnace at 500 to 600° C followed by acid hydrolysis in the presence of hydrochloric acid

Wet ashing

The sample is hydrolyzed with concentrated sulfuric acid at high temperature and/or pressure Iron extraction is more complete using wet ashing, but there are risks in handling hot, concentrated acids

Iron detection Once the iron has been extracted, it is detected using colorimetric or atomic absorption spectrophotometric (AAS) methods

Colorimetric methods

Reagents that produce changes in color depending on the level of iron in the food are utilized For this method iron is reduced to the ferrous form with a suitable agent (hydroxylamine hydrochloride or ascorbic acid) after which the reduced iron is reacted with an appropriate color agent (α-dipyridyl or orthophenanthroline) Orthophenanthroline does not react with most organic constituents (carbohydrates, lipids and proteins), hence is regarded as the best color reagent for analyzing samples with high organic matter

AAS method

This method can be used to detect and quantify iron (and other minerals) from a single extraction using an atomic absorption spectrophotometer Iron in solution is atomized and the absorbance is measured at a wavelength specific to iron (248 nm) It is an expensive method and requires skilled

Table 3
Iron Assays and their Advantages and Limitations

Assay	Advantages	Limitations
Spectro photometric	Sensitive Simple Inexpensive Rapid detection	Needs UV apparatus Needs overnight ashing Not applicable for field
AAS	Reliable Sensitive Accurate Rapid detection Ideal for large sample	Expensive equipment Training of personnel Needs overnight ashing Not applicable for field

Figure 5
Positive and Negative Spot Tests for Iodine in Salt

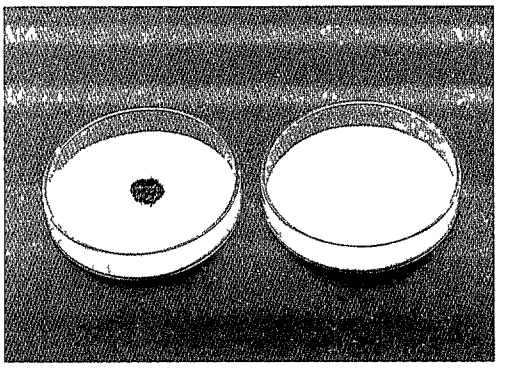


Table 4
Iodine Assays and their Advantages and Limitations

Assay	Advantages	Limitations
Spot tests	Simple Rapid Inexpensive Field friendly	Not quantitative
Titrations	Accurate Simpler than LC Rapid Inexpensive	Training of personnel Not applicable for field
LC	Sensitive Accurate Reliable No interferences	Expensive Training of personnel Sample pretreatment Not applicable for field

Table 5
List of Suppliers for Laboratory Equipment, Chemicals, and Fortificants

Aldrich P O Box 355 Milwaukee WI 53201 9358	Tel (414) 273 3852 Fax (414) 273 4979	Chemicals Glassware Lab equipment
BASF 6700 Ludwigfhafen Rhein Ludwigfhafen Germany	Tel (049) 621 600 Fax (049) 622 525	Fortificants Premixes
Beckman Instruments Inc 2500 Harbor Blvd Fullerton CA 92634	Tel (714) 871 4848 Fax (714) 521 3700	Spectrophotometer Chromatography equipment
Fisher Scientific 711 Forbes Ave Pittsburgh PA 15219 4785	Tel (412) 490 8300 Fax (201) 379 7638	Chemicals Glassware
F Hoffmann La Roche Ltd CH 4002 Basel Switzerland	Tel (061) 688 1111 Fax (061) 691 9600	Fortificants Premixes
Millipore Intertech P O Box 10 Marlborough MA 01752	Tel (508) 624 8400 Fax (508) 624 8630	Centrifuge Filtration devices
NIST[a] Bldg 202 Room 204 Gaithersburg MD 20899	Tel (301) 975 6776 Fax (301) 948 3730	Standards Reference materials
Perkin Elmer 761 Main Ave Norwalk CT 06859 0012	Tel (203) 762 1000 Fax (203) 762 6000	AAS instrument Chromatography equipment
Sarstedt P O Box 468 Newton NC 28658 0468	Tel (704) 465 4000 Fax (704) 465 4003	Biological assays
Sigma Chemical Co P O Box 14508 St Louis MO 63178 9916	Tel (314) 771 5750 Fax (314) 771 5757	Chemicals Test kits
VARIAN[b] 220 Humboldt Court Sunnyvale CA 94089	Tel (408) 734 5370 Fax (408) 744 0261	Spectrophotometer Chromatography equipment
UNICEF Supply Division UNICEF Plads Free port DK 2100 Copenhagen Denmark	Tel (45) 3 527 3527 Fax (45) 3 526 9421	Iodine spot test kits

[a] National Institute of Standards and Technology
[b] Parts and supplies center
Modification of the original table by Dary O G Arroyave H Flores F A C S Campos M H C B Lins 1996 Sugar Fortification with Vitamin A Part 3 Analytical methods for the control and evaluation of sugar fortification of vitamin A USAID/INCAP

personnel to optimize operating parameters AAS can also be used to simultaneously determine the content of other minerals including calcium copper magnesium manganese and zinc

The advantages and limitations of iron assays are shown in Table 3

Iodine assays

Qualitative method
Spot tests
Spot tests can be used in qualitative determinations of iodine in salt Qualitative iodine tests indicate only the presence or absence not the amount of iodine in salt (Fig 5) Spot tests are specific to the form of iodine in salt In the case of samples fortified with *iodide* salt iodide is oxidized with an acidic solution to liberate free iodine which then turns starch blue Salt fortified with *iodate* is analyzed with iodate spot tests where iodate in salt oxidizes an iodide reagent in the presence of hydrogen ions to form free iodine which turns starch blue

Quantitative methods
Titration method
Like spot tests titration procedures also are specific to the form of iodine in salt In samples fortified with *iodate* addition of an acidic solution liberates free iodine from salt iodate Free iodine is then titrated with thiosulfate and the amount of thiosulfate used is proportional to the amount of iodine in salt In salt fortified with *iodide* bromine oxidizes iodide ions to free iodine which is titrated with thiosulfate solution It is a fairly simple and rapid technique compared with the liquid chromatography method However it requires personnel with good laboratory skills

Liquid chromatographic method
Iodine can be quantitatively determined using liquid chromatography (LC) The sample is pretreated by passing it through a membrane filter to remove protein and other insoluble materials Iodide in the filtrate is separated by ion pair liquid chromatography and detected electrochemically at 0 to 50 mV It is a quick and sensitive method ideal for analyzing a large number of samples However it is an expensive method and requires skilled personnel to perform the analyses

The advantages and limitations of iodine assays are presented in Table 4

References

For details on any of the methods above please refer to
1 AACC 1994 Approved methods of the American Association of Cereal Chemists Eighth edition American Association of Cereal Chemists Inc Minnesota USA
2 AOAC 1993 Methods of analysis for nutrition labeling Edited by D M Sullivan and D E Carpenter Association of Official Analytical Chemists International Arlington, Virginia USA
3 Dustin J P and Ecoffey J P 1978 A field test for detecting iodine-enriched salt Bulletin of the World Health Organization 56(4) 657-658

The success of a fortification program depends on a number of factors including the stability of micronutrients added to the food Prior to selecting the fortificant(s) it is important to consider the factors affecting its/their stability

Physical and chemical factors include heat moisture exposure to air or light and acid or alkaline environments The exposure of the fortificant to any of these factors during food processing distribution or storage affects its stability The sensitivity of vitamins to various physical and chemical factors is presented in Table 1

Vitamin Stability During Processing and Storage

Food processing has the potential to alter the stability of vitamins in food The use of stabilized encapsulated forms of vitamins has greatly improved the resistance of vitamins to severe processing and storage conditions

The stability of *vitamin A* in fortified wheat and corn flour is excellent Studies show that wheat flour (see Table 2) and yellow corn flour, stored under normal conditions retain over 95 percent of their vitamin A after six months at room temperature However, the stability of vitamin A under high storage temperatures is not as good Wheat flour stored for three months at 45°C retained only 72 percent of vitamin A (see Table 3)

Baking fortified bread causes only limited losses of vitamin A (Table 4) while frying has an adverse effect on the stability of the vitamin After an initial frying of vitamin A-fortified soybean oil about 65 percent of the original vitamin A remained however after four repeated fryings less than 40 percent of the original level of vitamin A was retained (Figure 1)

The stability of *vitamin E* depends on its form, dl-α-tocopheryl-acetate being the most stable Vitamin E occuring naturally in foods in the form of a-tocopherol oxidizes slowly when exposed to air However vitamin E added in the form of α-tocopheryl acetate shows excellent retention in wheat flour (see Tables 2 and 3) Losses of vitamin E occur only during prolonged heating such as in boiling and frying

Thiamin (vitamin B_1) is one of the most unstable B vitamins Baking pasteurization or boiling of foods fortified with thiamin can reduce its content by up to 50 percent The stability of thiamin during storage depends greatly on the moisture content of the food Flours with a 12 percent moisture content retain 88 percent of the added thiamin after five months If the moisture level is reduced to 6 percent no losses occur Thiamin riboflavin and niacin are stable during bread baking between 5 to 25 percent of the vitamins are lost (Table 4)

Riboflavin (vitamin B_2) is very stable during thermal processing storage and food preparation Riboflavin however is susceptible to degradation on exposure to light The use of light-proof packaging material prevents its deterioration

Niacin is one of the most stable vitamins and the main loss

Table 1
Sensitivity of Vitamins

	Light	Oxidizing agents	Reducing agents	Heat	Humidity	Acids	Alkalis
Vitamin A	+++	+++	+	++	+	++	+
Vitamin D	+++	+++	+	++	+	++	++
Vitamin E	++	++	+	++	+	+	++
Vitamin K	+++	++	+	+	+	+	+++
Vitamin C	+	+++	+	++	++	++	+++
Thiamin	++	+	+	+++	++	+	+++
Riboflavin	+++	+	++	+	+	+	+++
Niacin	+	+	++	+	+	+	+
Vitamin B6	++	+	+	+	+	++	++
Vitamin B12	++	+	+++	+	++	+++	+++
Pantothenic Acid	+	+	+	++	++	+++	+++
Folic Acid	++	+++	+++	+	+	++	++
Biotin	+	+	+	+	+	++	++

+ Hardly or not sensitive ++ Sensitive +++ Highly sensitive

Source F Hoffmann La Roche Basel

Table 2
Vitamin Retention in Wheat Flour with 9% Humidity Stored at Room Temperature

Nutrient	Level per Kg				
	Label	Initial	2 mo	4 mo	6 mo
Vitamin A IU	16 534	18 078	18 078	17 681	17 526
Vitamin E IU	33 07	35 05	35 05	35 05	35 05
Vitamin B_6 mg	4 41	5 18	4 85	5 07	4 85

Source Cort W M B Borenstein J H Harley M Osadca and J Scheiner 1975 Nutrient stability of fortified cereal products 35th IFT Meeting Chicago IL

Table 3
Vitamin Retention in Wheat Flour with 9% Humidity Stored at 45°C

Nutrient	Level per Kg				
	Label	Initial	1 mo	2 mo	3 mo
Vitamin A IU	16 534	18 078	16 534	14 175	12 919
Vitamin E IU	33 07	35 05	35 05	35 27	35 49
Vitamin B_6 mg	4 41	5 18	4 85	4 85	4 63

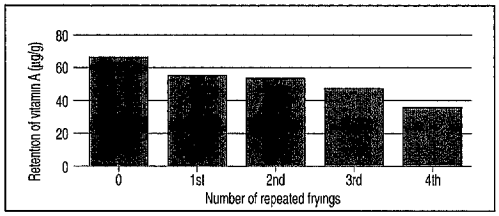
Source Cort W M B Borenstein J H Harley M Osadca and J Scheiner 1975 Nutrient stability of fortified cereal products 35th IFT Meeting Chicago IL

Table 4
Vitamin Losses During Typical Bread Baking

Nutrient	% Loss during baking
Vitamin A	10 20
Thiamin	15 25
Riboflavin	5 10
Niacin	0 5
Folic Acid	20 30

Source F Hoffmann La Roche Unpublished Data Basel

Figure 1
Stability of Vitamin A in Fortified Soybean Oil After Repeated Fryings of Potatoes at 117-170°C



Source Favaro R J Ferreira I Desai and J Dutra de Oliveira 1991 Studies on fortification of refined soybean oil with all trans retinyl palmitate in Brazil Stability during cooking and storage J Food Comp Anal 4 237 244

Table 5
Stability of Vitamin-Iron Premix in Yellow Corn Flour (6 5% Moisture Level) Stored at Room Temperature

Nutrient	Level per lb		
	Initial	3 mo	6 mo
Vitamin A (250 SD) IU	6000	5820	5880
Thiamin (vitamin B1) mg	3 2	3 2	3 1
Riboflavin (vitamin B2) mg	2 0	1 8	1 9
Niacin mg	26 0	25 7	na
Pyridoxine (vitamin B6) mg	4 5	4 0	4 5
Folic acid mg	0 6	0 5	0 5
Iron mg	41 0	39 0	40 0

na = not available
Source Rubin S H A Emodi and L Scalpi 1977 Micronutrient addition to cereal grain products Cereal Chem 54 (4) 895 903

Table 6
Stability of Vitamin C in Fortified Foods and Beverages Stored for 12 Months at 23°C

Product	Mean retention (%)
Ready to eat cereal	71
Dry fruit drink mix	94
Cocoa powder	97
Apple juice	68
Cranberry juice	81
Grapefruit juice	81
Pineapple juice	78
Tomato juice	80
Vegetable juice	68
Grape drink	76
Orange drink	80
Carbonated beverages	60
Evaporated milk	75

Source De Ritter E 1976 Stability characteristics of vitamins in processed foods Food Technology 30 (1) 43 54

occurs from leaching into cooking water Thiamin riboflavin and niacin fortified spaghetti retained 96 78 and 94 percent of their initial levels respectively after three months of storage in the dark followed by boiling for 14 minutes

Pyridoxine (vitamin B_6) losses depend on the type of thermal processing For example high losses of B_6 occur during sterilization of liquid infant formula in contrast B_6 in enriched flour and corn meal is resistant to baking temperatures B_6 is susceptible to light induced degradation and exposure to water can cause leaching and consequent losses However vitamin B_6 is stable during storage wheat flour stored at either room temperature or 45°C retained about 90 percent of the vitamin (see Tables 2 and 3)

Folic acid is unstable and loses its activity in the presence of light oxidizing or reducing agents and acidic and alkaline environments However it is relatively stable to heat and humidity thus premixes baked products and cereal flours retain almost 100 percent of the added folic acid after six months of storage Over 70 percent of folic acid added to wheat flour is retained during bread baking (Table 4)

Pantothenic acid is stable to heat in slightly acid to neutral conditions but its stability decreases in alkaline environments *Biotin* is sensitive to both acids and bases Good stability of various micronutrients during storage of fortified corn flour has been demonstrated (Table 5)

Ascorbic acid (vitamin C) is easily destroyed during processing and storage through the action of metals such as copper and iron Both exposure to oxygen and prolonged heating in the presence of oxygen destroy ascorbic acid thus the stability of vitamin C in fortified foods depends on the product processing method and type of packaging used Vitamin C retention in fortified foods and beverages stored for 12 months at room temperature ranges from 75 to 97 percent (Table 6)

Mineral Stability During Processing and Storage

Minerals are more resistant to manufacturing processes than vitamins However they do undergo changes when exposed to heat air or light Minerals such as copper iron and zinc are also affected by moisture and may react with other food components such as proteins and carbohydrates Minerals can be also lost through leaching into cooking/processing water as in the case of fortified rice where the rice grain is coated with the fortificant

Various forms of iron are used in fortification Among the most popular ones are ferrous sulphate and elemental iron powders because of their relatively high bioavailability Other potential iron sources include ferric orthophosphate sodium iron phosphate ferrous fumarate and iron-EDTA The stability of different forms of iron depends on various factors including the nature of the food it is added to particle size and exposure to heat and air

Due to its reactive nature ferrous sulfate is known to hasten the development of oxidative reactions resulting in off-flavors colors or odors When added to bakery flour levels higher than 40 ppm or storage for more than 3 months under high temperatures and humidity have been found to cause rancidity and taste deterioration

Elemental iron as reduced iron or electrolytic iron is used to fortify ready-to-eat breakfast cereals and has been found

to have excellent stability during processing and storage Reduced iron is generally the preferable form in flour when long shelf-life is desired However when used in bread and flour enrichment the finer particles tend to discolor the product Coarser particles have a tendency to segregate on pneumatic conveying systems and may be extracted by magnets that are used to remove contaminants

Effect of Packaging

Products that are improperly packaged and subsequently transported over long distances under hot and humid conditions experience micronutrient losses Vitamin A added to sugar is more stable in cold and dry conditions than in hot and humid environments (Table 7)

Packaging selection is greatly influenced by shelf-life considerations and cost Vitamin A must be protected from oxygen and light, vitamin C from oxygen and riboflavin and pyridoxine from light In liquid products such as beverages, milk and oils oxygen can quickly degrade vitamin A and C Glass containers are the best choice for these fortified products because they are not permeable to oxygen However glass is heavy fragile and expensive so plastics are often used instead Oxygen readily passes through plastic and will be in contact with the product This problem can be overcome by adding the appropriate plastic coatings and/or an appropriate overage of the most sensitive micronutrients such as vitamin A Figure 2 shows the stability of vitamin A in fortified sugar packaged in different materials Light-proof containers for example, dark glass or dark plastic, cans and aseptic boxes will minimize the exposure to light Because of high costs and the lack of availability of packaging material in developing countries, packaging assumes great importance and should be a major factor to consider at the beginning of a fortification program

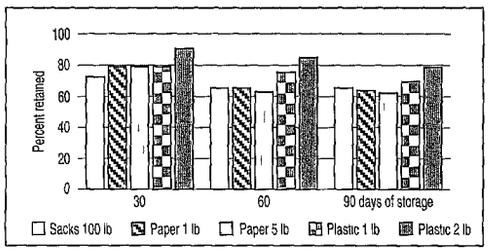
Table 7
Stability of Retinol in Fortified Sugar (% Retention)

Environment	Months of storage (12 5 lb bags)		
	3	6	9
Cold humid [1]	90	77	66
Hot dry [2]	92	71	63
Temperate humid [3]	83	69	43
Hot humid [4]	80	62	40

[1] 13 5°C 75% humidity [3] 18 8°C 79% humidity
[2] 27 7°C 63% humidity [4] 25 8°C 75% humidity

Source De Canahui E M M O Dary L De Leon 1996 Retinol stability in fortified sugar in Guatemala XVII IVACG Meeting Guatemala

Figure 2
Effect of Storage on the Stability of Vitamin A in Fortified Sugar Packaged in Different Materials



Source De Gracia M S FE Munllo 1993 Estabilidad de vitamina A en azucar fortificada resumen ejecutivo INCAP/Universidad de Panama

Table 8
Recommended Overages for Selected Nutrients and Vehicles Based on Losses During Processing

	Vitamins											Minerals	
Food	B Car	A	D	E	B_1	B_2	Niacin	B_6	B_{12}	Folic acid	C	Fe	Ca
Cereals													
Wheat flour		20	15	10	10	10	10	10		10		5	5
Wheat bread		30 40	25 35	20	20	10	10 30	10		25 50	N R	5	5
Corn flour		20	15	10	10	10	10	10		10	N R	5	5
Corn bread		40			10	20	10						
Corn Meal		10 30	20	20	20 50	20 30	15 30	5 25	25	50 100	30 70	5	5
Rice cooked		40			50	40	30			0 10		5	
Pasta	10	50			40	30	20	30		30		5	
RTE cereals	10	30 50	30 40	10 30	30 40	25 40	20 30	30	40 50	30 40	30 50	5	5
Noodles		25											
Cookies	10	30 65	30 40	40	40 70	30 100	20 50	30 50	30 40	40 80	N R	5	5
Arepas		35			10	20	10						
Milk													
Pasteurized	10	20	20	10	25	15	15	30	15	20	30	5	5
UHT	20	30	30	30	50	40	20	30	30	40	100	5	5
Dry milk	10	40	40	20	20	20	20	20 30	40	40	50	5	5
Milk desserts	0 10	20	20	10	25	15	15	30	20	20	30	5	5
Fats													
Oil	10	30	30	15									
Margarine	10	30	25	15	20	20	15	20	50	50			
Drinks													
Juices	5 15	30 40	40	15 25	40 50	30 40	20 25	30 50	70	30 60	20 80		
Drink mixes	5	15	15	10	10	10	10	10		10	10		
Other													
Sugar		15 20											

based on 3 months of storage at room temperature
based on 6 months of storage at room temperature after boiling/cooking
based on 1 month of storage at 27 45 C temperature
Varies greatly with preparation form
N R Not Recommended

Source F Hoffmann La Roche Unpublished data Basel

The shelf-life of foods processed at very high temperatures (aseptic processes) such as milk, can exceed one year and storage losses over this time must be taken into consideration in the calculation of required overages

Fortification levels should be monitored at factory retail and household levels In large countries, or in situations where transportation results in a long lag period between production and consumption regular monitoring at intermediate levels (distributor and wholesaler) may be needed to provide more rapid feedback and to indicate whether the fortified product has the adequate fortificant levels

Overage

The way food is handled before its consumption can negatively influence the content of micronutrients naturally present or added to the food Even with all the precautions taken to ensure the stability of micronutrients in food some losses still do occur during processing distribution and storage Consequently special attention must be paid to identify the best fortification technology as well as the corresponding overages 'Overage' refers to the additional amount of fortificant added to the food to compensate for losses which will ensure that the fortified food delivers the targeted level of nutrients at the time the food is used at home

The following example illustrates how overages are calculated

Target Wheat flour to be fortified with niacin at 40 ppm

- Estimated loss during processing 10%
- Amount remaining after processing (100 - 10) 90%
- Estimated loss during storage 20%
- Amount lost is 90% x 0 20 18%
- Amount remaining (90 - 18) 72%

Target amount of niacin 40 ppm

Amount of niacin to be added to wheat flour is

- 1 / amount remaining x target amount 1 / 0 72 x 40 ppm 56 ppm
- an overage of (56 - 40 ppm) 16 ppm

Table 8 provides approximate overages of selected nutrients to be added when fortifying different foods It should be noted however that these overages are based on processing losses only and additional overages may be necessary depending on storage time temperature and humidity conditions

Organoleptic Properties

For a food fortification program to be effective there should be no changes in color flavor smell or appearance of the fortified food The method of preparing the food also should not be altered

Changes in color occur due to the reactivity and concentration of micronutrients used Undesirable color changes are detected in corn flour for example when the level of riboflavin exceeds 2 5 mg/Kg or when ferrous sulfate is used as the source of iron under conditions of high humidity Some color problems can be avoided by changing the fortificant form by combining it with another source or by reducing the fortification levels

The most reactive micronutrients, e g iron shorten the shelf-life of certain products The addition of minerals to foods that contain fat such as milk margarine and wheat and corn flours can also cause off-flavors due to lipid oxidation Iron is a pro-oxidant and is involved in major flavor changes in fortified foods especially those that require longer shelf-life including wheat and corn flour Iron may also catalyze the oxidation of vitamins A and C

Conclusions

In general many physical and chemical factors have a negative impact on the stability of micronutrients naturally present or added to foods However the stability of micronutrients in fortified foods can be ensured if the food is packaged and stored appropriately Where necessary an overage of fortificant should be added to compensate for losses during processing distribution and storage

Fortification Basics

Sugar

Rationale

Sugar is an important source of energy for many people throughout the world It is produced in over 100 countries and production of sugar is increasing, especially in South America (Table 1) Sugar processing and refining is carried out at only a few mills in sugar producing countries while sugar refining only is done in some sugar importing countries For these reasons, fortifying sugar with micronutrients is both practical and feasible In addition, sugar is eaten by the vast majority of people on a regular basis, although consumption levels do vary (Table 2), thus, fortification is an effective means to provide nutrients that are deficient in the population

Among the micronutrient deficiencies, vitamin A deficiency is one of the most widespread, affecting more than 250 million children throughout the world (Fig 1) One approach to eliminating this problem has been the fortification of sugar with vitamin A

Fortification Criteria

The objective is to ensure that vitamin A needs are met for the groups at greatest risk of deficiency without resulting in excessive intakes for individuals having a high sugar intake

The level of vitamin A to be added is determined by nutritional requirements and sugar consumption patterns thus, nationally representative data disaggregated by socio-economic status and age groups are needed Children under 5 years old are most vulnerable to vitamin A deficiency, and their recommended daily allowance is 400 µg RE (1,330 IU) per day Pregnant women are also at high risk of deficiency, and their reccomended daily allowance is 600 µg RE (2,000 IU)

If, for example, the average sugar intake of children under five years old is 20 grams per day and that for adults in the highest consuming group is 150 grams per day, 15 µg of vitamin A per gram of sugar will both satisfy needs and remain below the maximum acceptable limit

Technology

Because the quantity of vitamin A being added is so small production of an homogeneously fortified product is facilitated by diluting the retinyl palmitate (the form of vitamin A used in fortification) in a small amount of sugar to form a premix

Premix contains

- Regular sugar
- Cold water soluble vitamin A palmitate beadlets containing 75,000 µg /g (250,000 IU/g)
- A low peroxide, low in unsaturated fat vegetable oil (e g coconut or peanut), which adheres the vitamin A beadlet to the sugar crystal (Fig 2) This prevents the separation of the vitamin A from the sugar crystal and results in an homogeneously fortified product, without noticeable changes in the sugar's organoleptic properties

Table 1
Regional and World Sugar Production ('000MT) [1]

Region	1988	1994
Central America	15,000	11,500
S America	13 000	17 000
Africa	8,000	7,000
Asia	26 500	33 300
Europe	31,500	27 300
N America	6 500	7,000
Oceania	4 200	5 800
World Total	104,700	110,300

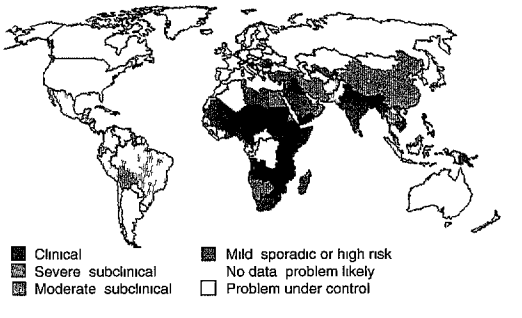
1 International Sugar Organization 1995

Table 2
Per Capita Sugar Consumption, and Percent of Daily Energy Intake in Selected Countries

Country (1994)	Consumption (g/person/day) [1]	% of daily energy intake [2]
Brazil	127	17
Peru	88	14
Guatemala	110	15
Honduras	85	12
India	42	5
Indonesia	42	5
Morocco	88	11
Mali	22	2
Egypt	80	10
Zambia	31	8
Cameroon	17	3
South Africa	100	15

1 International Sugar Association 1995
2 FAO Food Balance Sheets 1984 1986 average

Figure 1
Countries Categorized by Degree of Public Health Importance of Vitamin A Deficiency



WHO XVII IVACG Meeting Guatemala 1996

Figure 2
Vitamin A Beadlet Adhered to Sugar Crystal

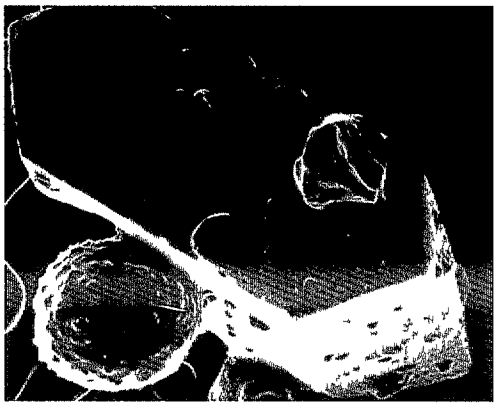


Figure 3
V-type Mixer and Oil Deposit

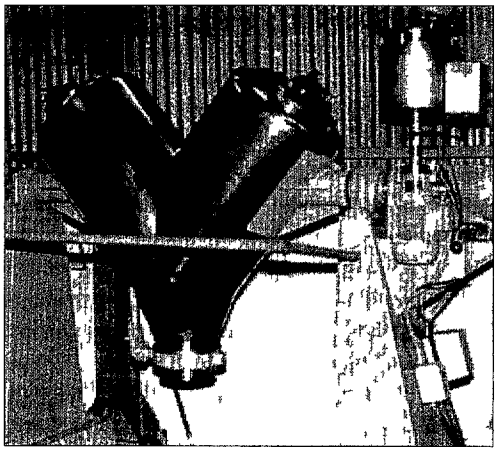
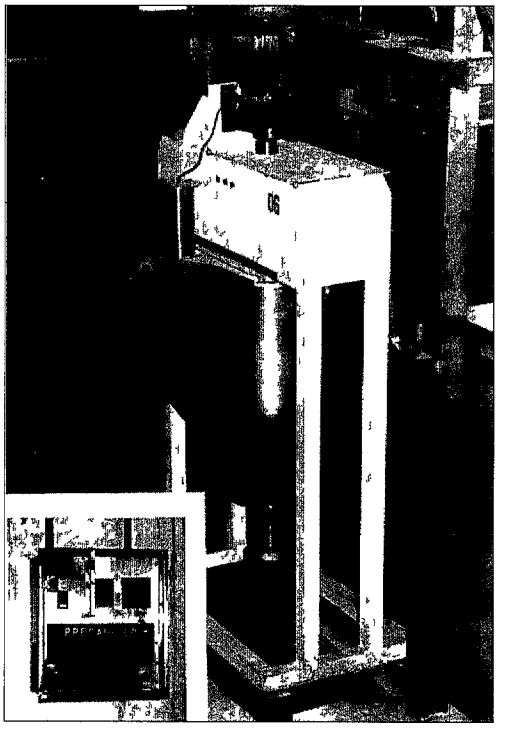


Figure 4
Automatic Dosifier and Control Panel



- An antioxidant blended from natural antioxic › (ascorbyl palmitate DL-alpha tocopherol and lecithin prevent the oil from going rancid Rancid oil destabilizes ramin A and has adverse effects on the sensory characte cs of sugar Blending the oil and antioxidant in an inert oxygen-free atmosphere i e , in the presence of nitrogen gas, prevents oxidation of the oil

Premix Composition

Ingredients	Amount	Units
Sugar	76 35	Kg
Vitamin A 250 CWS	22 03	Kg
Peanut oil	2	L
Antioxidant	0 008	Kg
TOTAL	100	Kg

Premix is made by mixing the sugar and vitamin A in a blender (generally a V-type, Fig 3) with a spraying device attached to it that allows the oil-antioxidant mixture to be added during the mixing operation
After 10 to 20 minutes of mixing, the premix is packaged in 25 Kg black polyethylene bags covered with polypropylene bags This minimizes exposure to light thereby preventing the destruction of retinol This premix is added to sugar in a ratio of 1 1000
The addition of premix to sugar can be done manually or automatically In manual operations, the premix is added into the centrifuges This method is not ideal because the accuracy of the amount of premix added is dependent on the operator In automatic operations (Fig 4) feeders can be placed in different sites along the production line (Fig 5) The best site is where the humidity and temperature are lowest, which would be just before packaging This is not always possible because of limitations in the amount of space available Fortified sugar is packaged in polyethylene bags

Stability of Retinyl Palmitate

An industrially produced encapsulated vitamin A compound that is dry, solid, and miscible in water, facilitated the development of fortification technology Despite its excellent stability, 250-CWS is still sensitive to air light moisture heat, and acids, thus, appropriate handling and storage conditions of the premix and fortified sugar are important

In the premix and, during the fortification process

Experimental data report retinol losses of between 10 and 20 percent during the processing of fortified sugar, and between 20 and 40 percent during storage after one year These losses need to be compensated for by adding the appropriate overage of premix to sugar during the fortification process
Retinyl palmitate is susceptible to oxidation in the presence of sun or artificial light Packaging premix in bags covered with black polyethylene bags reduces exposure to light and degradation of vitamin A
Retinyl palmitate beadlets resist temperatures of 105 °C for 10 minutes This is important because the premix is added to sugar before it passes through the drying turbines, where temperatures are between 65 and 70 °C

In fortified sugar
Stability tests show that fortified sugar packaged for retail sale in polyethylene bags retains between 50 and 70 percent of the initial vitamin A level after 3 months of storage (Fig 6 and 7) Heat and moisture together are believed to be more detrimental to retinyl palmitate than either alone (Table 3)

Fortified sugar in foods
Vitamin A in fortified sugar remains stable in foods prepared at home, although moisture, heat, and acidity do reduce its activity When fortified sugar is added to beverages such as lemonade and orangeade, 60 to 80 percent of the vitamin A remains after two days
Vitamin A is sensitive to acids and losses can be expected Most of the vitamin A in fortified sugar, however, can be lost in the manufacturing of soft drinks as a result of using activated charcoal and diatomaceous earth to eliminate color and impurities, thus, when non refined sugar is used in manufacturing soft drinks there is complete destruction of the vitamin If, however, refined sugar is used two-thirds of the original retinol level remains
The stability of vitamin A in baked foods is also good The retention of the micronutrient after baking is in the order of 80 to 90 percent Micronutrient interactions with vitamin A in sugar are unlikely because sugar is a pure product with minute quantities of other compounds

Quality Control
The vitamin A content of the premix is determined using quantitative methods, while that for fortified sugar is carried out using both semiquantitative and quantitative methods
Quantitative methods include the use of HPLC or spectrophotometric methods The HPLC method is based on the separation of vitamin A (retinol) from other substances that absorb radiant energy at an equal or similar wavelength to retinol Detection of retinol in the HPLC column can be done using UV light or fluorescence This method is accurate, does not destroy retinol, and requires a small amount of sample However, the equipment is expensive, highly trained personnel are required, and few samples can be run at a time, making the analysis expensive The spectrophotometric method involves measuring the absorbance of retinol in sugar after its selective destruction through exposure to UV light This method is easy to use, less expensive than the HPLC method, and results can be obtained in a much shorter period of time
The semiquantitative colorimetric method involves adding a chromogenic reagent to a volume of solubilized sugar to produce a blue color The intensity of this blue color is proportional to the amount of retinol in the sample measured against a set of standards Semiquantitative assays at 1 to 2 hours intervals during production verify that the fortified sugar contains the amount of vitamin A that falls within the range stipulated in the norms Results are immediate and permit adjustments to the amount of premix added to sugar

Costs
The costs of sugar fortification include the capital investments, i e building and equipment costs, and recurrent costs, i e personnel costs, premix and fortified sugar production costs as well as monitoring and evaluation costs In Guatemala, the cost of fortifying 1 metric ton of sugar is US$9 51, and the cost

Figure 5
Possible Points for Premix Addition During Sugar Production

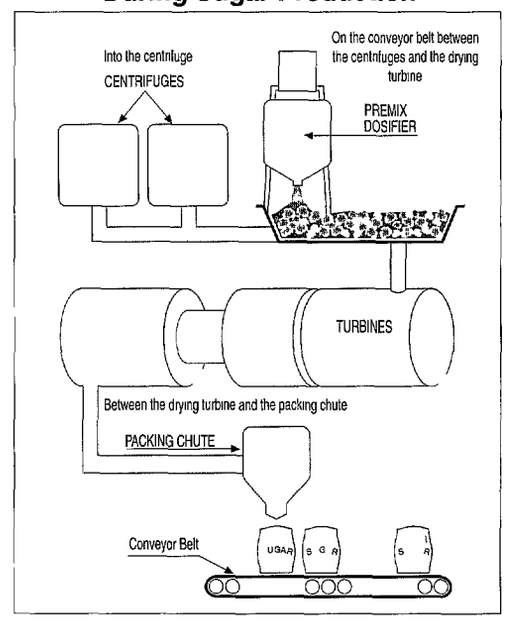
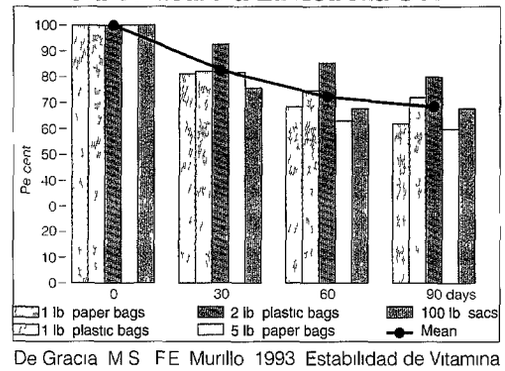
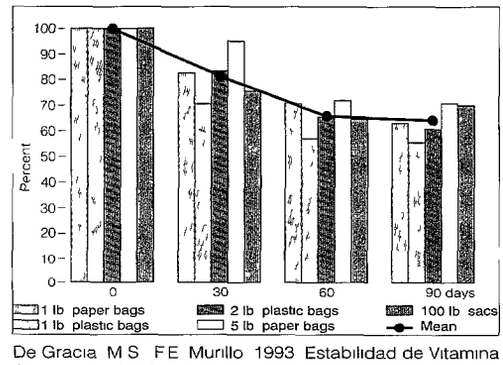


Figure 6
Stability of Vitamin A in Sugar, Cia Azucarera La Estrella S A



De Gracia M S F E Murillo 1993 Estabilidad de Vitamina A en azucar fortificada resumen ejecutivo INCAP/U de P

Figure 7
Stability of Vitamin A in Sugar, Cia Azucarera Nacional S A



De Gracia M S F E Murillo 1993 Estabilidad de Vitamina A en azucar fortificada resumen ejecutivo INCAP/U de P

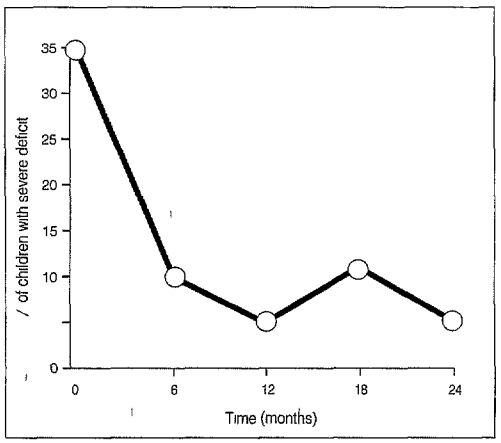
Table 3
Stability of Retinol in Fortified Sugar (% retention in 125 lb sacs)

Location Type	Months of Storage		
	3	6	9
Cold - Humid	90	77	66
Hot - Dry	92	71	63
Temperate - Humid	83	69	43
Hot - Humid	80	62	40

Dary O De leon L Conference on XVII IVACG Meeting Guatemala 1996

Figure 8

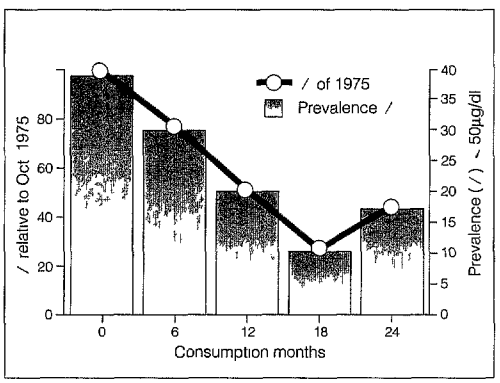
Decrease in % Children with Serum Retinol Level Below 10 mcg/dL After Consumption of Fortified Sugar



Arroyave G Aguilar Jr Flores M Guzmán Ma Evaluation of Sugar Fortification with Vitamin A at the National Level Pan American Health Organization Scientific Publication 384 Washington DC 1979

Figure 9

Effect of Fortified Sugar Consumption on the Prevalence of Low Retinol Levels in Human Milk



Arroyave G Aguilar Jr Flores M Guzman Ma Evaluation of Sugar Fortification with Vitamin A at the National Level Pan American Health Organization Scientific Publication 384 Washington DC 1979

Table 4

Status of Legislation for Sugar Fortification in Latin America

Countries Enforcing Legislation	Countries in Process of Legislating	Countries with Interest (Private, or Official)
Guatemala	Nicaragua	Brazil
Honduras	Ecuador	Dominican Rep
El Salvador		Colombia
		Bolivia

per person is US$0 36/year Given that a kilogram of sugar costs US$0 45 before fortification, adding vitamin A increases the price to US$0 459, that is, 2 percent above the original price
The economic analysis of a program can be presented in different ways, for example cost per metric ton cost per person, cost per person covered cost per possible beneficiary, and in terms of cost-effectiveness The cost of a sugar fortification program is inexpensive, especially when compared with the costs of vitamin A deficiency, and the cost of other interventions

Legislation

To be successful a fortification program requires the collaborative participation between various government sectors food producers private organizations and international agencies The strongest expression of political commitment to eliminate vitamin A deficiency is legislative action to make a vitamin A fortification program official Such legislation shall define the norms for implementing fortification, including the responsibilities of each sector involved
The regulations for vitamin A fortification must specify the type of vitamin A fortificant and the permitted range of retinyl palmitate in fortified sugar both at the refinery and at the point of sale when appropriate The regulations must define the precautions and food safety conditions to be observed during production, transportation, storage and sale of the fortified sugar
Labeling the bags of fortified sugar at the refinery should be enforced, especially when unfortified sugar is also produced for industrial use Sugar packaged for retail sale should be labeled in a way that is true and accurate, and provides essential information specified by the health authorities
The official creation of a specific committee, for example, a Food Fortification Committee, with representatives from different sectors is recommended The role of this committee would be to monitor program implementation and analyze the information coming from the different operating units and to ensure that the operating units and those responsible at the points of sale comply with their responsibilities

History and Successful Interventions

Guatemala was one of the first countries to implement a sugar fortification program to ensure an adequate intake by the population with satisfactory results (Fig 8 and 9)
Other countries in Latin America are now implementing vitamin A fortification programs (Table 4) Asian countries are also considering sugar fortification

Vitamin A is an essential nutrient and deficiency is associated with adverse health effects Sugar fortification presents an important intervention for improving the vitamin A status of at-risk populations
Although the current technology is adequate enough it can still be improved in order to increase the efficiency of the fortification program In existing refineries, space where the dosifiers can be installed is often limited Future plant layouts should make provisions for this limitation

Fortification Basics

Wheat Flour

Rationale

Wheat is the most widely produced cereal in the world, most of which is destined for human consumption, thus, its contribution to energy intake is significant, particularly in the Americas and the Middle East (Table 1)

The processing of whole wheat to wheat flour is generally concentrated in a few large mills The resulting flour is used to make bread, biscuits, pasta, and other products Because of its widespread geographic distribution, acceptance, stability, and versatility wheat flour is a suitable vehicle for delivering micronutrients to mankind

Table 1
Per Capita Wheat Comsumption in Selected Countries

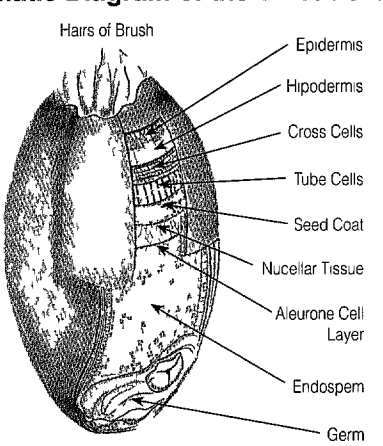
Country	Consumption (g/person/day)	% of Daily Energy Intake
Pakistan	318	45
Turkey	484	44
Syria	490	44
Chile	372	42
Egypt	397	35
Greece	371	28
Argentina	344	28
Uruguay	269	26
Bolivia	159	20
South Africa	191	18
Peru	136	17

Micronutrient Content of Wheat and Wheat Flour

In its natural state, wheat is a good source of vitamins B1 (thiamine), B2 (riboflavin), niacin, B6 (pyridoxine), E, as well as iron, and zinc

Nevertheless, because most of these nutrients are concentrated in the outer layers of the wheat grain (Figure 1), a significant proportion is lost during the milling process For lower extraction rates of flour (i e more refined flour) , the loss of vitamins and minerals is greater (Figure 2)

Figure 1
Schematic Diagram of the Wheat Grain



Nutrients Generally Added to Wheat Flour

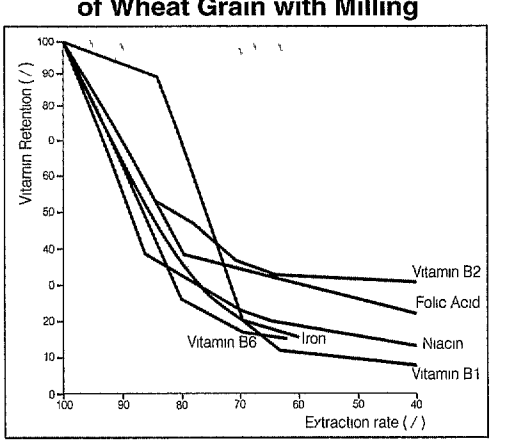
In developed countries, wheat flour is generally fortified with vitamins B1, B2, niacin, and iron In some countries calcium and folate are also added Vitamins A and D can also be added to flour

The levels of vitamin B1 niacin and iron added to wheat flour is often equivalent to the amount lost in milling i e these micronutrients are restored and the flour is *enriched*

For other micronutrients such as vitamin B2 the amount added is over and above that lost in milling, i e the flour is *fortified*

Fortification rather than enrichment is done when the overall diet is deficient in particular micronutrients and restoring the micronutrients lost in milling will not make good this deficit

Figure 2
Changes in Micronutrient Content of Wheat Grain with Milling



Adapted from FAO 1970 Wheat in Human Nutrition and Thomas B 1968 Nutritional physiological views in processing cereal products Vegetables 15 360

Technology

The technology for fortifying flour is simple First, a premix

Table 2
Example of Premix Composition

Nutrient	Level (mg/Kg Flour)	Product Form	grams/ Kg Premix
Vitamin B_1	4 45	Thiamine Mononitrate	61 80
Vitamin B_2	2 65	Riboflavin	36 90
Niacin	35 62	Nicotinamide	494 70
Iron	30 20	Reduced Iron	406 60

Dosage 72 g/ton of flour

Figure 3
Volumetric Feeder for Adding Micronutrient Premix

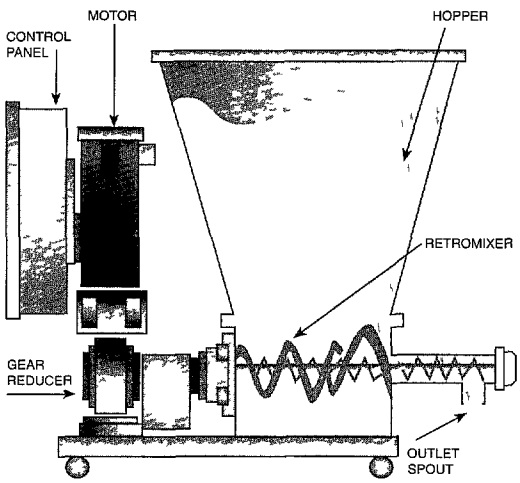
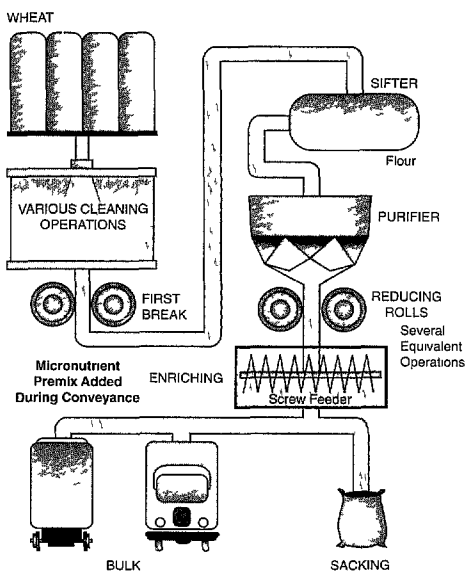


Figure 4
Simplified Flow Chart for Flour Milling



of the micronutrients to be added is needed (Table 2) The advantage of using a premix over that of adding micronutrients singly is that there is a greater likelihood of ensuring

- The correct concentration of micronutrients
- An even distribution of micronutrients

Furthermore, the logistics of adding micronutrients to flour will be simpler and the quality assurance system is more likely to be effective

The fortification process itself is accomplished by adding the micronutrients through a volumetric feeder (Figure 3) located towards the end of the milling process The most commonly used feeder consists of a rotating feed screw that is driven by a variable speed motor The screw rotates inside a chamber containing the premix and pushes the premix through an outlet spout The amount of premix added to the flour can be modified by changing the motor speed The concentration of premix added to the flour can be calculated by weighing the amount of premix deposited by the feeder in one minute divided by the volume of flow passing underneath in the same period of time The premix can be either fed directly into the flour by *gravity* or by air convection using a *pneumatic* system The homogeneity of micronutrients in fortified flour is largely dependent on the location of the feeder and it is very important that the mixing of the micronutrients with the flour is good In a gravity driven system, experience has shown that the best site for adding micronutrients is before the mid point along the screw conveyor that collects flour from all the mill passages, just before bulk storage or sacking (Figure 4) If the feeder is placed towards the beginning of the screw conveyor, the amount of flour in the conveyor will be too little If, on the other hand, the feeder is located toward the end of the screw conveyor the required homogenisation will not be achieved

In a pneumatic system feeders can be placed in a remote centralised location

The cost of the feeder varies between US$ 2000 and 5000, depending on whether a gravity or pneumatic system is installed and the quality of the device

Micronutrient Stability

In foods, the stability of vitamins is more precarious than that of minerals because vitamins are sensitive to heat, oxidising and reducing agents light and other kinds of physical and chemical stress

Vitamins are stable in flour as such, although high

humidity and temperatures together do adversely affect vitamin A The use of encapsulated forms of vitamin A will help to overcome this problem There is some evidence of minor losses of other vitamins during flour storage (Tables 3 and 4)

Most of the vitamin losses ocur during baking, which is the most common process all wheat flour products go through Although baking temperatures are high (over 200°C), the temperature inside the product is significantly lower, and over 70 percent of the vitamins remain unaltered (Table 5) Similarly, between 65 and 85 percent of vitamins remain intact after cooking pastas (Table 6)

Table 3
Nutrient Retention in Flour with 9% Humidity at Room Temperature

Nutrient	Level per Kg				
	Label Claim	Initial	2 mo	4 mo	6 mo
Vitamin A, IU	16 534	18,078	18 078	17,681	17,526
Vitamin B6 mg	4 41	5 18	4 85	5 07	4 85
Vitamin E IU	33 07	35 05	35 05	35 05	35 05
Folic Acid mg	0 66	0 82	0 66	0 77	0 66
Vitamin B1 mg	6 39	7 50	NR	NR	7 50

Table 4
Nutrient Retention in Flour with 9% Humidity at 45° C

Nutrient	Level per Kg				
	Label Claim	Initial	1 mo	2 mo	3 mo
Vitamin A IU	16 534	18,078	16 534	14 175	12 919
Vitamin B6 mg	4 41	5 18	4 85	4 85	4 63
Vitamin E, IU	33 07	35 05	35 05	35 27	35 49
Folic Acid mg	0 66	0 82	0 66	0 57	0 75
Vitamin B1 mg	6 39	7 50	NR	NR	NR

NR=Not registered
Cort W M B Borenstein B J H Harley M Osadca and J Scheiner 1975 Nutrient Stability of Fortified Cereal Products 35th IFT Meeting Chicago Ill

Quality Control

The determination of micronutrients in flour can be done by simple classical methods (e g fluorometric for B1 and B2 and spectrophotometric for iron) or by faster methods that require more sophisticated equipment (e g HPLC for vitamin A folic acid and niacin and atomic absorption for iron)

It is important to establish quality control standards for both commercial premixes and fortified flour

Legislation

Compulsory fortification of flour is increasing throughout the world Currently 14 countries have legislation or regulations that mandate wheat flour be fortified with various micronutrients (Table 7) Other countries are

Table 5
Nutrient Losses During Typical Bread Baking

Nutrient	% Loss during baking
Vitamin A	10 20
Vitamin B1	15 25
Vitamin B2	5 10
Niacin	0 5
Folic Acid	20 - 30

F Hoffmann La Roche Unpublished Data Basel

Table 6
Vitamin Losses in Long Durum Wheat Pasta After Drying and Cooking

Nutrient	% Loss After Drying (75ºC)	% Loss After Cooking
Vitamin A	13	17
Vitamin B1	0	32
Vitamin B6	5	35
Niacin	0	30

F Hoffmann La Roche 1990 Vitamins and Carotenoids in Pasta Basel

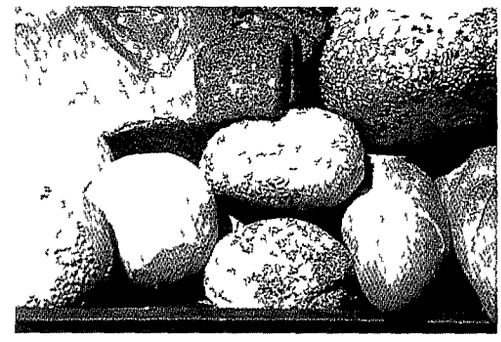
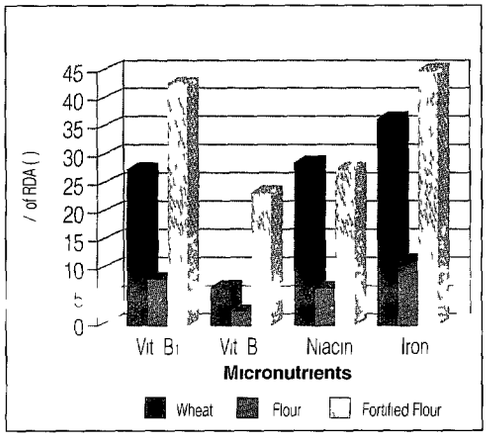
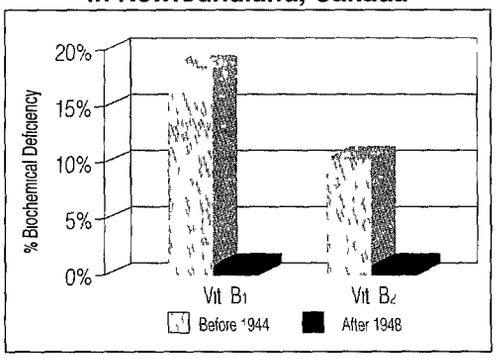


Figure 6
Nutrient Allowance per 100g of Different Wheat Products



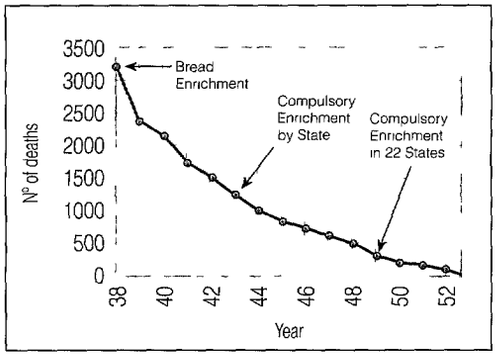
Code of Federal Regulations 1973 Enrichment Levels of Baked Goods Flour Farina etc Title 21 15 525
Nutrient data ESHA Research Food Processor II
NCR 1989 Recommended Dietary Allowances

Figure 7
Biochemical Impact of Flour Enrichment in Newfoundland, Canada



Aykroyd WR et al 1949 Medical Survey of Nutrition in Newfoundland 1948 The Canadian Med Assoc Journal 60 4

Figure 8
Deaths from Niacin Deficiency in the U S A Association with Wheat Flour Enrichment



Miller D F 1955 Enrichments Programs Helping Mother Nature Along Food Prod Dev 12 4 30 38

considering this option The low cost, and simplicity of the technology has made it one of the most sought after methods for combating micronutrient malnutrition Figure 6, for example, shows the contribution that flour fortified with vitamins B1 B2 and niacin as well as iron, makes toward meeting the Recommended Dietary Allowances (RDA) for adult men in the USA

Table 7
Compulsory Flour Enrichment Worldwide

Country	Vitamin B1 (Mg/Kg)	Vitamin B2 (Mg/Kg)	Niacin (Mg/Kg)	Folic Acid (Mg/Kg)	Iron (Mg/Kg)
Canada	4 4 7 7	2 7 4 8	35 64	(0 4 0 5)	29 43
Chile	6 30	1 30	13 00		30 00
Costa Rica	4 4 5 5	2 6 3 3	35 2 44 0		28 7 36 4
Dominican Republic	4 45	2 65	35 62		29 29
Ecuador	4 45	7 48	83 58	0 59	58 65
El Salvador	4 41	2 65	35 30		28 70
Guatemala	4 0 6 0	2 5 3 5	35 40	0 35 0 45	55 65
Honduras	4 40	2 60	35 20		28 70
Nigeria	4 5 5 5	2 7 3 3	35 5 44 4		28 9 36 7
Panama	4 40	2 60	35 20		28 70
Saudi Arabia	≥ 6 38	≥ 3 96	≥ 52 91		≥ 36 30
UK	≥ 2 4		≥ 16 0		≥ 16 5
USA	6 40	4 00	52 90		44 10
Venezuela	1 50	2 00	20 00		20 00

Note Figures in parenthesis indicate the enrichment is optional
Raunhardt O and A Bowley 1996 Mandatory Food Enrichment Nutriview 1

Costs

The cost of fortifying wheat flour is much lower than generally recognised For example, the total cost of adding mandatory nutrients to flour in the USA (i e 6 4 mg/Kg Vitamin B1, 4 0 mg/Kg Vitamin B2, 52 9 mg/Kg Niacin and 44 1 mg/Kg Iron), is less than one US Dollar per metric ton of flour This is about 0 1 percent of the cost of flour in the shops

On the other hand, if the cost in the USA is calculated on a per person per year basis, and average wheat consumption is 205 g/person/day, the total cost of fortification is US$ 0 07 per person per year

In addition to the recurrent costs for the micronutrients, there are the capital costs for the feeders, which are not great, and the recurrent costs for quality control

Impact on Public Health

Figures 7 and 8 show the association between the introduction of fortification initiatives and the reduction in vitamin B1 and B2 deficiencies in Canada and niacin deficiency in USA, respectively

Iron deficiency anaemia has also decreased in the USA, Great Britain, Sweden, and Chile and much of this decline is attributed to food fortification, including bread, with iron