*Food and Nutrition Bulletin,* vol. 19, no. 2

http://unu.edu/unupress/food/V192e/

# Technical aspects of food fortification

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## Abstract

*The nutritional status of the population is one of the important factors determining the quality and productivity of the population, which in turn affects national productivity. In the long term, good nutritional status contributes to the intelligence and health of the population. Consequently, programmes directed at improving the nutritional status of the population will undoubtedly be a high priority in the national development scheme of any country, developed or developing. Food fortification, i.e., the addition of nutrients to specific foods based on the dietary habits and nutritional status of the target population, is one of the most popular nutritional interventions for improving the population's nutritional status. For food-fortification programmes to be successful, their technical aspects need to be carefully assessed. These include the nutritional justification for food fortification, the acceptability of the fortified food product to consumers (both cost and taste), and any technical or analytical limitation to compliance with food regulations and labeling requirements. Important technical aspects of developing effective food-fortification programmes are the choice of food carrier, nutrient interactions, bioavailability of nutrients, stability of nutrients added under anticipated conditions of storage and processing (food preparation at the household level), and safety. A good fortified product should not cause nutrition imbalance, and excessive intake of nutrients should not have adverse effects. To provide better information for the consumer, the concept of overage should be introduced. Overage is the use of kinetic data on nutrient stability to calculate the amount of added nutrient so that the anticipated level of the nutrient at the end of the product's shelf life is in accordance with the level indicated on the label.*

## Introduction

The nutritional status of the population is one of the important factors in determining the quality and productivity of a population, which in turn will affect national productivity. In the long run, good nutritional status contributes to the social and economic development of a nation. However, many nutritional studies, particularly in developing countries, have indicated that certain segments of the population suffer from one or more nutrient deficiencies, which can have serious effects on their health and productivity. The causes are many and varied.

As in many other developing countries, three major nutritional (especially micronutrient) deficiencies are regarded as public health problems in Indonesia: iodine-deficiency disorders, vitamin A deficiency, and iron-deficiency anaemia. The government of Indonesia has instituted programmes to cope with these three deficiencies, one of which is a food-fortification programme.

# Definition of food fortification

Several terms besides fortification are used for the addition of nutrients to foods: restoration, enrichment, standardization, and supplementation [1, 2].

*Restoration* is the addition of a nutrient to a food in order to restore the original nutrient content. *Enrichments* the addition of nutrients to foods in accordance with a standard of identity as defined by food regulations. Both restoration and enrichment programmes usually involve the addition of nutrients that are naturally available or present in the food product.

*Standardization* is the addition of nutrients to foods to compensate for natural variation, so that a standard level is achieved. Standardization is an important step to ensure a consistent standardized quality of the final product.

*Supplementation* is the addition of nutrients that are not normally present or are present in only minute quantities in the food. More than one nutrient may be added, and they may be added in high quantities.

As compared with restoration and standardization, fortification has a special meaning: the nutrient added and the food chosen as a carrier have met certain criteria, so that the fortified product will become a good source of the nutrient for a targeted population. Nutrients added for food fortification may or may not have been present in the food carrier originally.

# Effectiveness of food-fortification programmes

Food fortification differs from other programmes that involve the addition of nutrients to foods. Fortification is a nutritional intervention programme with a specifically defined target, and fortified food products are expected to become a main source of the specific added nutrient. Consequently, food fortification is expected to help prevent nutritional inadequacy in targeted populations in which a risk of nutrient deficiency has been identified. The criterion of the effectiveness of a food-fortification programme is whether the nutritional and health status of a targeted population has been improved.

The effectiveness of a food-fortification programme depends on whether or not the fortified food is accepted, purchased, and consumed by the targeted population. Factors such as the quality, taste, and price of the fortified products will play important roles in determining the effectiveness of the fortification programme. Several other important factors that should be considered carefully in designing food-fortification programmes are the following:

» The food chosen as the carrier should be consumed in sufficient quantities to make a significant contribution to the diet of the targeted population. Salt, sugar, flour, monosodium glutamate (MSG), and cooking oil have been used. Other foods should be explored, especially with reference to the specific food habits and preferences of targeted populations.» The addition of nutrients should not create an imbalance of essential nutrients. This is especially important for doubly, triply, or multiply fortified foods, in which interaction among the added nutrients (and also among the added nutrients and the nutrients that are naturally present in the food carrier) is likely to occur.

» The added nutrient should be stable under normal conditions of storage and use. Data on the stability of the added nutrient are also important for labelling purposes.» The price of the fortified food should be affordable for the targeted population.

» Programmes of quality assurance and control of fortified food can be more easily implemented if the fortification programme is centralized and involves mass production.

» The food should be distributed to as much of the targeted population as possible.

# Nutrient stability

Nutrient stability under normal conditions of storage and use is one of the important factors determining the effectiveness of a food-fortification programme. From a technical standpoint, nutritional stability during formulation, preparation, and processing is very crucial in determining the effective production of fortified foods. The following factors relating to nutrient stability are important for the manufacturers of fortified foods [2]:

» The technologist needs to know the extent to which food processes and distribution systems could affect nutrient retention; at the same time, the technologist needs appropriate data to develop strategies for minimizing the losses caused by nutrient instability.

» The quality, legislative, and marketing specialists need adequate information on nutrient stability, especially to enable them to make statements or claims on labels and advertising.

» The accountant needs to be aware of the stability data to establish and justify expenditures on potential modifications of processing techniques, the cost of nutrient premixes, etc.

» The nutritionist needs to be aware of the stability data to assess the choices and, ultimately, the supply of nutrient(s) for consumers. Nutrient stability is affected by physical and chemical factors. A wide range of physical and chemical factors influencing the stability of nutrients can be seen in figure 1. Although many factors may cause serious nutrient degradation, measures can be developed to minimize losses by applying proper technology, which includes application of a protective coating for an individual nutrient; addition of antioxidants; control of temperature, moisture, and pH; and protection from air, light, and incompatible metals during processing and storage. In this paper, several means to reduce the magnitude of degradation will be discussed, especially with regard to vitamin A, iodine, and iron.

## Vitamin A

Vitamin A is a critical micronutrient, essential for night vision and for the maintenance of skin and mucosal integrity. An early sign of vitamin A deficiency is night-blindness. Severe vitamin A deficiency may result in permanent blindness. Vitamin A deficiency is still a major nutritional problem in Indonesia as well as in many other parts of the world. The main intervention programmes against vitamin A deficiency administered by the Indonesian government are nutrition education, distribution of vitamin A capsules, and fortification of selected widely consumed foods.

Fortification of foods with vitamin A has been shown to be a very promising strategy. A pilot project on vitamin A fortification of monosodium glutamate (MSG) in three provinces has resulted in reduction of the prevalence of vitamin A deficiency. Further developments are dependent on overcoming the colour changes caused by fortification of MSG with vitamin A. Other foods, such as palm oil and noodles, have also been considered as carriers for vitamin A.

Vitamin A occurs in many forms, such as retinol (alcohol), retinal (aldehyde), retinyl acetate or retinyl palmitate (esters), and provitamin A carotenoids (β-carotene, α-carotene, etc.). Vitamin A is relatively unstable under normal storage conditions, particularly in harsh environments. The instability is mostly due to its chemical structure, which contains many double bonds susceptible to degradation (fig. 2).

To minimize the degradation of vitamin A, several approaches have been introduced. Since vitamin A is sensitive to atmospheric oxygen (the alcohol form of vitamin A is less stable than the esters), it is normally available commercially as a preparation protected by a coating that includes antioxidant(s). According to Murphy [3], there has been only one major supplier of vitamin A (as retinyl palmitate or acetate) for food fortification, Hoffman-La Roche of Switzerland. Table 1 lists the major formulations that are or have been available.

Antioxidants that maybe added to vitamin A premixes are butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and α-tocopherols (vitamin E). The use of vitamin E as an antioxidant is gaining popularity. Trace metals (especially iron and copper) and ultraviolet light accelerate the degradation of vitamin A. The stability of vitamin A is also affected by acidity. Below a pH of 5.0, vitamin A is very unstable.

## Iron and iodine

Iron deficiency is the most widespread nutritional problem in the world. In Indonesia the prevalence of anaemia among pregnant women, children under five years of age, and women workers is 64%, 55%, and 30%, respectively. Iron deficiency has adverse effects on resistance to infection, morbidity and mortality from infectious disease, learning processes, behaviour, physical condition, and productivity.

One important factor that should be carefully assessed in the preparation of mineral premixes (as ingredients for food fortification) is the type of salt to be fortified. Iron is usually supplied in the form of ferric phosphate, ferric pyrophosphate, ferric sodium pyrophosphate, ferrous gluconate, ferrous lactate, ferrous sulphate, or reduced iron (table 2), whereas iodine is normally supplied in the form of potassium iodide or iodate.

**FIG. 1. Factors influencing the stability of nutrients**

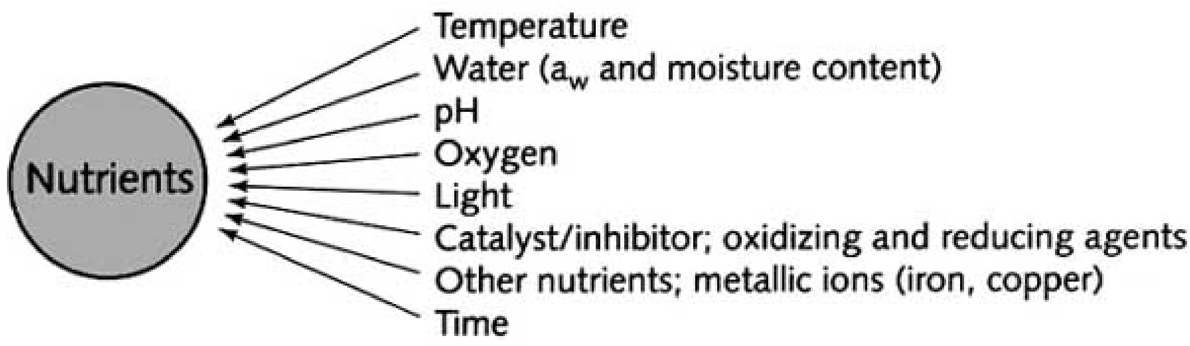



**FIG. 2. Chemical structure of vitamin A alcohol and β-carotene**

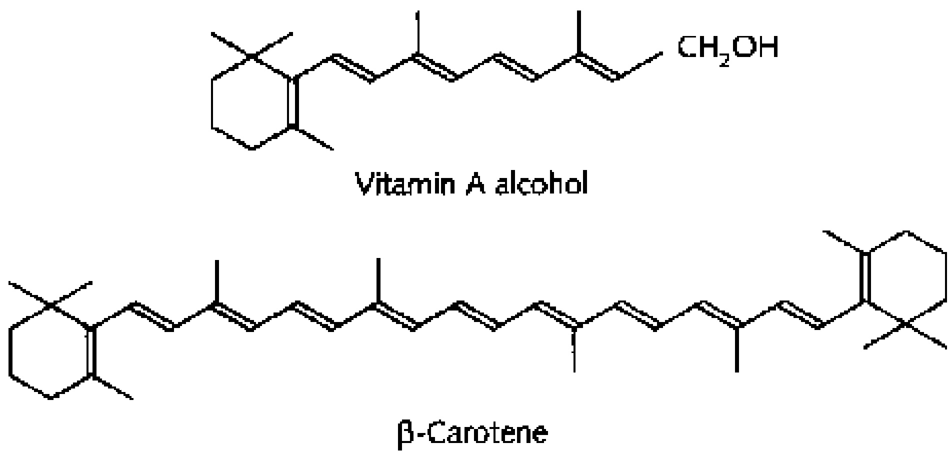



**TABLE 1. Commercial vitamin A preparations available from Hoffman-La Roche**

| Type | Ingredients | Food application |
|---|---|---|
| 250 CWS | Retinyl palmitate, acacia, sugar, modified food starch, BHT, BHA, sodium benzoate, α-tocopherol | Non-fat dry milk, dehydrated foods, dry cereals, beverage powders to be reconstituted before use |
| 250 S | Retinyl palmitate, gelatin, sorbitol-modified food starch, sodium citrate, corn syrup, ascorbic acid, coconut oil, BHT, α-tocopherol, silicon dioxide, BHA | Dry mix and fluid milk products |

| | | |
|---|---|---|
| 250 SD | Retinyl palmitate, acacia, lactose, coconut oil, BHT, sodium benzoate, sorbic acid, silicon dioxide, BHA | Foods and baked products, dehydrated potato flakes, dry milk |
| 500 | Retinyl palmitate, gelatin, invert sugar, tricalcium phosphate, BHT, BHA, sodium benzoate, sorbic acid, sodium bisulphite | Dry mix and fluid milk products |
| Emulsified RP | Sucrose - retinyl palmitate emulsion in water | Tea leaves |
| Oil | Retinyl palmitate, BHA, BHT | None |

Source: ref. 4.
Abbreviations: BHT, butylated hydroxytoluene; BHA, butylated hydroxyanisole; CWS, cold water soluble; RP, retinyl palmitate.

**TABLE 2. Selected iron sources currently used in food fortification**

| **Compound** | **Other common name** | **Formula** | **Iron content (g/kg)** | **RBV**[a] |
|---|---|---|---|---|
| Ferric phosphate | Ferric orthophosphate | $FePO_4 \times xH_2O$[b] | 280 | 3-46 |
| Ferric pyrophosphate | Iron pyrophosphate | $Fe_4(P_2O_7)_3 \times 9H_2O$ | 250 | 45 |
| Ferric sodium pyrophosphate | Sodium iron pyrophosphate | $FeNaP_2O_3 \times 2H_2O$ | 150 | 14 |
| Ferric ammonium citrate | | $Fe_xNH_3(C_6H_8O_7)_x$ | 170 | 107 |
| Ferrous fumarate | | $Fe(C_4H_2O_4)$ | 330 | 95 |
| Ferrous gluconate | | $Fe(C_6H_{12}O_7)_X$ [c] | 120 | 97 |
| Ferrous lactate | | $Fe(C_3H_5O_3)_2 \times 3H_2O$ | 380 | - |
| Ferrous sulphate | | $FeSO_4 \times 7H_2O$ | 320 | 100[C] |
| Iron | Elemental iron, ferrum reductum, metallic iron | Fe | 1,000 | |
| Reduced iron, $H_2$ or CO process | | Fe | 960 | 34 |
| Reduced iron, electrolytic | | Fe | 970 | 50 |
| Reduced iron, carbonyl | | Fe | 980 | 67 |

Source: ref. 4.

a. RBV denotes relative biological value. Iron-deficient rats are cured of iron deficiency by feeding them either a test iron sample or a reference dose of ferrous sulphate. The cure is measured by haemoglobin or packed-cell volume repletion in the rats' blood, and the bioavailability of the samples is reported against a value of 100 for ferrous sulphate. Thus, any iron sample that is less available than ferrous sulphate will have an RBV of less than 100.

b. Ferric orthophosphate contains from one to four molecules of hydration.

c. The precise structures of the iron salts are uncertain.

The following chemical and physical factors should be checked thoroughly in the formulation for food fortification, especially for iron:

» Solubility: ferrous salts are more soluble than ferric salts.

» Oxidative state: ferrous salts can be utilized more efficiently than ferric salts; however, ferrous salts are also more reactive in food systems.

» Ability to form complexes: ferric iron generally has a greater tendency to form complexes than ferrous iron; the formation of complexes will greatly reduce iron bioavailability.

In the preparation of iron as an ingredient for food fortification, the possibility that the iron will react or associate with other nutrients needs to be explored. The presence of metal ions (such as iron) may have a detrimental effect on quality if measures are not properly taken. Iron has been shown to speed up vitamin degradation (especially vitamins A and C and thiamine), catalyse the oxidative rancidity of oils and fats, and produce undesirable changes (colour, off flavours, etc.)

**Effect of processing on the stability of added nutrients**

The stability of nutrients is affected by many chemical and physical factors (fig. 1). Consequently, processing parameters must be selected and controlled during the processing of fortified food to minimize nutrient losses.

Compared with vitamins, minerals (iron and iodine) are very stable under extreme processing conditions. The primary mechanism of loss of minerals is through leaching of water-soluble materials [1]. Vitamin A, on the other hand, is very labile in the processing environment. Figure 3 illustrates the possibilities for the degradation of vitamin A (especially in its provitamin form β-carotene). Vitamin A is both oxygen and temperature sensitive. Borenstain [6] and Ottaway [7] have both reported that vitamin A (and also β-carotene) added to foods is sensitive to oxidative damage. In the form of retinol, vitamin A is more labile than its ester form; for this reason, vitamin A esters are usually used for food fortification, as illustrated by the list in table 1.

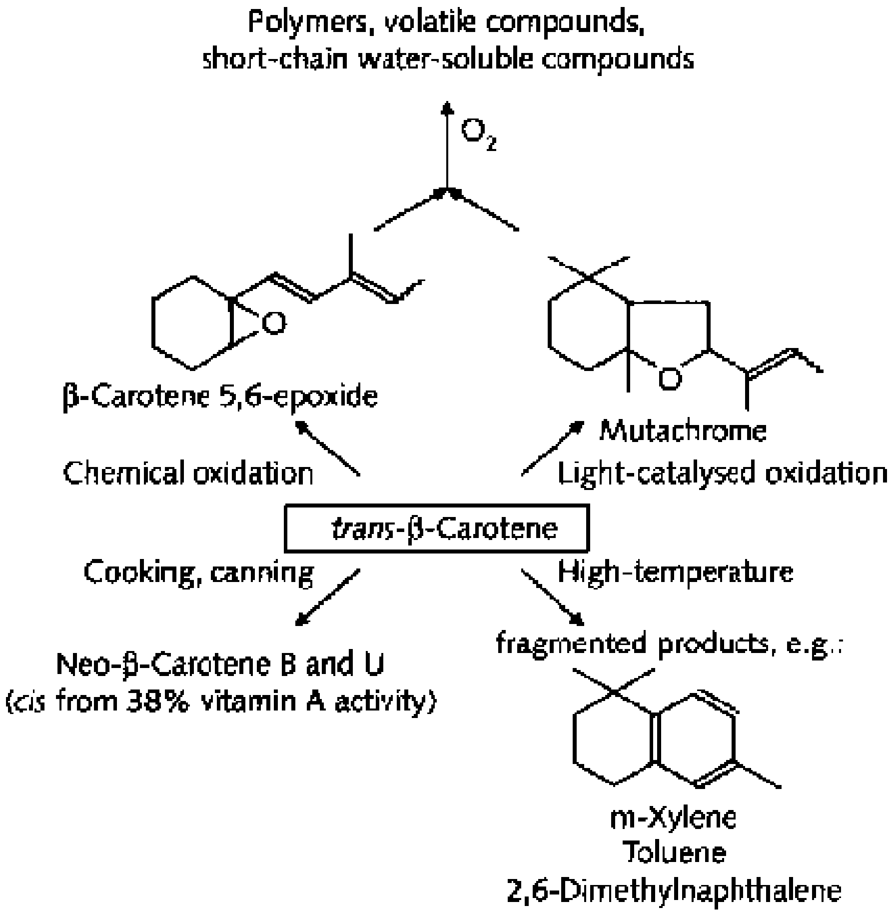
Table 3 shows the stability of vitamin A in pasteurized, multivitamin-supplemented orange juice. Vitamin A was slightly degraded during the first two months of storage. Vitamin A activity was much more stable when the vitamin was added as β-carotene.

The stability of vitamin A is also strongly affected by pH. At a pH of less than 5, vitamin A is susceptible to oxidation. At low pH, vitamin A tends to isomerize from the *trans* to the *cis* configuration, which has a lower vitamin activity. The problem of low pH is encountered especially during juice processing. Fruit juices usually have a low pH (about 3.0). To compensate for low pH, carbonation, which expels oxygen, may be used to stabilize vitamin A.

**TABLE 3. Degradation of vitamin A during processing and storage of pasteurized, multivitamin-supplemented orange juice**

| | **Amount of vitamin A - IU/100 ml (% of initial value)** | | | |
|---|---|---|---|---|
| Form of vitamin A | **Added** | **Total initial** | **2 mo** | **6 mo** |
| Retinol β-Carotene | 219 | 232 (100) | 168 (72) | 163 (70) |
| | 175 | 191(100) | 203(100) | 180 (94) |

**FIG. 3. Degradation pathway of β-carotene [5]**



**Effect of high-temperature treatment on nutrient (vitamin) stability**

Because high temperatures may be used in the manufacture of fortified foods, measures must be taken to minimize losses from thermal degradation. Drying is a processing method that uses high temperatures, and it has many applications in the manufacturing of fortified food. Drying is usually performed using several combinations of time and temperature, such as 9 to 12 hours at 50°C, 2 to 3 hours at 95°C, or 2 to 5 seconds at 140°C. To minimize nutrient losses, the use of lower combinations of time and temperature is desirable, which can be achieved by either increasing the surface area or reducing the pressure during the drying process.

Oven drying is the most common method. Pasta products, for example, may be dried in an oven for 9 to 12 hours at 50°C or for 2 to 3 hours at 95°C. O'Brien and Roberton [8] reported that β-carotene was more stable than the ester form of vitamin A during oven drying. During the processing of macaroni, oven drying for 9 to 12 hours at 50°C resulted in a 14% loss of vitamin A. However, the same treatment caused the loss of only approximately 5% of β-carotene. Furthermore, drying for 3 to 5 hours at 95°C caused the destruction of 23% of vitamin A but only 8% of β-carotene.

Drum drying is often used for manufacturing fortified food in powdered form. The advantage of drum drying over conventional oven drying is that higher temperatures can be used with a processing time of only 2 to 30 seconds. The combination of high temperature and short time (HTST) maximizes nutrient retention.

Furthermore, the drum dryer is usually used for liquid food slurries. Hence, the material may reach a very high temperature as it forms a film over the drum surface. The formation of this film during drying may offer some protection to the nutrients from oxidative damage, especially in comparison with similar HTST processes, such as the extrusion process. Table 4 shows that the retention of nutrients is much better during drum/ roller drying than extrusion processing because of the film formation [8].

Spray drying is another technique that can be used for manufacturing fortified food. Besides time-temperature combinations, other measures to prevent or minimize the contact of sprayed food products with oxygen need to be applied. During spray drying, a fine spray of food is introduced into the drying chamber where it encounters a stream of hot air, which produces rapid drying. The spraying process greatly increases the contact of the food with oxygen, thus accelerating oxidative damage.

Several ways to minimize oxidative damage have been introduced, including the addition of antioxidants and the application of coating materials and capsulation. Coating material can be applied by using sucrose in a raw material formulation. Johnson et al. [9] showed that a Coating containing at least 10% sucrose was needed to offer good protection from oxidative attack during spray drying. They also noted that, if possible, addition of 15% to 20% of sucrose to the raw material formulation is desirable, since it offers greater protection from oxidation.

**TABLE 4. Vitamin losses: extrusion vs. roller drying**

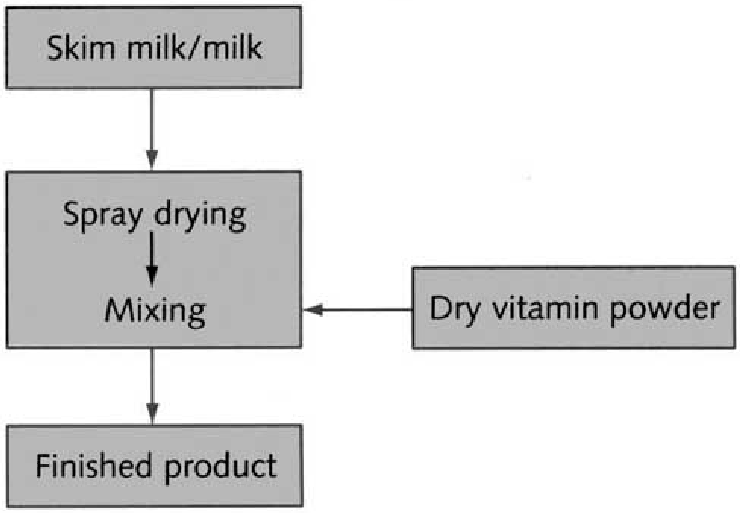
| Losses | Vitamin A | Vitamin C |
|---|---|---|
| Quantity added per 100 g dry material | 2,932 IU | 71.8 mg |
| Loss with extrusion (%) | | |
| Process loss | 62.4 | 8.2 |
| Storage loss | | |
| 6 mo | 75.0 | 31.1 |
| 12 mo | 85.3 | 45.2 |
| Loss with roller drying (%) | | |
| Process loss | 26.2 | 9.2 |
| Storage loss | | |
| 6 mo | 39.2 | 24.2 |
| 12 mo | 60.6 | 37.0 |

Source: ref. 8.

To minimize the deterioration caused by oxidation during drying, nutrients may be added after drying. This has been done in milk fortification, in which dry premixes containing the nutrient at the desired level were used. This process (fig. 4) is relatively simple and efficient, but requires extra mixing equipment.

Another food-processing operation that uses high temperatures is the extrusion process. Extrusion is very popular for manufacturing snack foods and ready-to-eat breakfast cereals. Extrusion has several advantages over other methods, since it is a very versatile process that includes several operations at once: mixing, cooking, and forming. Several parameters are important in determining the quality of the final product, including temperature (100° to 140°C or higher), moisture content, coating system, and oxygen, as well as other parameters characteristic of the extrusion process, such as pressure, throughput rate, velocity (rpm) of the screw, and die diameter [10]. If possible, fortification should be done during the final process in order to maximize nutrient retention. At this stage, fortification can be carried out during application of flavour.

**FIG. 4. Fortification of spray-dried milk with vitamins**




## Stability of nutrients and proper labelling

Increased consumer awareness of healthy eating has forced food producers to disclose information about the composition of their products on the label. With fortified foods, the amount of the added nutrient declared on the label is very important.

To meet label claims within a realistic shelf life, manufacturers must study the behaviour and kinetics of nutrient degradation thoroughly. To make correct claims about the nutrient content of a product on its label, the amount of the added nutrient should actually be more than that amount stated or declared on the label. The difference between the formulated and the declared levels is known as overage. Overage = (amount of nutrient present in the product - amount declared on the label)/amount declared on the label × 100.

The overage will vary according to the inherent stability of the nutrients, the conditions under which the food is prepared and packaged, and the anticipated shelf life of the product. Thus, the more labile or unstable nutrients, such as vitamin A, generally require high overages. Table 5 shows examples of vitamin A overages used in three different products. An overage of 25% means that if the declared amount of vitamin A is, for example, 20 mg per gram of product, then the input level or the amount of nutrient in the formulation should be 25 mg per gram of product.

The shelf life and the declared amount of a nutrient on the label (based on the amount of the nutrient remaining at the end of a product's shelf life) can be determined by several methods, one of which is Arrhenius' method as described by Labuza and Riboh [11].

The kinetics of nutrient degradation can be modelled as zero or first-order kinetics [12]. Using a simple kinetic model [11,12], we can predict the shelf life and the overages of a particular nutrient. Table 6 compares the nutrient losses predicted by Arrhenius' model with the actual amounts lost.

Another aspect of labelling of fortified foods is the claim for nutrients. In the United Kingdom, for example, if a claim is made on the label that a food is a “rich” or “excellent” source of a particular vitamin or mineral, the daily food portion (described as “the quantity of food that can reasonably be expected to be consumed in a day”) must contain at least half of the recommended dietary allowance (RDA) for that nutrient [2]. For the requirements of other countries, specific food laws and regulations should be consulted.

**TABLE 5. Vitamin A overages in three products**

| Product | Shelf life (mo) | Overage (%) |
|---|---|---|
| Milk-based fortified drink powder | 12 | 25 |
| Fortified meal replacement bar | 12 | 45 |
| Multivitamin tablet | 30 | 60 |

# Conclusion

Food fortification is a nutritional intervention programme with a specifically defined target population, and its effectiveness is measured by whether or not the fortified food is accepted, purchased, and consumed by that population. The success of a food-fortification programme is measured by whether or not the nutrition and health status of the targeted population has been improved. Therefore, several important aspects should be carefully assessed in the development of a food-fortification programme, such as determining nutrient stability under normal conditions of storage and use. From the technical point of view, nutritional stability during formulation, preparation, and processing is crucial for the effective production of fortified foods.

Many factors may cause serious nutrient degradation. Consequently, the proper technology to minimize losses needs to be implemented. Some strategies for stabilizing nutrient content include the application of protective coating for the individual nutrient; the addition of antioxidants; the control of temperature, moisture, and pH; and protection from air, light, and incompatible metals during processing and storage.

The stability of nutrients and the conditions under which fortified foods are prepared, manufactured, and packaged will affect the shelf life of the product and, concomitantly, the nutrient overages. The degree of nutrient degradation in food and the length of the shelf life will govern the level of overage. The degree of nutrient degradation can be determined by several methods, one of which is the relatively simple Arrhenius method, which can be used to predict the shelf life and the overages of a particular nutrient.

**TABLE 6. Vitamin losses (%) after six months of storage at 20°C and 75% relative humidity**

| Vitamin | Predicted from Arrhenius' model | Analysed after storage |
|---|---|---|
| Vitamin C | 24.0 | 23.0 |
| Vitamin A preparation | 15.0 | 10.0 |
| Folic acid | 8.1 | 7.4 |
| Vitamin $B_{12}$ | 9.2 | 7.7 |

Source: ref. 11.

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