TECHNICAL AND PRACTICAL BARRIERS TO FOOD FORTIFICATION
Case: Cereal Food Staples
(Wheat flour, maize flour, rice)

Forging Effective Strategies to Combat Iron Deficiency
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I will cover the subject of technical and practical barriers of food fortification in food staples, describing four facts.

FACT 1. Cereal domestication allowed human civilization by providing permanent, stable and rich sources of energy, BUT prompted micronutrient deficiencies.

Once humans learned how to manage cereal crops, survival without nomadism was possible. Thus, the evolution of human civilization was accelerated. However, weakening of hunting, fishing, and nut gathering caused the reduction of vital micronutrients in the diet. As consequence, micronutrient deficiency began to be a common ailment of cereal based communities.

Cereals, such as wheat, corn or rice are poor sources of iron, either because the iron-rich portions of their seeds are lost during milling, or because these seeds and their products contain strong iron absorption inhibitors. For example, consuming 100 grams of any of these foods barely provides from 1 to 4% of the daily iron requirements needed.

However, if these products happened to contain iron compounds that are fairly absorbed, then they would become excellent sources of this nutrient, because these foods are consumed in relatively large amounts. That is the second fact:

FACT 2. Cereals are good vehicles for micronutrients because they are consumed in constant and relatively large amounts, BUT only if they are centrally processed.

The latter is very important. One limitation to a wider and better impact of cereals as iron vehicles is that many poor and far away communities still consume domestically produced cereals. This is fundamentally true in the case of rice, and perhaps only biotechnology might improve its iron content to favor poor rice-eating communities. Nevertheless, there is an increasing urbanization trend and dependence on industrially processed foods worldwide. Therefore, there is a crescent opportunity to reach large population segments with fortified cereals. For example, universal and mandatory fortification of wheat flour is already a reality in Latin America. Iron fortification of maize flour, and even rice, might start as voluntary programs in countries where formal industries of these cereals operate. At least, persons who have access to centrally processed foods would be benefited. Little by little, more people would be covered, coinciding with their countries' industrial development.

FACT 3. Addition of micronutrients is technologically easy in flours (wheat or maize), BUT it is still a barrier to overcome in rice.

The wheat flour industry in most countries of the world is accustomed to adding different substances to this food during the milling process. Therefore, it is relatively simple, efficient and quick to incorporate a micronutrient premix. Introducing fortification into corn flour production requires some technological changes that are simple to attain. In both cases, dilution rates of the micronutrient premix is about 1:1000 to 1:2000, and the mixing process provides highly homogeneous results.

The situation is different with rice. For raw rice, two types of technologies have been developed. One is based on coating rice kernels with a layer of "sticky" micronutrients; and the other is based on the use of a synthesized kernel, which contains the needed micronutrients in its interior. These two technologies require the mixing of the enriched kernels in a proportion of 1:100 to 1:200. This condition makes distribution of the enriched premix very cumbersome to other rice mills that do not have the capacity for its production, and this is a common characteristic in developing countries' rice mills.

In the case of rice, the cost of synthesizing enriched kernels is another limitation. This process currently requires an investment of US$30.00/MT, which is 10 times higher than the coating process. At this cost, the rice's retail price would increase 5% or more, which is too high for a food staple. Other information that is still lacking is the absorption percentage of the different iron compounds added to rice. Currently, ferric orthophosphate or elemental iron are commonly used to fortify rice in developed countries, and these types of iron compounds have a very low absorption.

FACT 4. Biological impact of fortified flours (wheat and maize) depends not only on the iron absorption rate BUT also on the technological compatibility and the food consumption pattern.

In cereals, the most absorbable iron compound is FeNaEDTA. Iron compounds that are water-soluble or in slightly acid conditions, such as ferrous sulfate and ferrous fumarate, respectively, are less absorbed 2 to 3 times than FeNaEDTA. Ferrous bisglycinate presents an absorption level between FeNaEDTA and the other mentioned compounds. Elemental iron of the best type, that is the electrolytic type, has an absorption of approximately half of ferrous sulfate or fumarate. In all cases, absorption rates are lower in maize flour than in wheat flour, due to the presence of strong iron absorption inhibitors.

On the other hand, the most absorbable compounds usually have negative interactions with the food matrix. Thus, in Central America, experiments carried out at INCAP determined that for wheat flour, the maximum iron loads of elemental iron, ferrous fumarate, ferrous bisglycinate and FeNaEDTA were 80, 60, 20 and 10 mg/kg, respectively. The corresponding values for maize-masa flour were 40, 30, 15 and 10 mg/kg. It was not possible to use ferrous sulfate because it shows reactions with both types of flours under Central American weather and flour use.

The theoretical biological impact due to the consumption of fortified flours can be estimated combining iron absorption and technological compatibility data. In the Central American case, it is found that for wheat flour the best iron compound is ferrous fumarate. The same is true for maize-masa flour, but in this case both ferrous bisglycinate and FeNaEDTA are still good candidates. If the cost of fortification is also considered, the best alternative for corn-masa flour is ferrous fumarate followed by FeNaEDTA. Nevertheless, the final decision between these two compounds, and perhaps also ferrous bisglycinate (if its price were lower), should be supported by means of a field efficiency trial.

The biological impact estimates also permit to assess the expected outcome of these fortification examples. Thus, to provide 0.25 mg of absorbed iron, which represents about 20% of the adult daily, it is necessary to consume the following amounts of wheat flour: 90 g if fortified with 80 ppm iron from elemental compounds of the best type; 75 g if fortified with 60 ppm iron from ferrous fumarate; 100 g if fortified with 20 ppm iron from ferrous bisglycinate; and 140 g if fortified with 10 ppm iron from FeNaEDTA. In the case of maize-masa flour, the consumption amounts are larger: 350 g for 40 ppm iron from elemental compounds; 140 g for 30 ppm iron from ferrous fumarate; 190 g for 15 ppm iron from ferrous bisglycinate; and 210 g for 10 ppm iron from FeNaEDTA. These calculations explain why it is very difficult to provide sufficient iron to infants and small children through fortified staples. To cover these high risk groups, it becomes necessary to introduce other types of interventions, such as fortification of complementary foods and preventive supplementation.

CONCLUSIONS

1. Iron fortification of flours (wheat and maize) may contribute to reduce iron deficiency. The biological impact is inversely proportional to the amount of iron inhibitors in the diet, and directly proportional to the **iron absorption rate** and **total iron intake**. In turn, iron intake depends on technological compatibility between the iron compound and the food matrix, as well as the fortified food consumption pattern.

2. Low flour consumers, such as infants and preschoolers, need to increase their iron intake through other measures, for example fortification of complementary foods or preventive supplementation.

3. The most absorbable iron compounds are usually those that react most strongly with the food matrix. Therefore, it is important to determine the maximum load of iron in each case, before making any assumption regarding biological impact.

4. Simple inorganic iron compounds (ferrous sulfate or ferrous fumarate) are suitable candidates in the case of flours with low levels of iron inhibitors. In this case, elemental iron of the electrolytic and H-reduced (small particle size) types may be useful at 2-3 times higher fortification levels.

5. Field efficacy trials are needed to select suitable iron compounds (ferrous fumarate or ferrous sulfate or ferrous bisglycinate or FeNaEDTA) to fortify foods with high levels of iron inhibitors. At similar biological impact, the compound with the lowest cost is the best choice for public health programs.

6. Rice fortification with iron still requires more research, technological development, and industrial growth.

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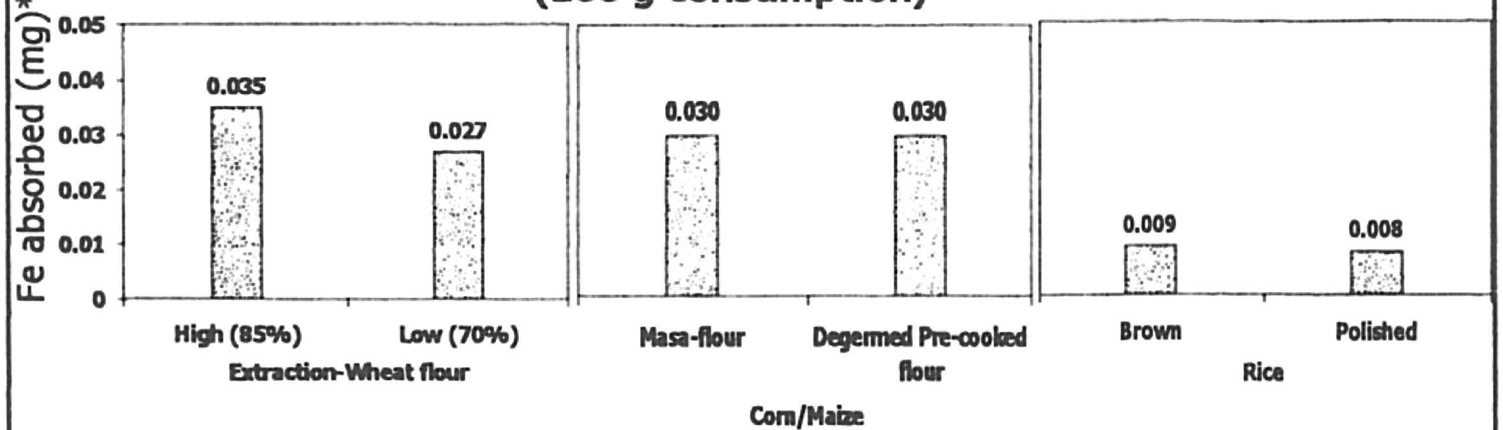
FACT 1. Cereal domestication allowed human civilization by providing permanent, stable and rich sources of energy, BUT prompted micronutrient deficiencies

Theoretical iron amount absorbed from cereals
(100 g consumption)



Iron content (mg/kg)	35.0	9.0	20-30	10.0	9.0	4.0
% Fe absorption	1.0	3.0	1.0	3.0	1.0	2.0

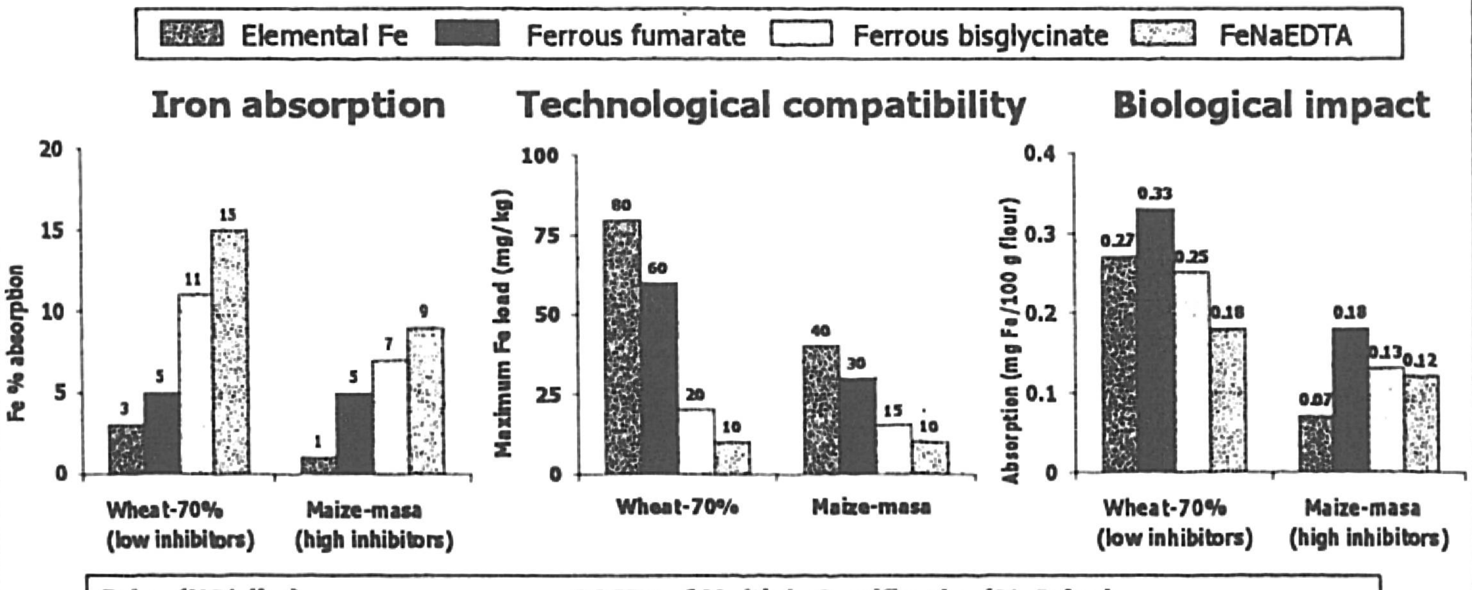
*Fe Daily Requirement: 0.8- 2.4 mg

FACT 2. **Cereals are good vehicles for micronutrients because they are consumed in constant and relatively large amounts, BUT only if they are centrally processed**

wheat flour >> maize >>> rice
(voluntary enrichment)

FACT 3. **Addition of micronutrients is technologically easy in flours (wheat or maize), BUT it is a barrier to overcome in rice.**

FACT 4. **Biological impact of fortified flours (wheat and maize) depends not only on the iron absorption rate BUT also on the technological compatibility and the food consumption pattern.**



Price (US$/kg)	**COSTS of Multiple Fortification(% Price)**
Wheat: **0.40**	**Elemental:** 0.35 (w), 0.15(m); **ferrous fumarate:** 0.42(w), 0.18(m)
Maize-masa: **0.45**	**Ferrous bisglyicinate:** 0.76-1.30(w), 0.46-0.79(m); **FeNaEDTA:** 0.49(w), 0.29(m)

CONCLUSIONS

1. **Iron fortification of flours (wheat or maize) might contribute to reduce iron deficiency. The biological impact is inversely proportional to the amount of Fe-inhibitors in the diet, and directly proportional to the Fe-absorption rate and total Fe-intake (technological compatibility + consumption pattern).**

2. **Low flour consumers (infants and preschoolers, e.g.) need to increase their iron intake through other means (fortification of complementary foods or preventive supplementation).**

3. **The most absorbable iron compounds are usually those ones that react most strongly with the food matrix. Therefore, it is important to determine the maximum load of iron in each case before making any assumption of biological impact.**

4. **Simple inorganic compounds of iron (ferrous sulfate or ferrous fumarate) are suitable candidates in the case of flours with low levels of Fe-inhibitors In this case, elemental iron of the types electrolytic and H-reduced (small particle size) may be useful at 2-3 times higher fortification levels.**

5. **Field efficacy trials are needed to select suitable iron compounds (ferrous fumarate or sulfate, ferrous bisglycinate or FeNaEDTA) to fortify foods with high levels of Fe-inhibitors. At similar biological impact, the compound with the lowest cost is the best choice.**

6. **Rice fortification with iron requires more research, technological development, and industrial growth.**