

Iron Compounds for Food Fortification: Guidelines for Latin America and the Caribbean 2002

Introduction

Iron deficiency is the most prevalent micronutrient deficiency in the world today. It affects millions of individuals throughout the life cycle, particularly infants and pregnant women, but also older children, adolescents, and women of reproductive age. Living organisms require iron for their cells to function normally. Iron is needed for the development of vital tissues—including the brain—and for transporting and storing oxygen in hemoglobin and muscle myoglobin. Iron deficiency anemia is the severe form of iron deficiency. It can result in low resistance to infection, impaired psychomotor development, and cognitive function in children, poor academic performance, as well as fatigue and poor physical/work endurance. In addition to the above, iron deficiency anemia in pregnancy can result in a low-birth-weight infant.

Three intervention strategies are available to prevent iron deficiency and, therefore, iron deficiency anemia. These are supplementation, dietary diversification, and both targeted and untargeted food fortification.

Nineteen countries in the Americas have a national food fortification program, in which iron and other micronutrients are added to at least one widely consumed food that is often wheat and/or corn flour. Table 1 shows the iron compounds added to the flours. Each iron compound has different properties and characteristics, which influence its bioavailability, as is discussed later. A number of countries also currently implement fortification programs targeted to specific groups of the population, primarily infants and young children age 6 to 24 months and school-age children.

Purpose of These Guidelines

This document presents a brief overview of the current information on iron compounds that can be used in food fortification and provides guidelines for selecting the most suitable iron compound(s) based on currently available information on bioavailability, stability, and cost.

The guidelines are written for program managers and the private sector involved in the design and implementation of food fortification programs in the Americas. They are a starting point for deciding on which iron

compound(s) to select when fortifying a particular food. For further information, the reader is referred to the publications listed in the section Further Reading at the end of this document.

These guidelines provide information for selecting the most suitable iron compound(s) for fortifying foods based on currently available information and may be subject to modification as further information becomes available.

Iron Absorption from the Diet

Iron is found in foods in the form of heme and non-heme iron. Iron in meat, especially red meat, is a main source of heme iron, while the main sources of non-heme iron are plant foods. The diet in Latin America and the Caribbean is generally based on corn, rice, wheat, beans, and potatoes, with relatively low intakes of foods of animal origin. Although both plant and animal foods are rich in iron, iron is not equally absorbed from all food sources. Heme iron is more readily available for use by the body than non-heme iron.

Bioavailability refers to the amount of iron that is absorbed from the diet for use in normal metabolic processes and functions, and is influenced by both dietary factors and host-related factors. The dietary factors include iron absorption inhibitors such as phytates, polyphenols, calcium, some vegetable proteins such as those in soy, and some animal proteins such as those found in milk products and eggs¹; and iron absorption enhancers, which include ascorbic acid and flesh derived from meat, fish, or poultry.^{1,2} The host-related factors include the individual's iron status. The acid concentration of gastric juice also influences the absorption of inorganic iron, which can be important where poorly water-soluble iron is used. For example, the absorption of poorly water-soluble iron compounds could be lower in young children, as compared with adolescents and adults.³ The same could apply to individuals with pathological or gastric disorders that cause low stomach acidity.⁴ Knowledge of the factors that influence iron absorption is critical to designing an effective iron fortification program.

Table 1. Wheat and Corn Flour Fortification in the Americas

Micronutrients Added and Countries Using Them	Iron Compound	Fortification Level
Wheat Flour: Vitamins B ₁ and B ₂ , Niacin, Folic acid, Iron USA, Canada, Belize, Bolivia, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Panama Chile, Cuba	Reduced iron Ferrous sulfate	44–65 mg/kg 30 mg/kg
Wheat Flour: Vitamins B ₁ and B ₂ , Niacin, Iron Venezuela	Ferrous fumarate	20 mg/kg
Wheat Flour: Iron Brazil (voluntary fortification)	Reduced iron	30 mg/kg
Peru	Ferrous sulfate	30 mg/kg
Corn Flour: Vitamins A, B ₁ , and B ₂ , Niacin, Iron Venezuela	Ferrous fumarate and reduced iron	30 mg/kg and 20 mg/kg
Nixtamalized Corn Flour: Vitamins B ₁ and B ₂ , Niacin, Iron Guatemala, El Salvador, Honduras, Nicaragua Costa Rica Mexico	Ferrous fumarate* Amino acid chelate Reduced iron	25 mg/kg 22 mg/kg 30 mg/kg

* Proposed, following INCAP/PAHO recommendation.

The mere addition of an iron compound to a food rich in iron absorption inhibitors may not be efficacious.

Stages in Developing Iron-Fortified Foods

There are three stages in food fortification with iron:

1. **Selecting the iron compound** by identifying the iron compound whose potential absorption is greatest and, when added at the appropriate level, causes no unacceptable sensory changes in either the fortified food or the final cooked product. This requires having information on the acceptability of the color, flavor, and odor after fortification, at the end of the normal shelf-life period, and after processing or cooking the final product.
2. **Optimizing iron absorption in order to meet nutritional needs** by adding absorption enhancers or eliminating or reducing the inhibitors, where possible.
3. **Measuring the change in iron status in the target population** by determining the prevalence and change of iron deficiency and iron deficiency anemia.

These guidelines provide information for selecting the most suitable iron compound(s) for fortifying foods, given the best information that is currently available (Stages 1 and 2), but programs must always be developed with a well-designed and built-in monitoring and evaluation system (Stage 3).

Iron Compounds for Food Fortification

There are two categories of iron compounds used for food fortification: inorganic iron compounds and protected iron compounds.*

Inorganic Iron Compounds

The inorganic iron compounds that can be used in food fortification are classified as: (a) water-soluble, (b) poorly water-soluble/soluble in dilute acid, and (c) water-insoluble/poorly soluble in dilute acid.

Water-soluble. The water-soluble iron compounds include ferrous sulfate. Its solubility is instantaneous in the stomach. Absorption can range from approximately 1% to perhaps 50% depending on the iron status of the individual, the presence of iron absorption enhancers and inhibitors in the meal, and the iron content of the meal.⁴

The disadvantage of ferrous sulfate is that it readily reacts with other substances that are naturally present in the food matrix. This can cause sensory (flavor, color, odor, and taste) changes due to fat oxidation (i.e., rancidity). Ferrous sulfate can also modify the physical properties of the final product made with the fortified

* Foods have also been fortified with dried red blood cells as a source of hemoglobin, but because of concerns about food safety and cultural and religious beliefs, as well as very intense changes in the color and taste of the fortified foods (strong flavorants are needed to overcome the taste), this practice has not been widely accepted.

food and precipitate as insoluble iron complexes when used in liquid preparations. Ferrous sulfate is mainly used in bread flour that is stored for less than 2 to 3 months. The cost of this iron compound is relatively low, taking into consideration its bioavailability.

Poorly water-soluble/soluble in dilute acid. These compounds dissolve slowly in the normal acid concentration of the stomach. Ferrous fumarate is the main compound in this category. It is as well absorbed as ferrous sulfate in adults and adolescents, but recent data indicate that it is less well absorbed in individuals with a lower gastric acid concentration, particularly young children.³ The advantage of this compound is that it interacts less with the food matrix, and it causes fewer sensory changes. For these reasons, it is usually used in cereals for children, chocolate beverages, and some commercially available cereal-based weaning foods. The price of ferrous fumarate is similar to that of ferrous sulfate.

Water-insoluble/poorly soluble in dilute acid. The compounds in this group include:

1. elemental iron, of which there are three types:
 - a. reduced (i.e., hydrogen-reduced [H-reduced], carbon monoxide-reduced [CO-reduced], and "Atomet"-reduced[†])
 - b. electrolytic
 - c. carbonyl iron
2. ferric pyrophosphate
3. ferric orthophosphate

These compounds are widely used by the food industry in industrialized countries because they are generally inert and have very little effect on the sensory properties of foods. However, their contribution to iron nutrition is questionable because of their very low solubility and absorption.

Depending on the type, elemental iron is 1.5 to 4 times cheaper than ferrous sulfate for an equivalent amount of iron, but more expensive when bioavailability is factored in the cost, as is discussed later. The only elemental iron compound for which there is evidence of absorption by humans is electrolytic iron of small particle size (less than 45 μm , 325 Mesh). Even under optimal dietary conditions, this iron is absorbed only one-half as much as ferrous sulfate. The other elemental irons require structural/surface improvements and further testing to determine their biological efficacy before their continued use as fortificants in foods for human consumption can be recommended.[‡] The use of ferric pyrophosphate and ferric orthophosphate, which are used in some breakfast cereals and other products in North

[†] This iron compound has sometimes been referred to as "atomized iron."

[‡] For more information on the types and uses of elemental iron, see: *Guidelines for Iron Fortification of Cereal Food Staples*. SUSTAIN, 2001.⁶

America, is also not recommended for food fortification because their solubility and absorption are very low in humans.

Protected Iron Compounds

Chelate compounds. The most commonly referred to iron chelate compound is NaFeEDTA (sodium iron ethylenediaminetetraacetate). The major advantage to using NaFeEDTA in food fortification is that in this form, the iron is protected from dietary iron absorption inhibitors in the stomach. Iron absorption from NaFeEDTA added to high-extraction cereal flour-based foods or to a meal containing phytate is two- to threefold higher than for ferrous sulfate. Although it does not promote fat oxidation (i.e., rancidity) in stored wheat flour, NaFeEDTA may cause unacceptable color changes in some food vehicles.⁵ NaFeEDTA has been approved by the Joint FAO/WHO Committee on Food Additives in 1999 for use in supervised programs in areas with a high prevalence of iron deficiency, at a maximum intake of 0.2 mg Fe/kg body weight per day. NaFeEDTA may be a good option for the fortification of both wheat and corn flours with a high extraction rate which, because they are less refined, have a high amount of iron absorption inhibitors. NaFeEDTA is not yet available in the commercial market because the demand is low; thus the price is high. The current price of NaFeEDTA is eight times more expensive than ferrous sulfate for an equivalent amount of iron, but only slightly more expensive when bioavailability is factored into the cost.

Another chelate compound available for use in food fortification programs is the amino acid chelate, also called amino chelate iron, of which there are two types: ferrous bisglycinate (Ferrochel®) and ferric trisglycinate ("taste-free" iron chelate). Iron absorption from ferrous bisglycinate has been found to be 1.1- to 5.0-fold higher than ferrous sulfate⁷⁻⁹ but lower than that from NaFeEDTA in comparative studies.¹⁰ Ferrous bisglycinate has a tendency to cause unwanted color reactions and fat oxidation (i.e., rancidity) in stored cereal flours, which limits its use in these foods. However, it appears to be useful for milk fortification. The current price of ferrous bisglycinate is 15 to 25 times higher than that of ferrous sulfate for an equivalent amount of iron. Ferric trisglycinate causes fewer reactions in foods, but its bioavailability is much lower than that of ferrous bisglycinate.⁷

Encapsulated compounds. Encapsulated ferrous sulfate and encapsulated ferrous fumarate are commercially available for food fortification. In these compounds, the iron salt is covered with layers of hydrogenated oil, ethyl cellulose, or maltodextrin, which prevent the iron atoms from coming into contact with other substances in the food matrix until they can be released and absorbed in the small intestine. The coating prevents or retards many of the adverse sensory changes that are associated with

Table 2. Characteristics of the Iron Compounds Used for Food Fortification

Characteristics	Iron Compounds				
	Water-soluble	Soluble in Dilute Acid	Poorly Soluble in Dilute Acid	Chelate Compounds	Encapsulated Compounds
Examples of iron compounds	Ferrous sulfate	Ferrous fumarate	Electrolytic iron	NaFeEDTA Ferrous bisglycinate	Encapsulated ferrous sulfate Encapsulated ferrous fumarate
Reactivity with the food matrix	High	Intermediate	Very low	Low to intermediate	Low
Bioavailability relative to ferrous sulfate	Equivalent 100%	Equivalent ^a 100%	Low 20–50%	Equivalent to higher 100–300%	Equivalent [†] 100%
Cost based on iron content	Intermediate	Intermediate	Low	High to very high	Intermediate to high
Cost based on iron content and bioavailability	Low	Low	Intermediate	High	Intermediate

* The bioavailability of this compound depends on the acidity of the gastric juices and may not always be equivalent to ferrous sulfate.

† The material used for the capsule and the thickness of the capsule can vary. All encapsulated compounds may not be equivalent in bioavailability to ferrous sulfate.³

these iron compounds. Encapsulated ferrous sulfate may be a useful compound for cereal flour fortification, as it prevents fat oxidation during storage. The capsule dissolves or melts with heat, which leads to color reactions in chocolate drinks or in cereal-based complementary foods containing fruits, but this should not be a problem in wheat bread. The cost of ferrous sulfate encapsulated with partially hydrogenated soybean oil is three to four times that of ferrous sulfate for an equivalent amount of iron and has recently been shown to be highly efficacious in improving the iron status of children consuming fortified salt.¹¹

Table 2 provides a summary of the characteristics of the different iron compounds with the potential for use in food fortification.

Methods to Improve Absorption

Adding Enhancers

Some dietary factors, such as ascorbic acid (vitamin C) can improve iron absorption. In relatively high quantities (at a molar ratio equal to or greater than 2:1—ascorbic acid to iron or a weight ratio of 6:1), ascorbic acid can increase iron absorption two- to threefold.^{12,13} The enhancing effect of vitamin C is because it converts ferric iron to its more readily absorbed ferrous form, forms chelates with iron in the stomach thereby protecting the iron from the dietary absorption inhibitors, and maintains the solubility of non-heme iron when iron enters the alkaline environment of the small intestine, which counteracts the effects of the dietary iron absorption inhibitors. However, ascorbic acid is not stable when exposed to air and heat, which means expensive packaging is required to retain its integrity. Encapsulation may be useful. However, either of these options may not be currently feasible for food fortification in many developing countries because they will most likely put the price

of the product beyond the reach of the people who are in most need of the fortified food.

Another compound that enhances iron absorption is Na2EDTA (disodium ethylenediaminetetraacetate), which readily chelates, or binds, the solubilized iron in the stomach and the intestine. Na2EDTA increases iron absorption by two to three times in diets containing high quantities of iron absorption inhibitors, provided that the iron comes from sources that are readily soluble in water (i.e., ferrous sulfate).¹⁴ Where the diet is low in dietary absorption inhibitors, the enhancing effect of Na2EDTA has little significance, but where the diet is high in iron absorption inhibitors, e.g., in high extraction cereal flours, Na2EDTA is a good option. Na2EDTA is heat stable and is often used as a food additive to reduce rancidity and preserve food. It is also stable to processing and storage. However, it may alter the physical properties of some food vehicles, and the amount that can be added to food is limited. Adding Na2EDTA at a molar ratio of EDTA to iron between 0.5:1 and 1:1 or a weight ratio of 3.3:1 and 6.6:1 can enhance iron absorption from foods fortified with ferrous sulfate.^{14,15}

Removing or Degrading Inhibitors

From a public health standpoint, the primary dietary absorption inhibitors are phytates that are abundant in grains and some legumes and polyphenols, which are present in tea, coffee, chocolate, and sorghum grains. These dietary absorption inhibitors form insoluble complexes with iron, rendering the iron unavailable for absorption. Because changing behavior to avoid or restrict the time at which beverages such as coffee and tea are consumed is very difficult, eliminating or reducing phytates (i.e., dephytinization) during the processing of iron-fortified foods may be a more feasible option for enhancing iron bioavailability. Dephytinization could be a particularly useful strategy for improving iron absorption from cereals, legume-based complementary foods,

and soy-based infant formula. However, virtually all the phytate has to be removed to obtain a meaningful increase in iron absorption.

Technological Compatibility, Comparative Costs, and Fortification Levels

Technological Compatibility with the Food Vehicle

Iron is a highly reactive element that can negatively affect the sensory properties of the fortified food. The technological compatibility with the food vehicle is therefore an important consideration. Appendix 1 describes a compatibility study on white wheat flour carried out in Guatemala. A similar study was done in Sri Lanka.¹⁶ Both studies showed that it was technologically possible to fortify white wheat flour under local conditions with ferrous fumarate up to 60 to 66 mg Fe/kg. The Guatemala study also showed that it was technologically possible with ferrous bisglycinate up to 22.5 mg Fe/kg. However, in the Guatemala study, ferrous sulfate and NaFeEDTA were not compatible with wheat flour at fortification levels as low as 30 and 15 mg Fe/kg, respectively. Nevertheless, ferrous sulfate at 30 mg Fe/kg has been used to fortify wheat flour in Chile for many years. This reinforces the need to know the shelf-life of the flour and its final products, the compatibility of iron fortification levels from different compounds in distinct food matrices, climatic conditions and consumption patterns within a country before making a decision on the final recipe for food fortification.

Comparative Costs

The most suitable iron compound for the fortification of a specific food vehicle is the compound that provides the highest proportion of the target *Recommended Nutrient Intake*[§] (RNI, see Appendix 2), does not cause unacceptable sensory changes, and has the lowest cost. Appendix 3 describes an example of taking these factors under consideration to compare costs for iron fortification of white wheat flour in Guatemala.

Fortification Levels

After selecting the most suitable iron compound for fortifying a specific food vehicle, determining the appro-

priate level of iron to add is an important next step to having an effective fortification program. Establishing the level of fortification is critical and should be based on the expert opinions of professional food scientists and nutritional epidemiologists. There is still no consensus on the specific levels of fortification for the different iron compounds, which are currently being discussed. However, for options on establishing fortification levels and step-wise guidelines on how to make this calculation, the reader is referred to the USAID Manual for Wheat Fortification with Iron: Part 2 (see Further Reading).

Food Fortification with Iron in Latin America and the Caribbean

In the developing world, the food industry in Latin America and the Caribbean have readily accepted the notion of food fortification because there is:

- (a) a well developed and therefore competitive industrial climate, which has facilitated the implementation of food fortification
- (b) growing urbanization and increased use of industrially processed foods
- (c) government and public acceptance of food fortification with micronutrients
- (d) legislative support

In the Americas, food fortification is widely practiced and can be classified into three types of programs (Figure 1): (a) mandatory fortification of food staples for mass consumption, such as wheat and corn flour; (b) targeted fortification for specific groups, such as fortification of infant formulas, infant cereals, and foods as a part of social welfare programs, which include processed complementary foods for young children, powdered milk, and food for school lunches, e.g., *atoles* (gruels) and cookies; and (c) voluntary fortification, where industry voluntarily adds iron and other micronutrients to processed foods, such as in breakfast cereals.

Despite the implementation of iron fortification programs, some limitations exist. These include the lack of a strong evidence base that fortification with micronutrients such as iron is efficacious, ineffective quality assurance and control systems, and the absence of good evaluations. In light of the currently available information, countries need to review the iron compounds used in their food fortification programs in terms of their quantity and quality to ensure that the fortified food can contribute to increasing the intake of bioavailable iron.

In terms of wheat flour fortification, virtually all of the countries of Latin America are currently fortifying with iron (and B-complex vitamins) (see Table 1). Belize, Bolivia, Brazil, Colombia, Costa Rica, the Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, and Panama add reduced iron at levels between 44 and 65 mg/kg of flour. Chile, Cuba, and Peru

[§] The term *Recommended Nutrient Intake* (RNI) is defined by WHO/FAO as the daily dietary intake levels sufficient to meet the nutrient requirements of 97–98% of healthy individuals within a particular age group, physiological condition (i.e., menstruation and lactation), and gender. The RNI values are similar to both the *Recommended Daily Allowance* (RDA) and the *Adequate Intake* (AI) values that are used in the USA and Canada, but it provides recommended intake levels for nutrients not determined in the RDA and AI.¹⁷

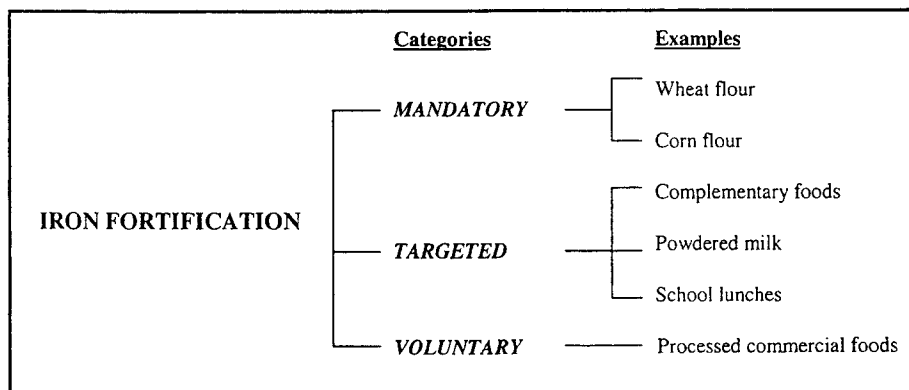


Figure 1. Categories of iron fortification programs in Latin America.

add 30 mg ferrous sulfate/kg flour, while Venezuela adds 20 mg ferrous fumarate/kg flour. The countries of Central America recently initiated discussions with wheat flour producers to switch from fortifying with reduced iron to fortifying with ferrous fumarate (45 mg/kg) in order to increase the intake of a more bioavailable iron.

In Venezuela, degermed precooked corn flour is fortified with ferrous fumarate (30 mg/kg) and reduced iron (20 mg/kg). Some companies in Mexico and throughout Central America are voluntarily fortifying nixtamalized corn flour (i.e., lime-treated). This practice may soon become mandatory in these countries. Mexico has proposed fortification with reduced iron (30 mg/kg), while Central America will do so with ferrous fumarate (25 mg/kg). Costa Rica already has an official regulation in place for fortification with ferrous bisglycinate (22 mg/kg), although a color change has been detected in the fortified product.

In Chile, iron as ferrous sulfate (100 mg/kg) and ascorbic acid (700 mg/kg) (at a molar ratio of 2.2:1—ascorbic acid to iron, which is equivalent to a weight ratio of 7:1) are added to powdered milk distributed through infant feeding programs. Argentina is working to introduce a similar practice. Costa Rica is considering fortification of powdered milk with ferrous bisglycinate (50 mg/kg). In all these cases, powdered milk is reconstituted at 10 to 12%. This means that the final iron content of liquid milk will be approximately one-tenth of that added to powdered milk and provide 5 to 10 mg Fe/L.

Iron in the form of ferrous sulfate or ferrous fumarate is added to blended complementary foods for young children and foods used for school lunches in Central America, Ecuador, Mexico, and Peru. The strong sensory characteristics (i.e., color, flavor, and consistency) of these products make it possible to add higher levels of iron (100–200 mg/kg) than with staple foods, without causing any apparent negative changes in their organoleptic properties.

There is some evidence that Chile's milk fortifica-

tion program may have been effective in reducing the prevalence of anemia.¹⁸ There is indirect evidence of a positive effect on iron status from consumption of wheat flour fortified with ferrous sulfate in Chile.¹⁹ Also, data collected from the processed complementary food program in Peru, targeted to older infants and young children, suggests that the iron-fortified complementary food reduced the prevalence of anemia.²⁰

Guidelines

These guidelines provide information for selecting the most suitable iron compound(s) for fortifying foods based on currently available information and may be subject to modification as further information becomes available.

Mandatory Fortification

Mandatory fortification is where national regulations dictate that fortification become a characteristic in the identity of a specific food product. This is the case for fortification of wheat and corn flour in many countries in Latin America and the Caribbean.

Iron fortification of staple foods with high levels of iron can result in unacceptable sensory changes in the raw ingredient and/or the final products (e.g., bread and pasta). Unacceptable organoleptic changes can occur depending on the type and level of iron compound added, ambient storage conditions, food preparation processes, etc. For example, ferrous sulfate can be used in wheat flour fortification in Chile but not in Central America, where the more tropical climate and the long time interval between production and use of the flour cause rancidity and the discoloring of bread.

Cereals contain large amounts of phytate, which inhibit iron absorption. In theory, dephytinization may be useful for eliminating or reducing phytates, but virtually all the phytate has to be removed to obtain a meaningful increase in iron absorption, which may be difficult to accomplish at a reasonable price for the mandatory fortification of staple foods. The addition of iron absorp-

tion enhancers, such as ascorbic acid and Na₂EDTA, is limited by cost or, in the case of Na₂EDTA, its tendency to alter the physical properties of the food and the final cooked product. For example, in Central America, Na₂EDTA cannot be used in wheat flour fortification because it changes the consistency of the dough and reduces bread volume. Also, any added ascorbic acid is destroyed in the baking process. Although a heat-stable form of ascorbic acid has been developed, its price is too high to be considered for this application. In short, the degradation of phytates and the addition of iron absorption enhancers to cereal flour are currently difficult to accomplish at a reasonable price.

Countries should test the technological compatibility of the amount of iron to add to both the flour and the final products made from the fortified flour to ensure that no unacceptable organoleptic changes occur. The levels of added iron recommended in these guidelines are based on previous experiences as well as studies that have been carried out.

Wheat flour

- 1.1 In countries that use low extraction wheat flour that is stored under low to moderate temperatures (20–30°C) and low relative humidity (<50%) for less than 2 to 3 months, ferrous sulfate is recommended as the fortificant of choice. Where environmental conditions are harsh or flour remains in the distribution chain for more than 3 months, ferrous fumarate is recommended as an alternative. In the event that this iron compound causes unacceptable organoleptic changes, double the amount of iron from electrolytic iron (less than 45 μm, 325 Mesh) may be used. If cost permits, ferrous sulfate or ferrous fumarate encapsulated with partially hydrogenated soybean oil can be considered.¹¹
- 1.2 Iron compounds should be added to achieve the target RNI for iron (see Appendix 1) and up to the maximum level that the flour and the final food can tolerate without causing unacceptable organoleptic changes, given ambient conditions. It is recommended that testing for organoleptic changes be done in both the flour and final products. Testing should begin at 60 ppm iron from ferrous sulfate or ferrous fumarate, or 80 ppm iron from electrolytic iron. Lower levels should be used if unacceptable sensory changes occur.

Wheat Flour

Type of iron:

1. ferrous sulfate
2. ferrous fumarate
3. double the amount of iron from electrolytic iron (<45 μm, 325 Mesh)

4. encapsulated ferrous sulfate or encapsulated ferrous fumarate

Level: Iron compounds should be added to achieve the target RNI and up to the maximum level that the food can tolerate without causing unacceptable organoleptic changes. Testing should begin at 60 ppm iron from ferrous sulfate or ferrous fumarate, or 80 ppm iron from electrolytic iron, and levels reduced if unacceptable sensory changes occur.

Corn flour

- 1.3 Given the high content of iron absorption inhibitors in nixtamalized corn flour, NaFeEDTA[¶] is recommended, provided there are no sensory problems. Double the amount of iron from ferrous fumarate may also be used to compensate for the lower absorption from this high-phytate, high-calcium product.²¹ Ferrous bisglycinate may be considered as an alternative when the cost becomes similar to that of NaFeEDTA. Ferrous sulfate is not recommended because it causes rancidity; however, ferrous sulfate or ferrous fumarate encapsulated with partially hydrogenated soybean oil should be considered.
- 1.4 For degermed corn flour, low in phytic acid, the same iron compounds as recommended for white wheat flour can be used, i.e.: (a) ferrous sulfate, (b) ferrous fumarate, (c) double the amount of electrolytic iron (<45 μm, 325 Mesh), or (d) ferrous sulfate or ferrous fumarate encapsulated with partially hydrogenated soybean oil.
- 1.5 Iron compounds should be added to corn flour to achieve the target RNI of iron and up to the maximum level that the flour and the final food can tolerate without causing unacceptable organoleptic changes, given ambient conditions. Testing for organoleptic changes should be done in both the flour and final products, starting at 20 ppm iron from NaFeEDTA or 40 ppm iron from ferrous fumarate for nixtamalized corn flour. For degermed corn flour, the same levels of the iron compounds recommended for wheat flour can be used. Levels may be reduced if unacceptable sensory changes occur.

Nixtamalized Corn Flour

Type of iron:

1. NaFeEDTA
2. double the amount of iron from ferrous fumarate
3. encapsulated ferrous sulfate or encapsulated ferrous fumarate

[¶] The market for this compound may be limited until greater demand.

Level: Iron compounds should be added to achieve the target RNI and up to the maximum level that the food can tolerate without causing unacceptable organoleptic changes. Testing should begin with 20 ppm iron from NaFeEDTA and 40 ppm iron from ferrous fumarate, and levels reduced if unacceptable sensory changes occur.

Degermed Corn Flour

Type of iron:

1. ferrous sulfate
2. ferrous fumarate
3. double the amount of iron from electrolytic iron (<45 μ m, 325 Mesh)
4. encapsulated ferrous sulfate or encapsulated ferrous fumarate

Level: Iron compounds should be added to achieve the target RNI and up to the maximum level that the food can tolerate without causing unacceptable organoleptic changes. Testing should begin at 60 ppm iron from ferrous sulfate or ferrous fumarate, or 80 ppm iron from electrolytic iron, and levels reduced if unacceptable sensory changes occur.

General

- 1.6 Fortification of more than one food should be considered, wherever possible, to increase the probability of increasing iron intake and thus the iron status of the population. This is because the total amount ingested and/or the level of fortification may not be sufficient to supply the desired amount of iron through a single food vehicle.

Targeted Fortification

Targeted fortification is the addition of micronutrients to foods consumed by specific groups of the population, such as fortified infant formulas, infant cereals, and foods as a part of social welfare programs (e.g., child health care, school lunch, and disaster relief programs). Commercial complementary foods, such as those made primarily for infants and young children age 6 to 24 months, are considered in this category.

Ordinarily, foods used for social welfare programs aim to provide additional energy, protein, and increasingly micronutrients at the lowest possible cost. This is almost often achieved by blending cereals with vegetable-derived proteins, fat, sugar, and milk powder. Vegetable blends are not favorable for iron absorption because they contain a lot of phytate. However, because these foods are less susceptible to organoleptic changes, much higher quantities of iron can be added—from 3 to 10 times more—than in mandatorily fortified cereals. For this reason, the use of protected iron compounds, which are more expensive, may not be necessary.

- 2.1 Sensory tests should be carried out using ferrous sulfate before implementation of the program. If this iron is unacceptable, ferrous fumarate may be useful in fortification of targeted foods, although a recent study has indicated that this compound may be less bioavailable in young children than in adults.³
- 2.2 The level of iron compound added should provide 30% of the RNI value for iron (see Appendix 1) per serving (assuming two servings per day) or 60% of the RNI value per daily ration, whereby the food may be considered as a good source of the nutrient.²⁰ Testing for sensory changes of the fortified food should begin at this level and adjusted, if unacceptable sensory changes occur.
- 2.3 Consideration should be given to eliminating phytates, wherever possible, through technological processing.
- 2.4 Alternatively, ascorbic acid should be added (at a molar ratio equal to or greater than 2:1—ascorbic acid to iron or a weight ratio of 6:1) to improve the bioavailability of iron, wherever technology and cost permit.

Targeted Fortification

Type of iron:

1. ferrous sulfate
2. ferrous fumarate

Level: The level of iron compound added should provide 30% of the RNI value for iron per serving or 60% of the RNI value per daily ration. Testing for sensory changes of the fortified food should begin at this level and adjusted, if unacceptable sensory changes occur.

Other considerations:

Phytates should be eliminated through technological processing, wherever possible. Ascorbic acid should be added (at a molar ratio equal to or greater than 2:1 or weight ratio of 6:1—ascorbic acid to iron), wherever technology and cost permit.

Voluntary Fortification

Voluntary fortification is where industry voluntarily adds micronutrients to processed foods directed toward children older than three years of age and adults. (Young children should continue to receive breast milk with complementary foods for up to 2 years or more. At the end of the period of complementary feeding [often at around age 2], children may gradually become accustomed to eating family foods, which may be voluntarily fortified).

- 3.1 Depending on the shelf life and ambient conditions, preference should be given to the use of ferrous sulfate, ferrous fumarate, or protected iron compounds.

- 3.2 Iron compounds that are poorly soluble in dilute acid should not be used. The exception is electrolytic iron (less than 45 μm , 325 Mesh), which may be used to fortify foods with low levels of iron absorption inhibitors.
- 3.2 Foods should be tested for any organoleptic changes in both the raw ingredient and final products. Iron compounds should be added to provide 5 to 10 mg Fe per serving, or 15 to 30% of the target RNI for iron (see Appendix 1), whereby the food may be considered as a good source of the nutrient (Codex Alimentarius, 1997).

Voluntary Fortification

Type of iron:

1. ferrous sulfate
2. ferrous fumarate
3. protected iron compounds
4. electrolytic iron (less than 45 μm , 325 Mesh) for foods with low levels of iron absorption inhibitors

Level: Iron compounds should be added to provide 5 to 10 mg Fe per serving, or 15 to 30% of the target RNI.

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Appendix 1

Comparative Analysis of Technological Compatibility and Estimated Supply of Iron of Different Iron Compounds as Fortificants of White Wheat Flour in Guatemala**

Methodology. White wheat flour was fortified with 30, 45, and 60 mg/kg of ferrous sulfate and ferrous fumarate, and 15, 22.5, and 30 mg/kg of ferrous bisglycinate and NaFeEDTA. Fortified flour samples were stored for 6 weeks at 37°C and 75% relative humidity (RH), and their color, peroxide and free fatty acid content, and dough viscosity were compared with those of a flour sample fortified with 60 mg/kg reduced iron. Separately, flour samples were stored under typical environmental conditions in Guatemala for 4 months, the average turnover time period for this product in the country. These samples were used to prepare bread, and their specific volumes were compared to that of bread prepared with flour fortified with reduced iron. The bread samples were analyzed for acceptability in color, odor and flavor by an expert sensory panel. The sample fortified with the highest iron concentration with similar sensory characteristics to that of flour fortified with 60 mg/kg of reduced iron was identified as the compound with the highest level that is technologically compatible with white wheat flour.

Results. White wheat flour fortified with either ferrous sulfate or NaFeEDTA at 30 mg/kg and 15 mg/kg, respectively, caused negative changes in the dough and bread characteristics. The acceptable iron levels for ferrous fumarate and ferrous bisglycinate were 60 mg/kg and 22.5 mg/kg, respectively. The potential iron absorption for these two compounds is estimated in **Table A1**. Although electrolytic iron was not tested in this study, it is included in the table for comparative purposes.

** Data from an unpublished source, part of a thesis paper by Misael Alvarado Guinac, "Evaluacion Tecnica y Economica de la Fortificacion de la Harina de Trigo con Diferentes Compuestos de Hierro," from the Centro Universitario de Suroccidente, Universidad de San Carlos de Guatemala, and INCAP/PAHO; Nov 2001.

Table A1. Comparative Iron Absorption from White Wheat Flour Fortified with Iron Compounds at their Maximum Load

Rows	Variables	Iron Compounds			
		Reduced Iron	Electrolytic Iron	Ferrous fumarate	Ferrous bisglycinate
A	Maximum load (mg Fe/kg)	60.0	60.0	60.0	22.5
B	Iron intake from 200 g flour/day consumption (mg)	12	12	12	4
C	RNI for iron in type II diets (mg Fe/day)	165	66	33	16.5
D	% RNI provided by consumption of 200 g flour/day	7%	18%	36%	24%
E	Proportion of RNI supplied relative to ferrous fumarate	0.2	0.5	1.0	0.7

Row A shows the maximum amounts of the iron compounds that were technologically compatible in the production of wheat flour and their final products (i.e., bread).

Row B lists the estimated iron intake for each of the iron compounds from 200 g of flour consumption.

Row C presents the target fortification Recommended Nutrient Intake (RNI) for iron in terms of the amount of bioavailable iron provided by each iron compound. In this study, since ferrous sulfate was not technologically compatible, ferrous fumarate is used as the reference compound, given that its bioavailability is usually equivalent to ferrous sulfate. The value for ferrous fumarate was divided by 2 for ferrous bisglycinate, multiplied by 2 for electrolytic iron, and multiplied by 5 for reduced iron.

Row D presents the percentage of RNI provided by wheat flour fortified with the different iron compounds consumed at 200 g of flour/day. (Wheat flour samples were fortified at the levels specified in row A.)

Row E presents the information in row D. $D = (B/C) \times 100$, thus the proportion of RNI supplied relative to ferrous fumarate.

Conclusion. Ferrous fumarate and ferrous bisglycinate are better biological alternatives than reduced or electrolytic iron for fortifying white wheat flour in Guatemala. Ferrous sulfate and NaFeEDTA caused negative sensory changes in both the white wheat flour and its final products even at low levels; thus, they are not suitable iron fortificants for white wheat flour in Guatemala.

Appendix 2

Recommended Nutrient Intake of Iron

Table A2. Recommended Nutrient Intake of Iron According to Iron Bioavailability in Different Types of Diet* (mg/day)

Age Group	Iron Bioavailability in Different Diets [†]	
	Type I (5%)	Type II (10%)
Children		
7–12 months	18.6	9.3
1–3 years	11.6	5.8
4–6 years	12.6	6.3
7–9 years	17.8	8.9
Women [‡]		
10–14 years	28.0	14.0
10–14 years (menstruating)	65.4	32.7
15–18 (menstruating)	62.0	31.0
19–50 (menstruating)	58.8	29.4
51–65	22.6	11.3
65+	22.6	11.3
During lactation	30.0	15.0

Age Group	Iron Bioavailability in Different Diets [†]	
	Type I (5%)	Type II (10%)
Men		
10–14	29.2	14.6
15–18	37.6	18.8
19–65	27.4	13.7
65+	27.4	13.7

*Source: *Recommended Nutrient Intakes*. WHO/FAO, 2002 (in press). WHO/FAO recommendations also include values for diets that are rich in heme-iron foods and iron-absorption promoters, and for which 12–15% iron absorption have been estimated.

[†] Diet Types: I: Based mainly on cereals and legume seeds, with very limited amounts of vitamin C-rich foods and foods of animal origin. II: Based on cereals and legumes but with occasional incorporation of flesh foods, including poultry and fish, and foods rich in vitamin C.

[‡] This table does not include requirements during pregnancy, as the iron need during this physiological stage is too high to be covered by the diet. Daily iron supplements should be given to non-anemic pregnant women during the second half of pregnancy. Anemic women should receive treatment with iron supplements as soon as possible.

Appendix 3

Comparative Costs of White Wheat Flour Fortification in Guatemala Using Technologically Compatible Iron Compounds

The results of the study described in Appendix 1 are used here to discuss the analysis on comparative costs.

Table A3. Comparative Costs of White Wheat Flour Fortified with Technologically Compatible Iron Compounds

Rows	Variables	Iron Compounds			
		Reduced Iron	Electrolytic Iron	Ferrous fumarate	Ferrous bisglycinate
A	Maximum load (mg Fe/kg)	60.0	60.0	60.0	22.5
B	Price of compound (\$US/kg)	\$2.00	\$6.70	\$3.00	\$25.00–40.00
C	Percentage of iron in compound (%)	97%	99%	33%	20%
D	Price of iron (\$US/kg Fe)	\$2.06	\$6.77	\$9.09	\$125.00–200.00
E	Fortificant cost (\$US/MT flour)	\$0.12	\$0.41	\$0.55	\$2.81–4.50
F	Fortificant cost relative to ferrous fumarate	0.3	0.8	1.0	4.5–7.3
G	% RNI provided by consumption of 200 g flour/day	7%	18%	36%	24%
H	Proportion of RNI supplied relative to ferrous fumarate	0.2	0.5	1.0	0.7
I	Relative fortification cost/Relative potential iron absorption	1.5	1.6	1.0	6.4–10.4

Row A shows the maximum amounts of the iron compounds that were technologically compatible in the production of wheat flour and their final products (i.e., bread).

Row B provides the U.S.-based prices of the different iron compounds.

Row C presents the percentage of iron contained in each compound, which permits the calculation of the price of each compound at equivalent amounts of iron (Row D).

Row E shows the total cost of iron fortificant per metric ton of wheat flour, added at the levels specified in row A, that is: $E = A \times D / 1,000$.

Row F presents the information in row E relative to ferrous fumarate, thus the cost of iron fortificants relative to ferrous fumarate.

Row G presents the percentage of RNI provided by wheat flour fortified with the different iron compounds consumed at 200 g of flour/day. (Wheat flour samples were fortified at the levels specified in row A.)

Row H presents the information in row G relative to ferrous fumarate, thus the proportion of RNI supplied relative to ferrous fumarate.

Row I provides the ratio of relative fortification cost (Row F) to relative proportion of RNI supplied (Row H). A lower value indicates a better cost-benefit ratio.

Conclusion. At the current prices, ferrous fumarate is the most suitable iron compound for fortifying white wheat flour in Guatemala.

Further Reading

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