

Fortification Basics

Milk

Milk is one of the most nutritious foods. It is rich in high quality protein providing all ten essential amino acids. It contributes to total daily energy intake (Table 1), as well as essential fatty acids, immunoglobulins, and other micronutrients. Cow's milk is the predominant type in several countries, although goat, buffalo, sheep, and camel milks are also consumed. Milk is also consumed in fermented forms such as cheese, yogurt, kefir, and buttermilk, and as butter. Commercially available milk can be classified into two major groups: liquid milk and dried or powdered milk.

Micronutrient Content of Milk

The micronutrient profile of whole milk (Table 2) shows that it is an excellent source of calcium and vitamin B₂, a good source of vitamin A, and a fair source of vitamin D, providing 26 to 40%, 23 to 52%, 10 to 24%, and about 5% of the USRDA, respectively, per serving of 250 milliliters. However, seasonal variations are observed in the natural vitamin content of milk due to differences in feeding patterns. Cattle generally graze on fresh pasture in summer while dry forage is commonly fed during the winter months. As a result, the vitamin A content of fresh milk, in the USA for example, varies from 600 to 1800 IU/liter (Figure 1) while the vitamin D content varies from 5 to 40 IU/liter.

Most of the milk intended for human consumption is heat-treated to prevent public health hazards due to pathogenic microorganisms present in raw milk. In developing countries, a significant proportion of milk is produced by small dairy farmers and sold directly to the consumer, where it is often boiled prior to consumption. The common industrial heat treatments for liquid milk include pasteurization, ultra-heat treatment or ultra-high temperature (UHT), and sterilization. To obtain dried milk, fresh milk is first heat-treated and then dried through a spray-drying, roller-drying, or drum-drying process. These industrial processes destroy some nutrients, especially the vitamins naturally present in milk, and the extent of the losses depends on the nutrient and the processing method. Nutrients that are lost during processing, however, can be replaced through fortification of the milk.

In many countries, the fat from milk commercially sold is either partially or completely removed to produce reduced-fat or fat-free milks. Fat-soluble vitamins, such as vitamins A and D, are lost when milk fat is removed, but they can be replaced through fortification.

Nutrients Generally Added to Milk

Liquid milk fortification with vitamins A and/or D is mandated in several countries. Some dairies in the USA fortify milk with vitamins C and E and calcium, in addition to vitamins A and D.

Table 1
Per Capita Consumption and Percent Daily Energy Intake from Whole Milk in Selected Countries (1997)

Country	Consumption (Kg/year)	% Daily energy intake
Somalia	242.9	32
Albania	232.4	15
Ireland	189.8	10
Estonia	165.7	9
Yugoslavia	156.1	9
Costa Rica	125.8	9
USA	117.4	5
Ecuador	99.1	7
Mexico	65.8	4
South Africa	59.5	3

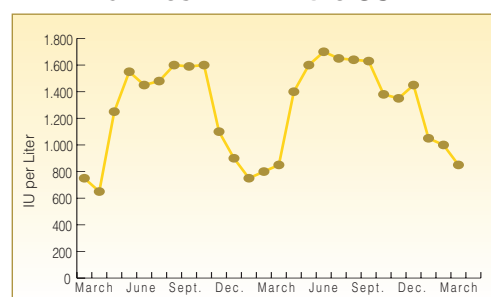
FAO Food Balance Sheets, 1997.

Table 2
Micronutrient Content of Cow's Whole Milk (3.3% Fat)

Vitamins	Quantity per liter	Minerals	Quantity per liter
A (IU)	1299.5	Calcium (mg)	1277.3
B1 (mg)	0.39	Chlorine (mg)	1031.36
B2 (mg)	1.67	Copper (mg)	0.1
B3 (mg)	0.87	Iodine (mcg)	237.21
B6 (mg)	0.43	Iron (mg)	0.52
B12 (mg)	3.68	Magnesium (mg)	138.2
Biotin (mcg)	19.6	Manganese (mg)	0.04
C (mg)	9.69	Molybdenum (mcg)	20.63
D (IU)	41.25	Phosphorus (mg)	963.28
E (IU)	1.54	Potassium (mg)	1567.66
Folate (mcg)	61.57	Selenium (mcg)	15.47
K (mcg)	41.25	Sodium (mg)	505.36
Panhotenate (mg)	3.24	Zinc (mg)	3.92

Genesis 6.01, ESHA Research, 1997.

Figure 1
Variation of Vitamin A Content of Fresh Milk in the USA



Bauernfeind, J.C. et al. 1963. Vitamin A and D Enrichment of Nonfat Dry Milk. J. Dairy Sci. 46(3):245-254.

β -Carotene is added as a color-enhancing agent to some milk products, such as butter.

Dried milk and flavored milk powders are often fortified with vitamins A and D, calcium, and iron. Milk-based infant formula and weaning foods are fortified with a range of vitamins, minerals, and other nutrients such as polyunsaturated fatty acids. Powdered milk used for complementary feeding in Chile is fortified with vitamin C, iron, copper, and zinc.

The levels at which nutrients are added to milk depend on a number of factors, including levels of milk consumption and nutritional requirements of the target population; the effect of added nutrients on the functional or sensory (odor, flavor, and color) characteristics of milk; and the stability of the nutrients during processing and storage of milk. Liquid milk, especially skim milk, should be fortified, at a minimum, with vitamins A and D at 5,000 and 500 IU per liter, respectively (Table 3). At these levels, a serving of 100 milliliters of milk will provide 21 to 38% of the USRDA for vitamin A (1,330 to 2,330 IU) and 13% of the USRDA for vitamin D (400 IU) for children 1 to 10 years old. Other nutrients can be added as appropriate.

Technology

The technology to fortify milk is simple. All the vitamins and minerals that can be added to milk are available in dry powder form. The fat-soluble vitamins are also available in an oily form. Because more than one nutrient is generally added to milk, they are added preferably as a premix, which is a homogenous mixture of the desired amount of fortificants (vitamins and minerals) concentrated in a small amount of the food to be fortified. Premixes ensure the addition of correct amounts and uniform homogenization of the micronutrients in the final product.

For example, a vitamin A and D premix can be obtained by diluting 1 part of a vitamin mixture containing 1 million IU of vitamin A and 1,000 IU of vitamin D in 10 parts of warm oil (40-50°C), and later homogenizing with 50 parts of fresh skim milk. Alternatively, the premix can also be made by diluting the vitamin mixture (usually 5 g/liter) in 8 liters of milk plus 2 liters of cream, and then homogenizing the mix. In the case of water-soluble or water-dispersible micronutrients, a premix can be made by diluting the nutrients to 20 times their weight with milk at 45°C, followed by stirring and thorough mixing. Any of the above premixes can then be added to the final product in a suitable ratio.

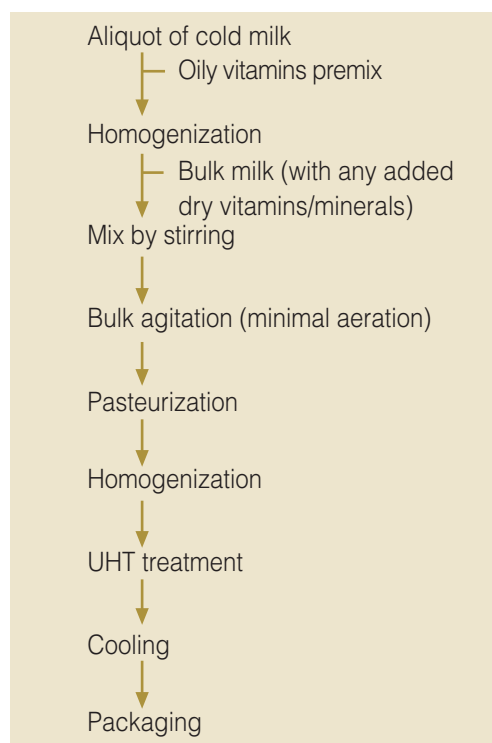
Liquid milk fortification: Fat-soluble vitamins can be added in dry or oily forms, whereas water-soluble vitamins and minerals are added in dry form directly to liquid milk. Liquid milk is fortified just prior to pasteurization or ultra-heat treatment, and it is essential to ensure a good distribution of the nutrients in milk prior to any heat treatment. Homogenization is especially crucial when using the oily forms of vitamins. A model process flow chart of liquid milk fortification is presented in Figure 2.

Dried milk fortification: The simplest way to fortify dried milk is to blend dry forms of vitamins and minerals with the dried milk powder, although oily forms can also be added. Unlike liquid milk, dried milk

Table 3
Recommended Minimum Fortification of Liquid Milk

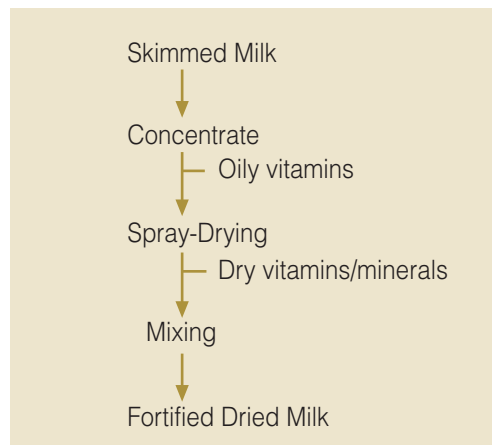
Vitamin	Suggested Level (IU/L)	Natural Content (IU/L)		Quantity to add (IU/L)
		Whole Milk	Skim Milk	
A	5,000	1,300	trace	4,000-5,000
D	500	40	trace	500

Figure 2
Process Flow Chart of Liquid Milk Fortification



Adapted from: O'Brien, A. and Robertson, D. The Technology of Vitamins in Food, P. Berry Ottaway (Ed.), 1993. Page 130.

Figure 3
Process Flow Chart of Spray-Dried Milk Fortification



F. Hoffmann - La Roche, 1985.

can be fortified either prior to or after the heat treatment. The most widely applied method of fortifying spray-dried milk is presented in Figure 3.

Micronutrient Stability

Vitamins are sensitive to heat, light, and humidity, as well as oxidizing and reducing agents to different degrees. Recent advances in technology have enabled the production of commercial forms of vitamins with improved stability and compatibility with other micronutrients. Minerals are, in general, less sensitive than vitamins to physical and chemical factors. Nevertheless, they are reactive in nature and must be selected after considering possible interactions with milk proteins, potential adverse effects on the sensory properties of milk, and the bioavailability of the mineral form.

Nutrients naturally present in or added to liquid milk are fairly stable during processing. Most vitamins and minerals show a retention of 70 to 100% after a single common industrial heat treatment. However, repeated heat treatments can result in extensive losses. The stability of most nutrients in liquid milk during storage is also good. Vitamin C, which is easily degraded by oxygen and light, is the exception. Cardboard/ polyethylene laminate cartons protect better than plastic containers both the nutrients (Table 4) and the taste and flavor of milk against the deleterious effects of light.

Fortified whole dried milk stored at ambient temperatures for 24 months retains 90 to 100% of the added vitamins B₁, B₂, B₆, C, E, and niacin throughout the storage period. Significant losses of vitamin A, however, can occur rapidly resulting in retention levels of 55 to 75% after 5 months and only 35 to 45% after 24 months of storage.

Thus, micronutrients added to milk can be destroyed during the normal thermal processing and storage of milk. To compensate for these losses, an appropriate overage of each micronutrient must be added during fortification. The recommended overages based on processing losses alone for common types of milk are presented in Table 5. Losses during storage vary with time, temperature, humidity, and exposure to light, and should be determined locally.

Quality Control

A vitamin and mineral fortification program requires periodic testing to ensure the desired amount of micronutrients in the final product prior to use. Facilities, procedures, and properly trained staff are, therefore, needed. A precise quality control plan must be outlined to determine the level of fortificant(s) in the fortified milk, especially for the more unstable nutrients such as vitamin A.

Vitamins A and D can be quantitatively determined by HPLC. This method is accurate, but the equipment is expensive and highly trained personnel are required. The spectrophotometric method is less expensive and relatively simpler and can also be used. Quantitative methods for other micronutrients include the fluorometric method for vitamins B₁ and B₂, and the spectrophotometric method

Table 4
Retention (%) of Vitamins in Liquid Milk Stored in Different Containers

Vitamin/ Container	3 hr daylight	72 hr dark	72 hr fluorescent
A Carton ^a	100	100	100
Plastic ^b	90	100	84
B ₁ Carton ^a	100	100	100
Plastic ^b	96	96	100
B ₂ Carton ^a	100	100	100
Plastic ^b	71	100	91
C Carton ^a	77	79	67
Plastic ^b	4	80	4
FA ^c Carton ^a	91	91	100
Plastic ^b	87	87	89

^a Opaque ^b Translucent ^c Folic acid

Haisman, D.R. et al. 1992. The effect of light on the flavour and nutritional content of milk. *Food Technology*, 46(2):16-19.

Table 5
Recommended Overages^a (%) for Selected Nutrients and Milk Forms

Nutrient	Pasteurized	UHT	Dry Milk	Milk Desserts
Vitamin A	20	30	40	20
Vitamin D	20	30	40	20
Vitamin E	10	30	20	10
Vitamin B ₁	25	50	20	25
Vitamin B ₂	15	40	20	15
Niacin	15	20	20	15
Vitamin B ₆	30	30	20-30	30
Vitamin B ₁₂	15	30	40	20
Folate	20	40	40	20
Vitamin C	30	100	50	30
Iron	5	5	5	5
Calcium	5	5	5	5

^a Based only on losses during processing

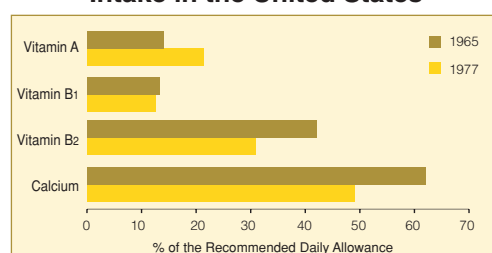
Table 6
Cost (US\$) of Milk Fortificants in the USA

Vitamin	Level (units/L)	Cost/1000 L ^a
A	5000 IU	0.26 ^b
D	500 IU	0.04 ^b
E	10 mg	0.42 ^b
C	60 mg	0.45
B ₁	1.5 mg	0.03
B ₂	1.7 mg	0.07
Niacin	19 mg	0.17
B ₆	2 mg	0.06
Folic acid	0.2 mg	0.02
B ₂	2 mcg	0.07
Total Cost		1.59

^a Costs based on U.S. prices (1999)

^b Costs based on fat soluble product forms

Figure 4
Contribution of Milk to Micronutrient Intake in the United States



Nationwide Food Consumption Surveys, 1965-66 & 1977-78

for minerals, including iron and calcium.

Cost

The cost of milk fortification is limited to the cost of the micronutrients to be added and the cost of monitoring the quality of fortification. Changes needed in the usual milk production line are minimal. The cost of raw materials to fortify pasteurized milk with 5,000 IU of vitamin A, 500 IU of vitamin D and 100% of the USRDA of vitamins E, C, B1, B2, B6, B12, niacin, and folate is estimated at US\$ 1.59 per 1,000 liters (Table 6). This amounts to less than 1% of the average wholesale price of liquid milk in the USA (\$ 0.29/liter).

History and Successful Interventions

Milk fortification began in the first half of this century. Vitamin D fortification of milk in the United Kingdom is reported to have begun in 1923; currently, milk fortification with vitamins A and D is practiced on a voluntary basis.

In the United States, the Food and Nutrition Council of the American Medical Association pronounced in 1939 the addition of no more than 400 IU of vitamin D per quart of milk, in the interest of public health. The marked decline in the prevalence of rickets, a vitamin D deficiency disorder, in the USA has been partially attributed to vitamin D fortification of milk. The contribution of milk to micronutrient intake in the US population is illustrated in Figure 4.

Chile introduced iron-fortified milk powder for children over 20 years ago. Today, complementary feeding programs provide powdered milk fortified with vitamin C, iron, copper, and zinc. Adding vitamin C, an enhancer of iron absorption, has been shown to improve the efficacy of iron-fortified milk. In controlled field trials, an iron and vitamin C-fortified milk formula fed daily to Chilean infants starting from 3 months until 15 months of age virtually eliminated iron deficiency anemia (Figure 5).

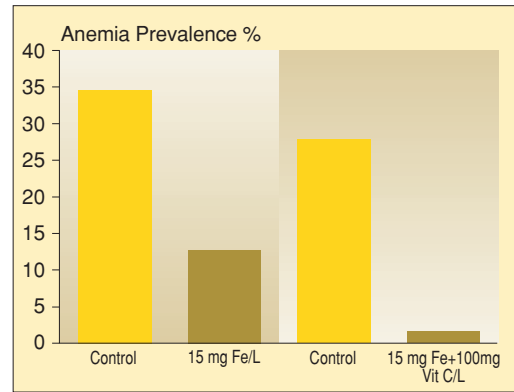
Argentina has successfully fortified liquid milk with iron using ferrous sulfate microencapsulated with phospholipids with no deleterious effects on the shelf life or sensory properties of milk. Recent bioavailability studies in humans showed promising results.

A number of dairies in Ireland fortified milk with vitamin D and calcium following the report of a high prevalence of hypovitaminosis D in the elderly. Vitamin D-fortified milk would be beneficial to populations in whom limited exposure to sunlight reduces vitamin D status, especially in the winter months.

Legislation

Several countries have established mandatory fortification of milk since early in this century. Table 7 illustrates the current status of milk fortification with vitamins A and D in different countries. Additionally, several other countries voluntarily add micronutrients to milk, particularly low-fat or fat-free liquid and dried milks.

Figure 5
Efficacy of Fortified Liquid Milk in Lowering Anemia in Infants



Anemia: Hemoglobin < 11 g/dl

Stekel A, et al. 1985. The role of ascorbic acid in the bioavailability of iron from infant foods. *Int. J. Vitamin Nutr. Res. Suppl.* 27: 167-175.

Table 7
Mandatory^a Fortification of Liquid and Dried Milk in Different Countries

Country	Product	Vitamin A (IU)	Vitamin D (IU)
Argentina	Fluid & dry milk (whole & skim)	2,500/L	400/L
Brazil	Dry skim milk for complementary food programs	15,000 - 25,000/kg	2000 - 2400/kg
Guatemala	Skim milk	2,000 - 3,000/L	400 - 600/L
Honduras	Milk	2,000/L	400/L
Malaysia	Evaporated/unsweetened	6,700/kg	-
Malaysia	Condensed milk Sweetened	6,700/kg	-
Malaysia	Condensed milk Filled	6,700/kg	-
Mexico	evaporated/filled condensed milk Sterilized low-fat milk	4,000/L	400/L
Mexico	Pasteurized low-fat milk	4,000/L	400/L
Mexico	Evaporated whole & low-fat milk	4,000/L	400/L
Philippines	Filled evaporated/filled	4,866/kg	(973/kg)
USA	Condensed milk Fortified nonfat dry milk (reconstituted)	2,115/L	425/L
USA	Evaporated milk	(4,225/L)	845/L
USA	Evaporated skim milk	4,225/L	845/L
Venezuela	Dry milk powder	4,000/L	400/L

^a Figures in parentheses indicate that addition is optional.

Adapted from: Raunhardt, O. and Bowley, A. Mandatory Food Enrichment. *Nutriview Supplement* to 1/1996 Issue.