Fortification Basics

Stability

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

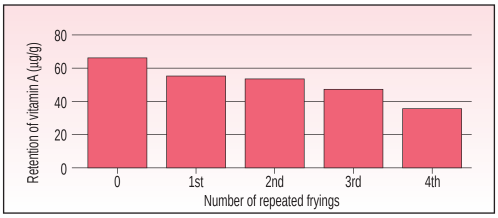
Source: Cort, W.M., B. Borenstein, J.H. Harley, M. Osadca, and J. Scheiner. 1975. Nutrient stability of fortified cereal products. 35th IFT Meeting. Chicago, IL.

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.

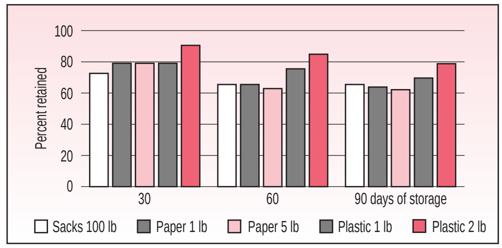
Table 7
Stability of Retinol in Fortified Sugar (% Retention)

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
[2] 27.7°C, 63% humidity
[3] 18.8°C, 79% 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 Meetting, Guatemala.

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



Source: De Gracia, M.S., F.E. Murillo. 1993. Estabilidad de vitamina A en azúcar fortificada resumen ejecutivo. INCAP/Universidad de Panamá.

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.

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