

## Staple Food Fortification with Iron: a Multifactorial Decision

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### Introduction

Iron deficiency is not restricted to infants and pregnant women; it also affects school-age children, adolescents, elders, and even adult males in developing countries, including those of Latin America.<sup>1</sup> Therefore, interventions with extensive coverage are suitable to prevent and to control this deficiency. Fortification of staple foods is an adequate strategy to provide additional iron to populations. However, unlike fortification with vitamin A, iodine, and B vitamins, food fortification with iron has not been very successful. Iron is a reactive compound, whose level in foods is limited because iron causes negative changes in the original properties of the food that is being fortified. This feature combined with the low absorption of iron compounds used for fortification—usually not higher than 10%<sup>2</sup>—makes prevention of iron deficiency through food fortification of very few commodities a great challenge. This review will cover several factors that need to be taken into consideration to plan, understand, evaluate, and make a decision about fortification of staple foods with iron. Included is a discussion regarding bioavailability, technologic compatibility, and cost effectiveness. To conclude, the review mentions additional advantages of fortifying staple foods with iron and the indispensable need to combine this strategy with other interventions. All of these factors must be considered before launching a field efficacy trial, which should be the ultimate proof for a decision made wisely and with possibilities of success.

### Iron Nutrition Depends on Iron Quality Rather than Iron Supply

The countries in the north of Central America—Guatemala, Honduras, El Salvador, and Nicaragua—are typical examples of developing countries. Poverty is widespread and chronic undernutrition is still a public health problem. Iron deficiency anemia (IDA) affects all social groups and ages. The diet in these countries is based on

corn and beans, with a very small proportion of foods from animal origin. Based on the composition of this diet, it is possible to estimate that the amount of iron supplied is sufficient to cover the recommended daily intake (RDI). For example, analyzing the consumption and nutritional composition of tortilla made with nixtamalized corn flour (NCF), it is calculated that on average this food provides between 18 and 55% of the RDI for iron. A similar amount is provided by beans. It is therefore difficult to explain through a dietary analysis why IDA is so large and extended in these countries.

A study carried out by Solomons and colleagues<sup>3</sup> from the Center for Studies of Sensory Impairment, Aging, and Metabolism (CeSSIAM) in a rural village of Guatemala, demonstrated that the iron adequacy for preschoolers was 127%. Other micronutrients were deficient: mainly riboflavin, niacin, calcium, and vitamin C. Nevertheless, anemia of this type in this population was diagnosed to be due to iron deficiency. It is therefore possible to conclude that the amount of iron is not the limiting factor causing IDA; rather its absorption is the problem. An analysis of the diet of those preschoolers revealed that indeed the main sources of iron were corn tortilla and beans, with negligible participation of flesh and other foods of animal source. Therefore, these diets were lacking good quality iron and iron absorption enhancers. Furthermore, these diets were rich in iron absorption inhibitors such as phytic acid and polyphenols. The influence of the diet composition on iron absorption has been well summarized by Layrisse and Garcia-Casal.<sup>4</sup>

Hallberg and his collaborators<sup>5</sup> have analyzed the influence of diet composition in iron absorption and storage in the liver. They estimated that vegetarian diets with large amounts of cereals and legumes limit iron bioavailability to 25  $\mu\text{g}/\text{kg}$  of food per day. This reduced absorption, which is 2.5% on average, and in turn causes low liver iron stores, approximately 25 mg. IDA is therefore prevalent in communities with that type of diet. Hallberg et al.<sup>5</sup> also calculated that diets of developed countries have an iron bioavailability between 5.0 and 7.5%, producing average iron storage in the liver of approximately 250 mg, that is 10 times more than in a

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**Table 1.** Bioavailability (%) of Different Iron Compounds in Distinct Food Matrixes

Food Matrix	Ferrous Sulfate	Ferrous Fumarate	Ferrous Bisglycinate	NaFe EDTA	Reference
White wheat flour (70% extraction)	5.3	—	10.8	14.9	7
Precooked corn flour	4.7	—	8.4	10.5	7
Lime-treated corn flour	—	5.0	—	9.0	8
Whole-maize porridge	1.3	—	6.4	—	9
Complementary foods:					
Vegetable base	9.0	—	9.9	—	10
Whole-cereal base	3.8	—	5.2	—	10
Milk	4.0/8.0*	—	8.3/10.7*	—	11, 12
Water	32.5*	—	9.1	—	9
	29.9*	—	34.6	—	12

Note: Ferric trisglycinate ("taste-free amino-chelate") has been less studied. It was determined that its absorption in water was 15.3% and in whole-maize porridge 2.3%.<sup>9</sup>

\* In the presence of vitamin C.

cereal-based diet. Comparatively, they also estimated that in the primitive diet of early humans, which was mainly based on meat and fish, iron absorption was 15%, which caused liver storage of 500 mg. Other important conclusions included that the steady-state level of iron storage is determined by iron bioavailability, and that any change in the quality of the diet affects this parameter within the first year. Therefore, any effectiveness evaluation of a food fortification program should be monitored mainly during its first year.

The bioavailability of ferrous sulfate has been estimated between 2 and 12%, depending on the food matrix.<sup>2</sup> On the other hand, bioavailability of elemental iron is best at approximately half of that value.<sup>6</sup> Therefore, fortifying with elemental iron would increase the amount of iron in the diet but not its quality, which indeed is the most important characteristic to enhance. Considering these arguments, food fortification with the commercially available elemental iron would have a very small impact in iron nutrition in the diets of most developing countries.

### Bioavailability of Different Iron Compounds in Industrially Produced Foods

During the last 5 years, several research groups have studied the bioavailability of iron in commonly consumed foods in Latin America using radioactive and stable isotopes of iron (Table 1). Investigators found that absorption of ferrous bisglycinate and NaFeEDTA is usually two and three times better than that of ferrous fumarate or ferrous sulfate in flours.<sup>7,8</sup> Absorption of iron from these compounds is approximately 5% in white wheat flour and in corn flour, which can be lime-treated (nixtamalized) or not. In milk, ferrous bisglycinate was also absorbed two to three times better than ferrous sulfate.<sup>11,12</sup> In summary, absorption pattern depends not

only on the nature of the iron compound but also to a great extent on the food matrix. Hence, one should not extrapolate conclusions from one situation to another. In general, however, these studies confirmed that chelating forms of iron are better absorbed than salt forms, but not by much. Nevertheless, a nutritionist may be tempted to recommend the use of NaFeEDTA or ferrous bisglycinate as food fortificants over other iron sources, but life is a little more complicated, and other factors must be also considered.

### Technologic Compatibility

In Central America, even the chelating iron forms cause undesirable changes in the sensorial properties of wheat and nixtamalized corn flours (NCF). NaFeEDTA or EDTA alone affects the dough viscosity of wheat flour and specific volume of bread, and hence the best bioavailable option, NaFeEDTA, must be discarded as a fortificant of white wheat flour in Central America. Ferrous sulfate was also inadequate at levels as low as 30 mg Fe/kg. Table 2 shows the estimation of iron absorption for different fortification recipes in white wheat flour. The most suitable candidates are ferrous fumarate and ferrous trisglycinate. With NCF, the color of tortillas made with fortified flour changes depending on the levels of each of the assayed iron compounds used (Table 3). The maximum iron levels that were compatible with the product were 30 mg/kg ferrous fumarate, 15 mg/kg ferrous bisglycinate, and 15 mg/kg NaFeEDTA. Therefore, the apparent advantages of the latter compounds over ferrous fumarate from a bioavailability point of view are reduced because of the maximum possible amounts able to be loaded into the flour. Iron absorption is a matter of balance between biologic bioavailability and technologic compatibility, i.e., maximum iron level that is possible to incorporate. In this example, ferrous

**Table 2.** Estimation of Iron Absorption in White Wheat Flour\*\*

Variable	Intrinsic Iron	Reduced Iron	Ferrous Fumarate	Ferrous Bisglycinate	NaFeEDTA
Maximum iron load (mg Fe/kg)	10	60	60	22.5	10*
Iron bioavailability (%)	2.0	2.0	5.3	10.8	14.9
Fe absorption in 200 g flour (mg)	0.04	0.24	0.64	0.48	0.30
+ Plus intrinsic Fe (mg)	0.04	0.28	0.68	0.52	0.34

\*\* Unpublished data, Alvarado M., licentiate thesis, Universidad de San Carlos de Guatemala, and the Institute of Nutrition of Central America and Panama (INCAP/PAHO).

\* It might be lower.

**Table 3.** Estimation of Iron Absorption in Nixtamalized Corn Flour\*\*

Variable	Intrinsic Iron	Reduced Iron	Ferrous Fumarate	Ferrous Bisglycinate	NaFeEDTA
Maximum iron load (mg Fe/kg)	29	30	30	15	15
Iron bioavailability (%)	1.0	1.0	5.0	(7.0)*	9.0
Fe absorption in 200 g flour (mg)	0.06	0.06	0.30	(0.21)	0.27
+ Plus intrinsic Fe (mg)	0.06	0.12	0.36	(0.27)	0.33

\*\* Unpublished data, de Pereda CL, Unit of Food Technology, Institute of Nutrition of Central America and Panama (INCAP/PAHO).

\* Extrapolation of the data from reference 8, assuming that bioavailability of ferrous bisglycinate is intermediate between ferrous fumarate and NaFeEDTA.

fumarate, ferrous bisglycinate, and NaFeEDTA are more or less equivalent candidates to fortify NCF. To decide which iron compound is the most suitable deserves a cost-effectiveness analysis, to be discussed later.

If the biologic and technical information is combined with the consumption patterns of the fortified foods, it is possible to make some theoretic estimations regarding the contributions of these foods to iron status. If bioavailability were not taken into consideration, one could estimate that the consumption of 200 g of NCF alone would provide 32% of the recommended daily intake of iron, assuming an 18 mg Fe/day DRI, when in fact this is not the case. The consumption of this amount of NCF would provide approximately 0.06 mg Fe/day, which is 2.0 to 7.5% of the daily needs of iron, depending on the age and sex (0.8–2.8 mg Fe/day). This example explains why communities with high consumption of NCF are anemic, despite the fact that this food supplies an apparently good amount of dietary iron.

If NCF were fortified to an average level of 30 mg/kg with reduced iron, then the amount of iron that is absorbed would rise to 0.12 mg Fe/day. That is 4 to 15% of the daily needs, but it is still insufficient to be considered important.

The situation changes with the other iron compounds. In the cases of ferrous fumarate, ferrous bisglycinate, and NaFeEDTA, the contribution to the daily absorbed iron would be two to three times higher than the figure estimated for reduced iron. These fortification examples may have a positive biologic impact.

Similar estimations can be done with fortified white wheat flour. Under the consumption conditions of white wheat flour in Central America (50 g/day), both elemental iron and NaFeEDTA would provide a very modest contribution of absorbable iron, not more than 10% of the daily needs. The other two choices, ferrous fumarate and ferrous bisglycinate, would provide higher amounts that are still insufficient to cause an important biologic change in iron nutriture for most individuals. In other countries, where consumption of wheat flour is high, the impact in preventing IDA is surely better than in Central America. In spite of this limitation, it is still important to fortify this commodity with the best iron source because the combined effect of several small contributions may improve iron status. Similar to the case of NCF, the choice between ferrous fumarate and ferrous bisglycinate becomes an economic matter. The most cost-effective compound should be the one to select.

### Cost Effectiveness Analysis

Food industries aim to profit. They try to save as much expense as possible. This is especially true in the case of commodities because most consumers in the developing world purchase them for their low prices rather than nutritional quality. It is important, therefore, to recommend the least costly iron compound that still has potential to solve a nutritional problem.

In NCF, ferrous fumarate, ferrous bisglycinate, and NaFeEDTA, would have a similar impact when nearly at

**Table 4.** Theoretical Effectiveness and Cost Analysis of Nixtamalized Corn Flour Fortification in Central America

Variable	Reduced Iron	Ferrous Fumarate	Ferrous Bisglycinate	NaFeEDTA
Maximum iron load (mg Fe/kg)	30	30	15	15
Iron absorption in 200 g flour (mg)*	0.12	0.36	(0.27)	0.33
Relative absorption	0.33	1.00	0.75	0.92
Cost of the compound (US\$/kg)	\$2.00	\$3.00	\$25.00	\$10.50
Percentage iron in the compound	97%	33%	20%	14%
Cost per kilogram of iron (US\$/kg)	\$2.06	\$9.09	\$125.00	\$75.00
Relative cost per kilogram of iron	0.23	1.00	13.75	8.25
Iron fortification cost (US\$/M.T.)**	\$0.06	\$0.27	\$1.87	\$1.13
Relative iron fortification cost	0.22	1.00	6.93	4.19
Multiple fortification cost (US\$/M.T.)§	\$0.66	\$0.87	\$2.47	\$1.73
Percentage of price over US\$45/kg	0.15%	0.19%	0.55%	0.38%
Relative multiple fortification cost	0.76	1.00	2.84	2.00
Total annual cost per million persons	\$48,180	\$63,510	\$207,320	\$126,290

\* Including absorption of intrinsic iron.

\*\* Estimated to the maximum iron load listed in the first row.

§ Including thiamine (3.0 mg/kg), riboflavin (2.0 mg/kg), niacin (25 mg/kg), and folic acid (1.0 mg/kg).

the maximum possible levels of fortification. When prices are introduced into the scenario, however, it is easy to see that for a similar biologic impact, one needs to invest four times more with NaFeEDTA and seven times more with ferrous bisglycinate than with ferrous fumarate (Table 4). This cost difference is reduced 2.0 and 2.8 times with NaFeEDTA and ferrous bisglycinate, respectively, when the investment of the other micronutrients that are added together with iron is taken into consideration. Therefore, when using multiple fortification, both ferrous fumarate and NaFeEDTA remain good options for fortifying NCF, especially considering the latter may help to improve the absorption of intrinsic iron. The final decision between these two compounds should be made by means of an efficacy trial evaluation. From a practical point of view, it is possible to recommend the use of ferrous fumarate to start the fortification program of NCF, but depending on results, investigators may wish to switch to NaFeEDTA. Nevertheless, ferrous bisglycinate should not be completely discarded, especially if in the future its price reduced to one-third to one-fifth of its present value (Tables 4 and 5).

Another point to emphasize in this cost-effectiveness analysis is that it is worthless to consider the inclusion of elemental iron as one of the fortificant candidates of NCF because its biologic impact is very doubtful, and the savings are negligible. Once the total cost of the multiple fortification (iron plus vitamin B complex) is taken into consideration, the increment in the consumer price of NCF using elemental iron is 0.15% versus 0.19% using ferrous fumarate.

If vitamin A were added into the NCF fortificants,

the investment would be US\$1.00 per metric ton, when fortified at 2.0 mg vitamin A/kg. This amount would provide approximately 50% of the DRI of vitamin A in 200 g of flour. However, the percentage of increment in price would be still sufficiently low (0.4–0.5%) to permit its inclusion. This is an important aspect to keep in mind, especially if vitamin A deficiency is problem in the country and consumption of industrially produced NCF is considerable. For comparison reasons, the increment in the price of sugar fortified with vitamin A is 2%.

A similar analysis done with white wheat flour in Central America would lead to the conclusion that the best and perhaps only option to fortify wheat flour among the studied iron compounds is ferrous fumarate. The supply of absorbable iron with NaFeEDTA is half of that using ferrous fumarate, and the use of ferrous bisglycinate is very expensive compared with ferrous fumarate. Similar to NCF, wheat flour has the potential to become a good vehicle for vitamin A.

The prior deductions do not imply that ferrous fumarate is a better iron fortificant compound than ferrous bisglycinate and NaFeEDTA. The comparisons that were made are valid only for white wheat flour and NCF, under the conditions found in Central America. With other foods, the situation may change as is apparently the case with whole-maize porridge fortified with ferrous bisglycinate,<sup>9</sup> and rice and Egyptian flatbread fortified with NaFeEDTA.<sup>2</sup> The important thought to keep in mind is that exercises such as this should be carried out to reach a wise decision in the selection of the best compounds for fortification. Furthermore, an analysis of

**Table 5. Theoretical Effectiveness and Cost Analysis of White Wheat Flour Fortification in Central America**

Variable	Reduced Iron	Ferrous Fumarate	Ferrous Bisglycinate	NaFeEDTA
Maximum iron load (mg Fe/kg)	60	60	22.5	10.0*
Iron absorption in 200 g flour (mg)**	0.28	0.68	0.52	0.34
Relative absorption	0.41	1.00	0.76	0.50
Cost of the compound (US\$/kg)	\$2.00	\$3.00	\$25.00	\$10.50
Percentage iron in the compound	97%	33%	20%	14%
Cost per kilogram of iron (US\$/kg)	\$2.06	\$9.09	\$125.00	\$75.00
Relative cost per kilogram of iron	0.23	1.00	13.75	8.25
Iron fortification cost (US\$/M.T.)***	\$0.12	\$0.55	\$2.81	\$0.75
Relative iron fortification cost	0.22	1.00	5.20	1.39
Multiple fortification cost (US\$/M.T.)§	\$1.62	\$2.05	\$4.31	\$2.25
Percentage of price over US\$40/kg	0.40%	0.51%	1.08%	0.56%
Relative multiple fortification cost	0.79	1.00	2.10	1.10
Total annual cost per million persons	\$118,260	\$149,650	\$314,630	\$164,250

\* It might be lower.

\*\* Including absorption of intrinsic iron.

\*\*\* Estimated to the maximum iron load listed in the first row.

§ Including thiamine (5.4 mg/kg), riboflavin (3.6 mg/kg), niacin (45 mg/kg) and folic acid (1.8 mg/kg).

this type should be required to justify an expensive, laborious, and time-consuming field trial. Field efficacy trials are the final verification of the validity of any fortification program, but they should be planned only after theoretic calculation points to a successful biologic outcome, as well as the potential presence of a practical and acceptable application by the industry.

#### Additional Advantages of Staple Food Fortification with Iron

Typically when iron fortification is planned, the inclusion of B vitamins is also considered. This increases the investment, but it is still low enough to be acceptable by the food industry.

Although not well known, staple foods fortified with iron and other nutrients are generally better vehicles for B complex vitamins, including folic acid, than for iron itself. Flours are also good potential sources of vitamin A if the consumers are willing to pay the extra cost and if there are systems in place to enforce regulations in order to maintain fair competition among producers and importers. The latter consideration is very important because higher differences in price prompt breaking and bending of the rules.

It is also important to pay attention to the addition of other minerals, such as calcium and zinc, especially in those countries where meat and milk products are not readily consumed. Competition with iron absorption may be a subject to review, but this competition may be less important than providing an integrated nutritious diet.

#### Limitations of Staple Food Fortification with Iron

Impact of iron fortification not only depends on iron quality to assure good absorption but also on the distribution of the fortified food and on the amount consumed. It is frequently difficult to attain all of these requirements. For example, in the case of Central America, NCF is a much better vehicle for micronutrients than wheat flour because NCF is consumed in larger quantities. This is not always true, however, because only a small proportion of the population has accessibility to industrially produced NCF. Therefore, NCF is still a potential good vehicle, but its impact will not be seen until the industrial product covers a large proportion of the market.

On the other hand, small children do not eat staple foods in sufficient amounts. Hence, they will continue to be at risk of suffering IDA, despite the existence of food fortification programs with good coverage and good iron quality. Infants require special attention because anemia in this group is a severe problem. Not only must complementary foods be fortified, but also preventive supplementation should be strengthened.

To really overcome iron deficiency, fortification of staple foods should be complemented with the implementation of other interventions:

1. Search to fortify of other widely consumed foods, for example, milk, composite flours, and complementary foods.
2. Voluntary enrichment of processed foods aimed at the free market should be encouraged. It is a normal practice in the developed world, where breakfast cereals and natural juices, among others, are being

**Table 6.** Iron Fortification of Complementary Foods in Latin America

Product (ingredients)	Country	Iron Type	Iron Level (mg/kg)	Serving Size (g)	% Daily Needs*	Reference
Incaparina (corn, cottonseed, soybean)	Guatemala	Ferrous fumarate	100–200	2 × 18	18–36	13
Bienestarina (soybean, corn, wheat, rice, nonfat milk)	Colombia	Ferrous sulfate	141	30	21	14
Alli alimentu (20% animal protein)	Peru	?	100	250	125	15
Progesa-project (hydrolyzed cornstarch, whole milk)	Mexico	?	230	44	50	16

\* Assuming 1 mg iron a day, and a 5% absorption.

fortified with micronutrients. However, clear guidelines need to be enacted for developing countries in order to avoid false claims and unnecessary rise of prices.

- The composition of the natural diet must improve because the presence of iron inhibitors is the main constraint to enhancement of iron absorption. Inclusion of meat is very important in the diets of developing countries.
- Nutritional education is essential to achieve a good impact of food fortification programs, promoting simultaneously the consumption of iron absorption enhancers (such as ascorbic acid and flesh) and avoiding iron inhibitors (coffee, for example).
- Preventive supplementation is an excellent and effective intervention, mainly if it is focused on the most vulnerable groups such as infants and pregnant women. Efforts in this regard must continue in order to overcome identified limitations of iron capsule supply and compliance with treatment.
- Correction of iron deficiency should not conceal attention to other minerals that probably are also deficient in the diet, such as calcium and zinc.

### Iron Fortification of Complementary Foods in Latin America

Iron fortification of staple foods would benefit large segments of the population, but it would be very difficult to solve iron deficiency entirely, mainly owing to the low levels of iron that these foods allow. Fortification of foods aimed at target groups, such as infants and school-age children, usually permits much higher amounts of iron, and hence enhances the biologic impact (Table 6). That has been the case of porridges, cookies, beverages, and atoles in Latin America. These almost ready-to-eat foods are not ingredients for other food industries, as is the case with the staple foods, and therefore their fortification and acceptance are much easier. Their flavor, color, and odor are sufficiently strong to cover sensorial

changes caused by the nature of iron. Nevertheless, iron bioavailability studies are needed not only to determine the true supply of iron by these food sources but also to confirm safety of the fortification levels. It is especially important for those foods made with soybean, corn, and rice flours, which contain large amounts of iron absorption inhibitors.

### Voluntary Enrichment of Foods

The subject of voluntary enrichment of foods in developing countries deserves urgent attention. Food industries have discovered that with small investments they can advertise their products as having "improved" nutritional value because they contain vitamins and minerals. Their purpose is to profit by means of attracting the attention of consumers, sometimes with false claims. From a public health perspective, industry's interest should be channeled properly to benefit consumer health and economy.

A minimum level of each micronutrient should be suggested in order to allow making a claim, but a high level would also be recommended to avoid unnecessarily large intakes of some micronutrients and to keep the increment in food price within a reasonable range. Mention of valid claims to prevent the use of advertisement-oriented words is also important.

Together with the nutritional guidelines, it is also necessary to establish which products are not adequate to fortify because adding micronutrients does not make an undesirable product a good food; such is the case with snacks, candies, beverages made with sugar, and similar products. Exclusions might be considered, such as iodine in salt and vitamin A in sugar, if such additions are justifiable within public health programs.

In summary, voluntary enrichment of processed food might become a good tool to supply micronutrients to populations in the developing world, ensuring that public health and economy are protected against false or

exaggerated claims, as well as encouraging establishment of good dietary and healthy practices.

## **Some Questions and Answers as Conclusions**

### ***Is it worth the effort to fortify a staple food with iron?***

Definitively yes. Iron deficiency and iron deficiency anemia is a problem that affects almost all individuals in developing countries. Therefore, despite the fact that the fortification of only one staple may not prevent iron deficiency entirely, the added iron will contribute to narrowing the nutritional gap.

### ***Which type of iron and level should be used to fortify a staple food or a complementary food?***

One should use a highly bioavailable type, such as ferrous sulfate or ferrous fumarate, or a chelating compound such as ferrous bisglycinate or NaFeEDTA, nearly the maximum amount that the food allows. Unlike fortification with vitamin A, iodine, or B complex vitamins, the biologically safe maximum is not usually a matter of concern. The food matrix will limit the amount of iron at a level much lower than that desirable for biologic intake. It seems that ferrous fumarate is the best alternative to fortify staple flours (corn and wheat flour), and ferrous sulfate is the best alternative to fortify complementary dry foods. Nevertheless, NaFeEDTA may still be a good candidate especially for food matrixes with high amounts of iron absorption inhibitors. Ferrous bisglycinate is a good option for milk and beverages, and it may become a good option for food fortification of solid foods once its price is between that of ferrous fumarate and NaFeEDTA.

### ***What about using elemental iron to fortify a staple food or a complementary food?***

Bioavailability of elemental iron in its best form (electrolytic iron) is usually half that of ferrous sulfate. Therefore, until it is demonstrated that elemental iron compounds that are commercially available have similar absorption properties to ferrous sulfate, it is unwise to use this type of iron to fortify foods in developing countries. Iron deficiency in many of these countries is usually a problem of iron quality rather than iron quantity.

### ***How should one decide about the best option of an iron compound to fortify a food within a public health program?***

First, it is important to establish the maximum amount of iron possible (of each one of the fortificant candidates) to incorporate into the food (technologic compatibility). Then, it is important to establish the average iron absorp-

tion by individuals who represent the target population (bioavailability) using stable isotopes or radioisotopes. With this information, it is possible to calculate the theoretic iron intake with specific consumption amounts of the fortified food for each of the fortificants. The best compound will be that one with the maximum iron intake under the selected fortification conditions. If more than one iron product produces similar iron intake figures, a cost-effectiveness analysis is needed. Here, it is important to know the price of the iron compound in terms of kilograms of iron. This analysis will establish the iron compound with the lowest investment that has an acceptable biologic effect. If, despite this process, there are still doubts about the best option, then a field efficacy trial might be planned to solve the issue.

### ***When is a field efficacy trial necessary to evaluate whether a food fortification program is adequate?***

A field efficacy trial is a large, expensive, time-consuming, and laborious task. Therefore, it should be reserved to confirm biologic impact of a food fortification program only if the theoretic estimations using bioavailability and consumption data suggest that 25% or more of the daily iron needs are supplied by this means. A food fortification program that supplies less iron may be still worth launching as one intervention among others aimed to reduce iron deficiency anemia. In this circumstance, the effect of the program would be better measured following the evolution of this ailment in the population.

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