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Overview of Iron Fortification of Foods

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Foods have been fortified with iron for over 50 years. In the 1930s and 1940s, iron was first added to cereal flour to restore the iron lost in milling. Today, many foods, including infant formulae and weaning foods, are fortified according to standards and principles defined by established bodies, including FAO/WHO (1976), the ESPGAN Committee on Nutrition (1982), and the National Research Council (1989). This presentation reviews food vehicles suitable for iron fortification, iron requirements, iron fortificants, and the technological and nutritional criteria required for food fortification. Examples of successful applications are also presented. A considerable amount of data is available on the bioavailability of iron from standardized diets and single meals (Monsen et al., 1978; Cook, 1983; Cook and Reuseur, 1983; Hallberg, Brune, and Rossander, 1989a; Hallberg, 1985; Stekel et al., 1985; Monsen, 1988; Hallberg, Brune, and Rossander, 1989b; Hurrell, 1989; Hurrell et al., 1989); however, it is beyond the scope of this presentation to review this data.

Criteria for selecting food vehicles

Four criteria exist for selecting an appropriate food vehicle for iron. First, it is essential that frequency and average consumption of the food by the target group is both known and predictable, especially for young children, adolescents, and pregnant women. Second, there should be no risk of overconsumption. Third, the addition of iron should not affect the organoleptic qualities of the food: iron in its ionized form is an aggressive compound that interacts with vitamins, minerals, and other nutrients. Finally, the cost of the fortified product should not be beyond the reach of those for whom it is intended. Cost will be influenced by the type of iron compound added to the food vehicle, which depends on the nature of the food and its shelf life. Some iron compounds cost as much as a complete vitamin/mineral premix; this needs to be considered in designing micronutrient concepts and priorities.

Iron requirements

Net iron losses from the body through the skin, urine, and blood are about 2 mg/day for women, 1 mg/day for men, and 0.8 mg/day for children, reflecting that net iron requirements are indeed very low. The Recommended Dietary Allowances (RDA) are 15 mg/day for women and 12 mg/day for men, which is 7.5 and 12 times higher than net iron requirements; therefore, the RDAs take into account the low bioavailability of dietary iron (Herbert, 1987; National Research Council, 1989).

The bioavailability, or more specifically the relative bioavailability (RBV), of iron in foods is measured as the incremental absorption of that iron in a standardized diet or test meal. Ferrous sulfate has been used as a reference and has an RBV of 100 percent, against which other iron compounds are compared. For example ferrous fumarate, which is used in infant foods, has an RBV that is equal to ferrous sulfate, while ferric pyrophosphate, ferric orthophosphate, and reduced iron have an RBV of one-half to one-third of ferrous sulfate (Hurrell, 1989; Hurrell et al., 1989; Hurrell and Cook, 1990).

Food vehicles for iron fortification

Suitable food vehicles for iron fortification include cereal flours, such as wheat and corn. These foods already contain iron, although most of it has been removed during milling to white flour. Suitable technologies to fortify flour with reduced iron or iron pyrophosphate have been developed. In general, the quality of bread, fine bakery products, and pasta is not negatively affected by reduced iron or iron pyrophosphate.

In the process of cooking cereal, free iron binds to proteins and amino acids, resulting in a rearrangement of the iron in food. Because of a low interaction with other food components, flour, ready-to-eat cereals, and extruded cereals are suitable vehicles for iron. Cocoa beverages, such as chocolate breakfast drinks, are suitable, even though they contain tannins that reduce iron absorption, because iron can be added to compensate for this. UHT milk, liquid diets, infant formulae, and powdered skim milk lend themselves very well technologically and nutritionally as a vehicle for iron.

Foods not recommended as vehicles for iron fortification include soft drinks and isotonic beverages. This is because consumption is poorly controlled and people may drink as much as 2 or 3 liters per day, thereby exceeding the maximum recommended daily intake for iron. Fat-based foods are also not suitable for fortification, because iron catalyzes oxidation and degradation of fat, making the food rancid; thus, fresh dairy products are not suitable vehicles for iron fortification. Salt and sugar are not good vehicles because they are hygroscopic and, in a moist environment, the addition of iron causes color changes and adverse iron-nutrient interactions. Salt poses another problem, because it is used in food preservation. For example, iron-fortified salt may cause severe quality problems when used for curing vegetables, meat, and cheese. A special iron-vitamin A, double-fortified salt has been developed, which may be suitable for fortification of powdered weaning foods (The Micronutrient Initiative, pers. com.).

Iron fortificants

A number of iron compounds are listed as "generally recognized as safe" (GRAS) by the U.S. Food and Drug Administration (Code of Federal Regulations, 1994). Iron fortificants listed as GRAS are reduced iron, ferric phosphate, ferric pyrophosphate, ferric-sodium-pyrophosphate, ferrous gluconate, ferrous lactate, and ferrous sulfate; however, some non-GRAS iron fortificants are also being recommended and used. These compounds may be safe, but in some cases more data are needed to corroborate their safety. Examples of these include carbonyl iron, iron amino acid chelates, and sodium iron EDTA (MacPhail et al., 1994). As of today, sodium iron EDTA is not manufactured on a commercial scale. Furthermore, the compound is expensive to produce and its superior bioavailability has only been shown in diets high in phytate (MacPhail et al., 1994).

Food technology criteria

The most frequent problems encountered in adding iron compounds to food are discoloration, appearance of specks, segregation, sedimentation, and sandy texture. Other quality problems that may occur are lipid oxidation, off-flavor development, and vitamin degradation.

From a technical point of view, solid or liquid foods present different challenges for successful fortification. In liquid foods, solubility and dispersibility of the iron fortificant are important factors.

Nutritional criteria

Bioavailability and safety are the most important nutritional criteria. The main dietary factors affecting iron bioavailability are vitamin C and the presence of iron inhibitors such as phytate and tannin. Iron compounds added to foods should be safe and not cause gastric irritation. The iron should not interact with vitamins and minerals, and it should be of high purity. The purity of some of the non-GRAS iron compounds may not be defined, and they may contain traces of other metals. For this reason iron fortificants should comply with quality standards outlined in the U.S. Pharmacopoeia or Food Chemical Codex (FCC). Finally, the safety of the iron compound should be recognized by the U.S. Food and Drug Administration or other regulatory agencies. To date, no "accepted daily intake" (ADI) values for iron fortificants have been established.

Successful applications of iron fortification

A number of iron compounds can be successfully added to foods on a large scale. Reduced iron is used to fortify wheat added to flour and ready-to-eat cereals in combination with vitamins B¹, B², B⁶, and niacin. The amount of reduced iron actually absorbed from fortified flours has been investigated and depends on the type of diet (Hallberg, 1985; Hallberg, Brune, and Rossander, 1989a and 1989b).

Desiccated ferrous sulfate is used to fortify low acid foods and infant formulae. For prevention of color changes, the food has to be slightly acid because ferrous sulfate turns food brown above pH 6.3.

Ferric pyrophosphate has a low solubility. The compound can be dispersed and suspended in a liquid food. It is used to fortify cereals, pasta products, milk powder, liquid diets, infant formulae, and cocoa drinks. Ferric pyrophosphate interacts least with food components, and its bioavailability is considered to be good. In the acid environment of the stomach, its solubility and, thus, bioavailability is increased.

In extensive tests, ferrous fumarate was found to be suitable for fortification of cereal-based weaning foods, biscuits, and wafers; however, because of its brown color and insolubility, it is not appropriate for fortification of milk and white or off-white foods (Hurrell, 1989; Hurrell et al., 1989; Hurrell and Cook, 1990).

Ferrous lactate is highly hygroscopic and cannot, therefore, be used in dry foods. It is the preferred iron

source for liquid foods such as UHT milk and liquid formulae diets.

Technical measures to enhance iron bioavailability

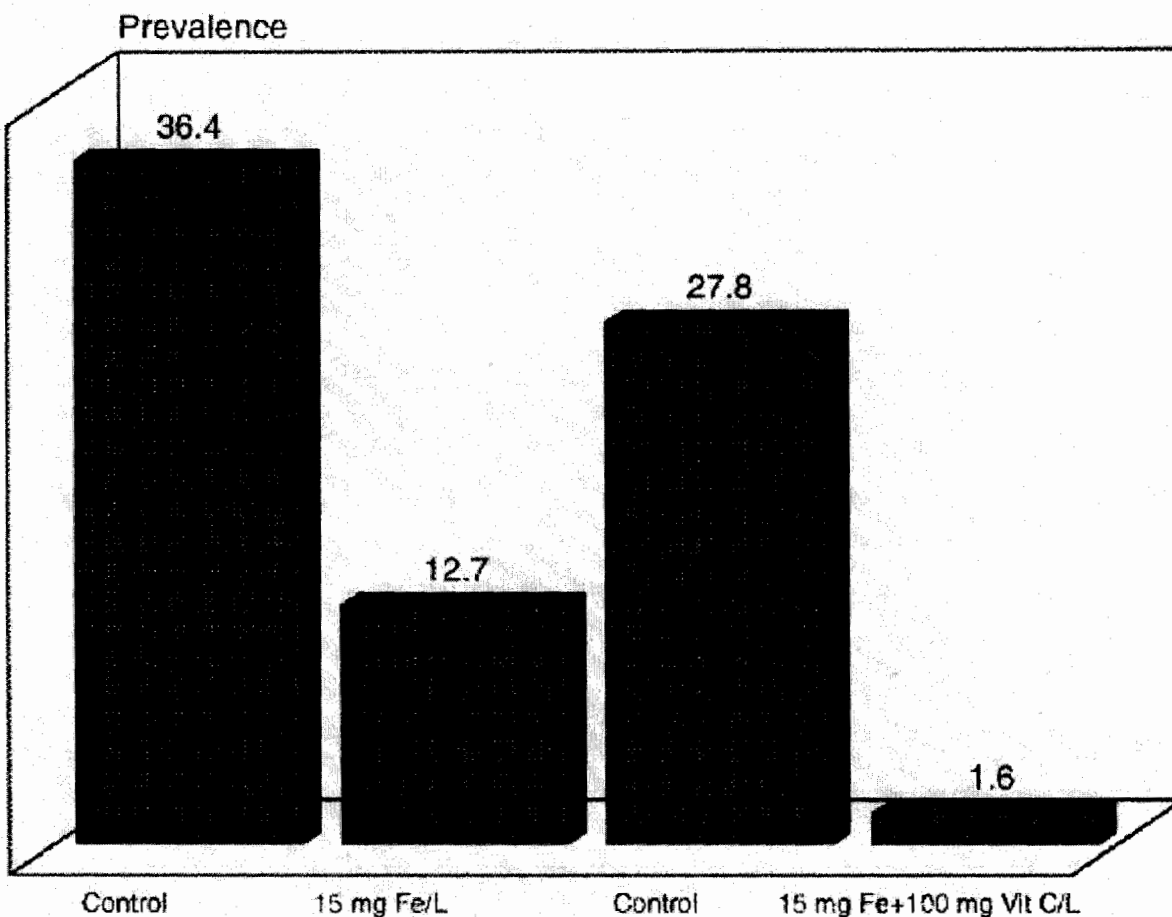
Phytate is a powerful inhibitor of iron absorption. Its inhibitory effect can be neutralized by yeast fermentation through activation of the enzyme phytase (Cook, 1983; Cook and Reusseau, 1983; Acosta et al., 1984; Beard, 1986).

Acidification of foods represents another strategy to increase iron bioavailability. Lactic acid may be used to acidify vegetables and other foods. Vitamin C fortification and lactic acid fermentation have been shown to increase iron bioavailability (Hallberg, Brune, and Rossander, 1989a; Borch-Johnsen et al., 1994).

Impact of iron fortification on anemia

Few studies show the efficacy of iron fortification on anemia prevention. One such study was conducted in Chile (Stekel et al., 1985), in which the prevalence of anemia in children between 3 and 15 months old supplemented with iron-fortified milk was reduced from 36 percent to 13 percent. Anemia prevalence was reduced from 28 percent to 2 percent in children supplemented with both iron- and vitamin C-fortified milk. The data show that vitamin C and iron together were more effective in reducing anemia than iron supplementation alone (see figure 4.1).

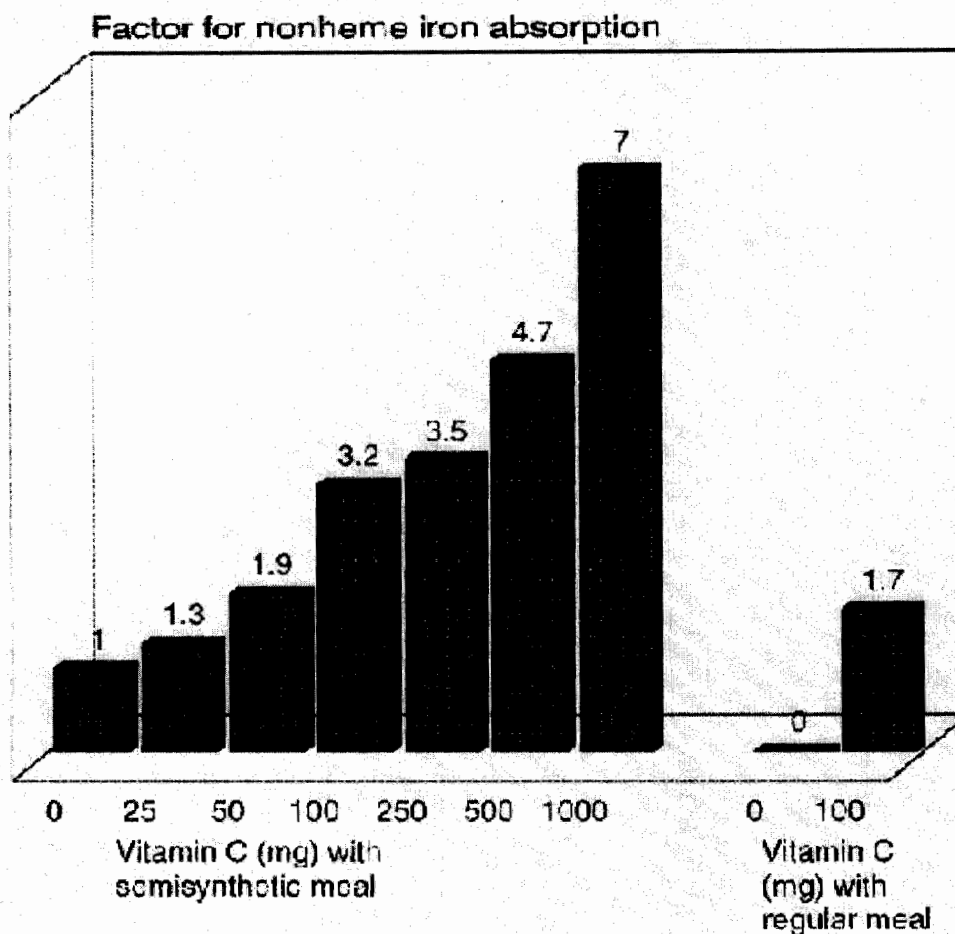
Figure 4.1: Prevalence of anemia in children age 3 to 15 months fed iron and iron/vitamin C-fortified milk



Source: Stekel et al. (1985)

The effect of vitamin C on increasing nonheme iron absorption in a synthetic test diet and in a standard meal was investigated by Monsen (1988). By taking 50 mg, 100 mg, and 500 mg of vitamin C with a semisynthetic test meal, absorption of nonheme iron was increased 1.9, 3.2, and 4.7 times, respectively. In the same study, nonheme iron absorption increased 1.7 times when 100 mg of vitamin C was included in a standard diet (see figure 4.2).

Figure 4.2: Effect of vitamin C on non-heme iron absorption

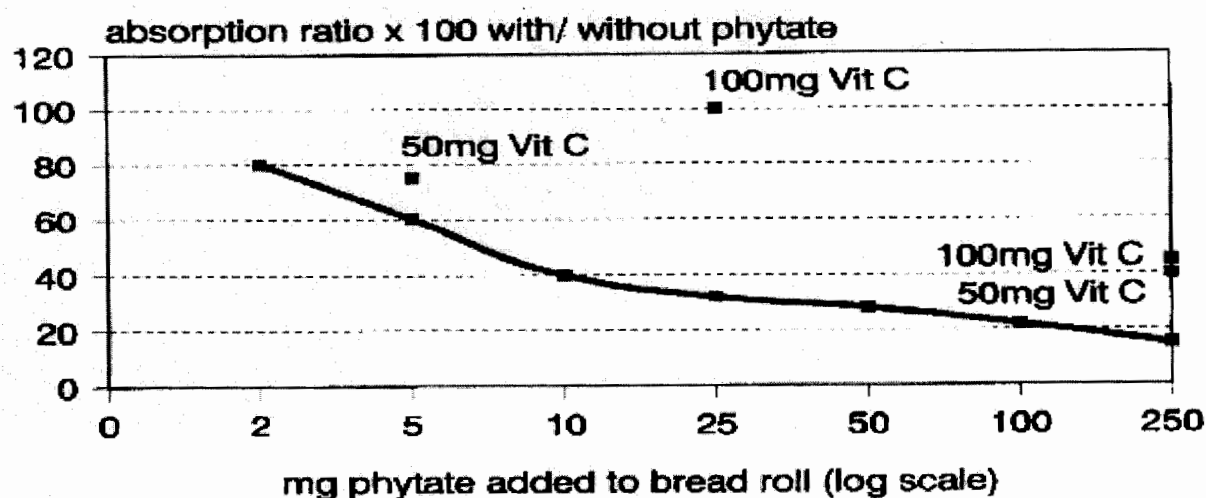


Source: Monsen (1989)

The inhibitory effect of phytate on iron absorption from bread rolls has been studied by Hallberg et al. (1989b). Increasing the amount of phytate in bread rolls was found to decrease the ratio of iron absorbed from 80 to 20 percent. The inhibitory effect of phytate (25 mg) was neutralized by taking 100 mg vitamin C as a beverage with the bread roll (see figure 4.3).

In the process of establishing strategies for anemia prevention, it is important to realize that micronutrients other than iron are important in anemia prevention. In addition to iron, copper, vitamins A, B₂, B₁₂, C, and folate are essential for hemoglobin formation; thus, it is important to look at the total diet and not just iron when discussing anemia prevention. The premise of any fortification program should be to design a diet to increase the availability of nutrients needed to maintain good iron status.

Figure 4.3: Effect of sodium phytate and vitamin C on iron Absorption



Source: Modified from Hallberg et al. (1989)

Summary

Iron fortification is a widely used public health measure for prevention of iron deficiency anemia. The selection of iron fortificants should be based on technological suitability, bioavailability, efficacy in reducing anemia, safety, and low cost. There is no point in fortifying a food with iron alone if the cost of the compound is higher than the cost of a vitamin-mineral mix that includes iron. Alternative strategies to increase iron bioavailability in foods must continue to be sought.

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Dr. Lorri commented that most of the nonrecommended food vehicles are those commonly consumed in developing countries; thus, it is questionable whether fortification is a viable solution for developing countries. Dr. Blum replied that different criteria have to be applied depending on the country, because of unique dietary characteristics. Mr. Mannar added that because of the limited number of foods that can be fortified with iron in developing countries, the University of Toronto is developing a stable formulation of doubly fortified salt with iron (ferrous fumarate) and iodine (potassium iodate) using a special encapsulation technique, in which dextrin encapsulates the compounds. The formula is stable for

up to six months. In vivo and in vitro trials are needed before carrying out a community-based trial.

Dr. Henry asked about the use of bovine blood for iron fortification. Dr. Blum replied that studies in Chile have shown that bovine hemoglobin can be successfully used in fortification; however, disease problems in blood mean that governments have strict regulations about shipping blood products. Ethical considerations also exist because there are groups, for example, Muslims, who could not accept such products for religious reasons.

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