Fortification of foods: Historical development and current practices

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Abstract

Differences exist between food enrichment and food fortification. A wide array of fortifying agents and food carriers have been developed to date. Numerous objectives and factors must be taken into consideration to guarantee a successful food-fortification intervention—for example, legal issues and how they affect programme outcomes. Technological constraints are also faced by food-fortification technology; however, research is being conducted to overcome these problems.

Introduction

Nutrient supplementation of foods was mentioned for the first time in the year 400 B.C. by the Persian physician Melanpus, who suggested adding iron filings to wine to increase soldiers' "potency." In 1831 the French physician Boussingault urged adding iodine to salt to prevent goitre. However, it was between the First and Second World Wars (1924–1944) that supplementation was established as a measure either to correct or prevent nutritional deficiencies in populations or to restore nutrients lost during food processing. Thus, during this period the adding of iodine to salt, vitamins A and D to margarine, vitamin D to milk, and vitamins B_1, B_2, niacin, and iron to flours and bread was established.

Currently, food fortification encompasses a broader concept, and might be done for several reasons. The first is to restore nutrients lost during food processing, a process known as enrichment. In this case, the amount of nutrients added is approx equal to the natural content in the food befc cessing. A second reason is to add nutrier may not be present naturally in food, a known as fortification. In this case, the amoun trient added may be higher than that present processing. Fortification also standardizes t tents of nutrients that show variable concent A typical example is the addition of vitam orange juice to standardize vitamin C concer and compensate for changes due to seasoi processing variations. Finally, for technologi poses, a preservative or colouring agents ar to processed foods.

Therefore, depending on the reasons for nutrients, the objectives may be: to maint nutritional quality of foods, keeping nutrien adequate to correct or prevent specific nu deficiencies in the population at large or in at risk of certain deficiencies (i.e., the vegetarians, pregnant women, etc.); to incr added nutritional value of a product (con view); and to provide certain technological fu in food processing.

According to these principles, currently in countries nutrients are added to a wide va food carriers, such as cereals, flours, brea margarine, infant formulas, soy milk, orang salt, sugar, monosodium glutamate, tea, diete erages, and even parenteral and enteral s (table 1). Most fortifying agents are vitam minerals, and in some cases essential amir and proteins. These additions have helped public health problems, such as salt iodizatio vent goitre [1].

Definitions of terms

The words enrichment and fortification have cal origins. Enrichment was originally intro the 1940s with enactment of the Standards

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TABLE 1. Fortified foods

	Fortifying agent
Salt	Iodine, iron, flour
Flours, bread, rice	Vitamins B_1, B_2, niacin, iron
Milk, margarine	Vitamins A and D
Sugar, monosodium glutamate, tea	Vitamin A
Infant formulas, cookies	Iron
Vegetable mixtures	Vitamins, minerals, amino acids, proteins
Soy milk, orange juice	Calcium
Ready-to-eat cereals	Vitamins, minerals
Diet beverages	Vitamins, minerals
Enteral and parenteral solutions	Vitamins, minerals

richment Programs aimed at replenishing nutrients lost during cereal processing. This was expanded into a broader context to include nutrients not naturally present in the food, or fortification. Currently, the two words are often used interchangeably, which is wrong from a historical standpoint. However, taking into consideration the fact that the aim in both cases is to improve the nutritional value of foods, the term *nutrification* was suggested, which would include both enrichment and fortification [2].

Public health programmes

In specific intervention programmes the addition of nutrients has successfully reduced or even eradicated a particular deficiency. The technology for most of these programmes is readily available, and it is well known that political decisions and know-how guarantee success. For example, in the Central America region, fortification of sugar with vitamin A has effectively reduced the prevalence of hypovitaminosis A in the population.

To maximize the success of such programmes, several factors must be taken into consideration. The carrier has to be a staple food of the target population. Also, centralized processing is necessary, and frequent as well as reasonably constant consumption is desirable. The nutrient or fortifying agent must have adequate physicochemical, organoleptic, and bioavailability characteristics. This means that the colour, taste, odour, and appearance of the carrier food must not be affected. Bioavailability is extremely important. In the case of vitamins it is not a problem, but it is when minerals are added.

Another important issue is related to the cost of the fortifying agent. It is desirable that the fortification process does not significantly increase the total cost of the final product. Furthermore, it is necessary to have a monitoring and control system that guarantees both adequate nutrient concentration and programme compliance. It is also important to verify the adequate addition of nutrients to ensure the programme's effectiveness, and, in the case of potentially toxic nutrients, to guarantee that excessive concentrations are not added, which could put the population at risk. Several questions must be answered in relation to legal issues. Should the programme be compulsory or voluntary? Should it be financed by the government, the private sector, or both? In view of previous unsuccessful experiences, where food-fortification programmes were mandatory but failed to secure compliance, it becomes necessary to identify different approaches for adequate implementation, possibly including fiscal and tariff incentives. It is also important to demonstrate and document the cost-benefit of the intervention in order to gain objective evidence to support the continuance of these programmes [3].

Technological issues

Food science and technology play a key role with respect to several issues. For example, it is necessary to maintain the overall quality of the product in terms of the bioavailability of the fortifying agent. Although bioavailability may increase, the product's quality is at risk, especially its stability. Iron, for example, may react with fatty acids in the fortified food, forming free radicals that induce oxidation. Other characteristics that may be affected are colour, taste, odour, and appearance, alterations that should be avoided altogether since they affect consumer acceptability of the product.

This phenomenon, typical in mineral salts, is related to the solubility of the fortifying agent. In general, as solubility of the compound increases, the nutrient is more bioavailable, but at the same time is more reactive with the fortified food, making it less stable and susceptible to the changes described. Table 2 shows, as an example, the addition of several iron salts to different processed foods.

Iron salts, potentially useful in food fortification, could be divided into different categories. First, the compounds that are soluble in water, such as ferrous sulphate and ferrous gluconate, show the highest bioavailability; however, they can easily alter the quality of most foods (stability, colour, odour) and are used only in infant formulas. Second are compounds that are slightly soluble in water and soluble in diluted acids, for example, ferrous fumarate and ferrous succinate. These compounds have quite good bioavailability in relation to ferrous sulphate, but they still have significant limitations when added to

TABLE 2. Relative bioavailability of iron compounds used in food fortification (%)

Compounds	Rats	Humans	Fortified food
Soluble in water			
ferrous sulphate	100	100	infant formulas
ferrous gluconate	97	89	infant formulas
Slightly soluble in water and soluble in diluted acids			
ferrous fumarate	95	100	infant cereals
ferrous succinate	113	92	infant cereals
Insoluble in water but soluble in diluted acids			
ferric pyrophosphate	45	21–74	infant cereals
ferric orthophosphate	6–46	25–31	infant cereals
elemental iron	8–76	5–90	flours, cereals

Source: Ref. 4.

TABLE 3. Nutrients' stability under different conditions

	pH 7	pH<7	pH>7	Air/O_2	Light	Heat	Maximum cooking loss (%)
Vitamin C	U	S	U	U	U	U	100
Folic acid	U	U	S	U	U	U	100
Vitamin A	S	U	S	U	U	U	40
Niacin	S	S	S	S	S	S	75
Cobalamine	S	S	S	U	U	S	10
Mineral salts	S	S	S	S	S	S	3

Source: Modified from Ref. 5.

S = stable; U = unstable.

food, except when added to infant cereals, where relative success has been achieved.

Third, compounds that are insoluble in water and slightly soluble in diluted acids, such as iron salts, are more inert and have low reactivity with the food carrier. Therefore, they are likely to be used as fortifying agents. Unfortunately, for the same reasons, they are less bioavailable; for example, ferric salts such as ferric pyrophosphate and ferric orthophosphate are widely used in foods even though their bioavailability is low. However, several compounds of elemental iron that are reduced by different technological processes have higher bioavailability, and at the same time cause no significant changes in food characteristics [4].

Another important issue is the stability of the fortifying agent. Changes in nutrients' stability may depend on factors such as pH, oxygen, air, light, and temperature (table 3). These should be controlled during processing and storage of fortified foods. A good example is vitamin C, which is extremely unstable under several conditions, especially in high heat and humidity.

Percentage loss of different vitamins during processing and storage may be significant, especially for vitamins C, A, folic acid, and niacin. It is useless to fortify foods if the nutrient concentration decreases after fortification, so that when the food is consumed the nutrient is no longer present.

As part of the fortifying process, a permanent monitoring system of nutrient concentrations is extremely important to ensure the required levels, since high or low concentrations are unacceptable owing to the potential risk of toxicity. Legal issues are important and must be addressed so that country regulations are adhered to, facilitating the implementation of regional fortification.

Food fortification will continue to be an important tool, not only to treat or prevent specific nutritional deficiencies, but also to promote a general state of well-being in different populations, and possibly to prevent certain chronic diseases. The identification and development of fortifying agents that will guarantee product quality and high bioavailability are technological and scientific challenges. Some options for the future are the microencapsulation of nu-

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trients, the use of nutrient bioavailability stimulants (addition of ascorbic or other organic acids to promote iron absorption), and the elimination of inhibitors of mineral absorption in the intestine (e.g., phytates).

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