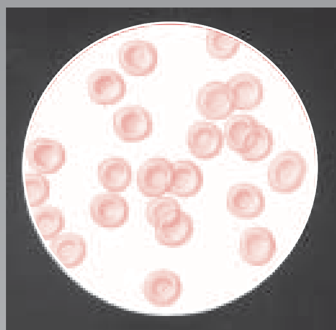

INACG
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BRIEF

This statement was prepared by Dr. Penelope Nestel and Dr. Ritu Nalubola, and was reviewed by the INACG Steering Committee.

Technical Brief on Iron Compounds for Fortification of Staple Foods

Iron fortification of food is generally considered to be the best long-term strategy to increase iron intake and has been reported to contribute to iron intake among those consuming fortified foods (Samuelson et al. 2000, Osler et al. 1999, Subar et al. 1998a, 1998b, Olsson et al. 1997) in developed countries, where it has been practiced for many years. Wheat flours and breakfast cereals are the most commonly fortified foods, but maize flour (Layrisse et al. 1996) and milk (Olivares et al. 1989) are also fortified in some developing countries. Intervention trials have shown that condiments such as fish sauce, sugar, curry powder (Lynch et al. 1993), and salt (Nadiger et al. 1980) can be effectively fortified with iron and improve iron status.

The amount of iron available for absorption (bioavailability) in the gut is dependent on its solubility in gastric juice, which in turn is dependent on the chemical and physical characteristics of the compounds (size, shape, and surface area of particles) as well as on gastric acid secretion in the individual, the presence of dietary absorption enhancers or inhibitors in the meal, and the iron status of the individual. This technical brief summarizes information on the iron fortificants currently available to fortification programs, and it can be used as a guide for deciding which iron fortificant to use as well as the maximum level to add to the food vehicle. Iron fortificants for which there are no data on efficacy and feasibility (cost efficacy) are not discussed.

Table 1 shows the characteristics of commonly used iron fortificants and **Table 2** the technical specifications for these compounds. The preferred and optional iron compounds normally used to fortify cereals and condiments, based on relative bioavailability and sensory evaluations of the fortified food, are shown in **Table 3.** Because ambient environmental conditions can affect the sensory characteristics of food, and because acceptability criteria can vary by country or cultural group, fortified foods must be tested for sensory changes after different storage times and after cooking as part of program development. **Table 4** shows the available data for upper-level sensory thresholds in wheat flour given ambient environmental conditions. A lack of data prevented the compilation of such information for foods other than wheat flour. Because the bioavailability of the iron is essential to successful fortification programs, the addition of an iron absorption enhancer can be considered. **Table 5** discusses two options for optimizing iron bioavailability. The names and contacts for some of the manufacturers and suppliers of the iron compounds discussed in this brief are listed in **Table 6.**

Table 1. Characteristics of Commonly Used Iron Fortificant Compounds

Fortificant	Approximate iron content (%)	Average relative bioavailability (RBV)	Potential for adverse sensory changes[a]	Cost[b] ($/kg)	Cost[c] ($/kg Fe)	Cost ($/kg bioavailable Fe)[c]
Freely water soluble						
Dried ferrous sulfate	32	100	High	2.40	1.00	1.00
Poorly water soluble/soluble in dilute acid						
Ferrous fumarate	33	100	Low	3.00	1.21	1.21
Water insoluble/poorly soluble in dilute acid						
Electrolytic iron	98	50	Negligible	6.70	0.91	1.82
H-reduced iron	97	13–148	Negligible	3.25	0.45	0.30–3.44
CO-reduced (sponge) iron	97	No data	Negligible	6.60	0.91	NA[e]
Chelates						
Sodium iron EDTA	13	150–300	Medium to low	6.50–8.70	6.67–8.92	2.22–5.95

Note: NA = not available.
[a] Ferrous sulfate promotes the oxidation of fat naturally found in flour during storage and results in rancidity.
[b] These figures represent average costs. Costs may vary with supplier, region, and/or quantity purchased.
[c] Relative to dried sulfate = 1.0, for the same level of total iron.
[d] *Guidelines for Iron Fortification of Cereal Food Staples* (SUSTAIN 2001).
[e] NA as RBV unknown.

Table 2. Technical Specifications for Iron Compounds

Specification	Ferrous sulfate	Ferrous fumarate	Electrolytic
Color	Dried—white to greenish-white or off-white; hydrated—blue-green	Reddish-orange to red-brown	Dark gray
Form	Dried—fine powder with 1 water of hydration; hydrated—about 7 waters of hydration	Powder—may contain soft lumps that produce a yellow streak when crushed	Magnetic powder that dissolves in dilute mineral acids
Odor	None or almost none	None	None
Assay/purity	86.0–89.0%	97.0–101.0%	Min 97.0%; 98.2% Fe typical
Iron content	31.6–32.7%	31.9–33.2%	ND
Ferric iron	NA	Max 2.0%	NA
Acid-insoluble substances	Max 0.05%	ND	Max 0.2%; 0.05 typical
Water-insoluble matter	Max 0.5%	ND	ND
Loss on drying	Max 3.0%	Max 1.5%	ND
Hydrogen loss	ND	1%	1.5% typical
Arsenic	Max 3 ppm	Max 3 ppm	Max 4 ppm
Carbon, total	ND	ND	0.02% typical
Chloride	ND	ND	NA
Lead	Max 10 ppm	10 ppm	Max 0.002%; <0.001 typical
Manganese	ND	ND	0.004% typical
Mercury	Max 3 ppm	Max 3 ppm	Max 2 ppm
Nitrogen	ND	ND	0.005% typical
Oxygen	ND	ND	ND
Phosphorus	ND	ND	0.002% typical
Silicon	ND	ND	0.003% typical
Sulfate/sulfur	ND	Max 0.2%	0.008% typical
EDTA	NA	NA	NA
All other	ND	ND	0.07% typical
Particle size	USP mesh no. 325: 85% of particles are < 45 μm		USP mesh no. 325: 39% <10 μm, 35% 10–20 μm, 16% 20–30 μm, 8% 30–44 μm
Aerobic bacteria	Max 1000/g	ND	ND
Manufacturer	Dr. Paul Lohmann GmbH	Jost Chemical; Dr. Paul Lohmann GmbH	OMG America, Inc.
Suppliers of iron (not iron in premix)	Hoffmann-La Roche; Mallinckrodt Inc.; Dr. Paul Lohmann GmbH	Jost Chemical; Mallinckrodt, Inc.; Dr. Paul Lohmann GmbH	OMG America, Inc.

Note: NA = not applicable; ND = no data.

Comments
Although the heptahydrate form of ferrous sulfate has been used as the reference standard in bioavailability studies, the dried form is preferable because the heptahydrate form can cause color and spotting problems. Encapsulation using a coating such as hydrogenated oils, maltodextrin, or ethyl cellulose may prevent or retard negative sensory changes, but the influence of the various encapsulation methods on iron bioavailability and efficacy in fortification programs is not known. Encapsulated compounds cost more than noncapsulated compounds. Codex approved.
Cause fewer unacceptable sensory changes than water-soluble compounds but have a similar, or slightly lower, RBV depending on how well they dissolve in the gastric juice during digestion. Encapsulation using a coating such as hydrogenated oils, maltodextrin, or ethyl cellulose may prevent or retard negative sensory changes, but the influence of the various encapsulation mehods on iron bioavailability and efficacy in fortification programs is not known. Encapsulated compounds cost more than noncapsulated compounds. Codex approved.
Powder of choice for food fortification.[d] Codex approved. Insufficient information available to decide on its usefulness in fortification. Codex approved. Insufficient information available to decide on its usefulness in fortification.
Approved for food fortification by the Joint FAO/WHO Expert Committee on Food Additives (1999) in supervised programs in areas with a high prevalence of iron deficiency at a maximum intake of 0.2 mg iron/kg body weight per day. The major advantage of sodium iron EDTA over other fortification compounds is that it prevents iron binding to phytic acid.

Hydrogen reduced	CO reduced	Sodium iron EDTA
Gray-black	Gray	Brownish-yellow
Magnetic powder that dissolves in dilute mineral acids	Magnetic powder that dissolves in dilute mineral acids	Powder
None	None	None
96.0–100.5% Fe	ND	ND
98+%	99%	NA
NA	NA	12.5–14.0%
Max 1.25%	ND	ND
ND	ND	Max 0.1%
ND	ND	ND
Max 1.75%	0.44%	ND
Max 8 ppm	Max 1 ppm	Max 3 ppm
0.05–0.15%	0.02%	ND
NA	NA	Max 0.05%
Max 10 ppm	Max 0.001%	Max 0.001%
ND	0.02%	ND
Max 5 ppm	Max 1 ppm	ND
ND	ND	ND
0.40–0.75%	ND	ND
0.025%	0.0015%	ND
ND	0.13%	ND
0.006–0.008%	0.006%	Max 0.2%
NA	NA	66.0–71.0%
ND	0.50%	ND
USP mesh no. 325: 95% < 45 μm	USP mesh no. 325: 95% < 45 μm; mesh no. 300: 95% < 50 μm; mesh no. 100: 95% <150 μm	ND
ND	ND	ND
Pyron Corp; Quebec Metal Powders, Ltd.	Höganäs AB	Dr. Paul Lohmann GmbH; Akzo Nobel Chemicals
Mallinckrodt, Inc.	American International Chemical	Dr. Paul Lohmann GmbH; Akzo Nobel Chemicals

Table 3. Potential Use of Different Iron Forms in the Fortification of Cereals, Condiments, and Other Foods

Product	Extraction rate (%)	Preferred iron compound	Optional iron compounds
Cereals[a]			
Whole-wheat flour (atta)	97	Sodium iron EDTA[b]	Electrolytic iron, ferrous fumarate
All-purpose flour[c]	75	Electrolytic iron	Ferrous fumarate
Bread flour	75	Dried ferrous sulfate	Electrolytic iron, ferrous fumarate
Semolina	60–65	Dried ferrous sulfate	Electrolytic iron, ferrous fumarate
Cake flour	50–55	Electrolytic iron	Ferrous fumarate
Pastry flour	45	Electrolytic iron	Ferrous fumarate
Corn flour/nixtamalized corn flour/ maize meal	75–95	Electrolytic iron (low extraction); Sodium-iron EDTA (high extraction)	Ferrous fumarate (low extraction)
Condiments[d]			
Fish sauce[e]	NA	Sodium iron EDTA	
Sugar	NA	Sodium iron EDTA	
Curry powder	NA	Sodium iron EDTA	
Salt[f]	NA	Ferrous fumarate	
Other[g]			
Powdered milk	NA	Ferrous sulfate	

Note: NA = not applicable.
[a]Based on information from Clydesdale and Wiemer (1985), stability trials in Sri Lanka (Gooneratne et al. 1996), and unpublished investigations in Central America by INCAP.
[b]Food-grade NaFeEDTA is commecially available with production planned according to orders.
[c]Because ferrous sulfate is appropriate only for flours that are used within 1–2 months of production, and because all-purpose flour for home use may not be used within this time, electrolytic rather than dried ferrous sulfate is listed as the preferred iron compound.
[d]Reviewed by INACG (Lynch et al. 1993).
[e]Thuy et al. (2001).
[f]Sattarzadeh and Zlotkin (1999).
[g]Olivares et al. (1989) and Stekel et al. (1988).

Table 4. Upper-level Sensory Thresholds (ppm) for Iron Fortificants Added to Wheat Flour

	Wheat flour stored up to 3 months	
	High temperature (30–40 °C), high relative humidity (70–80%)	Low-moderate temperature (20–30 °C), low relative humidity (<50%)
Ferrous sulfate	30[a]	40[b]
Ferrous fumarate	60[a]	NA
Electrolytic iron	66[c]	NA
H-reduced iron	66[c]	88[d]
CO-reduced iron	NA	NA
Sodium iron EDTA	15[a]	NA

Note: NA = published data or study results not available.
[a]Alvarado et al. (unpublished).
[b]Barrett and Ranum (1985).
[c]Gooneratne et al. (1996).
[d]Rubin et al. (1977)

Table 5. Optimizing Iron Bioavailability

Because the bioavailability of water-insoluble iron powders is lower than that of freely soluble ferrous sulfate, double the amount of water-insoluble iron should be added so long as it does not exceed the level that will result in organoleptic changes (see Table 4) (Hurell 1999). For example, add 50 ppm electrolytic iron instead of 25 ppm ferrous sulfate.

Ascorbic acid is an effective enhancer of iron absorption. Besides being dose dependent, the enhancing effect of ascorbic acid also depends on the form and concentration of the iron fortificant in the food and the amount of iron absorption inhibitors (phytic acid and polyphenols) in the meal. It can increase iron absorption from food fortified with ferrous sulfate. Published studies suggest that a significant increase in iron absorption can be expected when the weight ratio of ascorbic acid to iron (from ferrous sulfate) is about 6:1 (molar ratio of 2:1) (Lynch, personal communication, 2001). It is important to note, however, that the above studies did not include meals containing large amounts of phytic acid or phenolic compounds. Thus caution should be applied in using this ratio for meals with large amounts of phytic acid or phenolic compounds. The extent to which ascorbic acid can enhance the absorption of ferrous fumarate or elemental iron powders, especially in infants, is not fully understood (Lynch, personal communication, 2002).

Ascorbic acid is very susceptible to losses during storage and food preparation, which limits its use as an iron absorption enhancer. Storage losses can be unacceptably high, particularly under hot and humid conditions. The use of appropriate packaging materials can prevent much of the ascorbic acid degradation, but the cost of sophisticated packaging is often prohibitive. Vitamin C is not added to iron-fortified staple cereal flours because much of the vitamin C would likely be lost during storage and cooking.

Sodium EDTA is an accepted food additive in many countries that is stable during storage and food preparation. It can also be used as an iron absorption enhancer (Lynch et al. 1993), although the enhancing effect has been demonstrated only for ferrous sulfate. Based on available data, iron absorption from foods fortified with ferrous sulfate will be enhanced at a molar ratio of sodium EDTA to iron of about 0.5:1–1.1. While this effect can probably also be expected with other water-soluble iron compounds, whether sodium EDTA enhances the absorption of less soluble iron compounds remains unknown.

Table 6. Manufacturers and Suppliers

Akzo Nobel Chemicals pte. Ltd. 510 Thomson Road #17-00 SLF Building Singapore 298135 Ph: +65 2581 1333 Fax: +65 358 0659 Website: www.Dissolvine.com	Dr. Paul Lohmann GmbH KG Chemische Fabrik, Haupstr. 2 31860 Emmerthal Germany Ph: +49 5155 63140 Fax: +49 5155 63118 Website: www.lomapharm.de
American International Chemical 17 Strathmore Road Natick, MA 01760 Ph: (508) 655 5805/(800) 238 0001 Fax: (508) 655 0927 Website: www.aicma.com	Mallinckrodt, Inc. Specialty Chemicals Division 675 McDonnell Blvd. P.O. Box 5840 St. Louis, MO 63134 Ph: (314) 654 6065/(800) 554 5343 Fax: (314) 654 6527 Website: www.mallinckrodt.com
BASF, Inc. 6700 Ludwigshafen-Rhein Ludwigshafen Germany Ph: +49 621 600 Fax: +49 622 525 Website: www.basf.com	OMG America, Inc. 50 Public Square, Ste. 3500 Cleveland, OH 44113 Ph: (216) 781 0083 Fax: (216) 781 1502 Website: www.omgi.com
Hoffmann-La Roche CH-4002, Basel Switzerland Ph: +61 688 1111 Fax: +61 691 9600 Website: www.roche.com	Pyron Corporation (Div. of Zemex Corporation) P.O. Box 310 5950 Packard Road Niagara Falls, NY 14304 Ph: (716) 285 3451 Fax: (716) 285 3454
Höganäs AB S-263 83 Höganäs Sweden Ph: +46 42 33 80 00 Fax: +46 42 33 81 50 Website: www.hoganas.com	Quebec Metal Powders, Ltd. 770 Sherbrooke Street West Suite 1800 Montreal, Quebec H3A 1G1 Canada Ph: (514) 288 8400 Fax: (514) 288 1333 Website: www.qmp-powders.com
Jost Chemical 8130 Lackland Rd. St. Louis, MO 63114 Ph: (314) 428 4300 Fax: (314) 428 4366 Website: www.jostchemical.com	

Note: Other suppliers are available internationally and possibly locally.

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The International Nutritional Anemia Consultative Group (INACG) is dedicated to reducing the prevalence of iron deficiency anemia and other nutritionally preventable anemias worldwide. It sponsors international meetings and scientific reviews and convenes task forces to analyze issues related to etiology, treatment, and prevention of nutritional anemias. Examination of these issues is important to the establishment of public policy and action programs.

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This publication is made possible by support from Micronutrient Global Leadership, a project of the Office of Health, Infectious Disease and Nutrition, Bureau for Global Health, U.S. Agency for International Development, under Cooperative Agreement Number HRN-A-00-98-00027-00.

May 2002 Printed in the United States of America

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