Chapter

Dietary Iron

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Abstract

Iron metabolism differs from the metabolism of other metals in that there is no physiologic mechanism for iron excretion, it is unusual; approximately 90% of daily iron needs are obtained from an endogenous source, the breakdown of circulating RBCs. Additionally humans derive iron from their everyday diet, predominantly from plant foods and the rest from foods of animal origin. Iron is found in food as either haem or non-haem iron. Iron bioavailability has been estimated to be in the range of 14–18% for mixed diets and 5–12% for vegetarian diets in subjects with no iron stores. Iron absorption in humans is dependent on physiological requirements, but may be restricted by the quantity and availability of iron in the diet. Bioavailability of food iron is strongly influenced by enhancers and inhibitors in the diet. Iron absorption can vary from 1 to 40%. A range of iron bioavailability factors that depend on the consumption of meat, fruit, vegetables, processed foods, iron-fortified foods, and the prevalence of obesity. The methods of food preparation and processing influence the bioavailability of iron. Cooking, fermentation, or germination can, by thermal or enzymatic action, reduce the phytic acid and the hexa- and penta-inositol phosphate content. Thus improving bioavailability of non-haem iron. This chapter will elaborate the dietary iron sources and means of enhancing bioavailability.

Keywords: iron, diet, haem iron, non haem iron, bioavailibility, fortification, biofortification

1. Introduction

Iron has an essential physiologic role, as it is involved in oxygen transportation and energy formation. The body cannot synthesize iron and must acquire it. Though the human body recycles and reutilizes iron, it also loses some iron daily; these lost pools require replacement. However recycling the iron from senescent erythrocytes meets most of the body's iron needs by macrophages; only 5–10% of iron requirements come from food [1].

Iron differs from other minerals because iron balance in the human body is regulated by absorption only and there is no physiologic mechanism for excretion [2].

Haem iron derived from animal sources is better absorbed than non-haem iron derived from plant sources, whole cereals, whole pulses, and vegetables, particularly green leafy vegetables, contribute to a significant intake of dietary iron [3].

Dietary iron bioavailability depends primarily on the availability of iron for absorption in the GI tract, determined by the physicochemical form of iron in the lumen of the GI tract, largely dictated by the composition of meals, and secondarily by an individual's absorptive efficiency, which depends on physiological requirements for iron and homeostatic mechanisms designed to maintain null balance. Bioavailability factors have been derived based on the balance of enhancers and inhibitors of iron absorption in diet [4].

Various strategies can be adopted to enhance bioavalibility and to combat iron deficiency which includes dietary diversification, food fortification, weekly iron and folic acid supplementation among others [1].

Iron is found naturally in many foods and is added to some fortified food products; recommended amounts of iron can be obtained by eating a variety of foods, including non-vegetarian food viz. lean meat, seafood, and poultry etc. in addition to the iron-fortified breakfast cereals and breads, white beans, lentils, spinach, kidney beans, and peas, nuts and some dried fruits [5].

Food diversification approach designed to increase micronutrient intake through diet represents the most desirable and sustainable method for preventing iron deficiency [3].

Reference intakes are used for a wide range of activities, such as planning diets, formulating complementary foods, setting levels of food fortification, implementing biofortification programs, and food labeling [4].

2. Types of dietary iron

Dietary iron has two primary forms: haem and non-haem [1, 2, 6]. Haem iron has a higher bioavailability and is absorbed easier without the need for absorption-enhancing cofactors (**Figure 1**) [1, 2].

Haem iron is estimated to contribute 10–15% of total iron intake in meat-eating populations, but, because of its higher and more uniform absorption (estimated at 15–35%), it could contribute 40% of total absorbed iron during iron deficiency to about 10 percent during iron repletion [7].

Non-haem iron, which is the most important dietary source in vegetarians, shows lower bioavailability [1, 2]; All non-haem food iron that enters the common iron pool in the digestive tract, however, it is important to note that not all fortification iron enters the common pool [2]; 17% of dietary non-haem iron gets absorbed [1].

Studies shows that, iron bioavailability is estimated to be 14–18% for mixed diet consumers and 5–12% for vegetarian diet consumers. Thereby, less than one-fifth of the dietary iron gets absorbed by the body [1].

Iron absorption in humans is dependent on physiological requirements, but may be restricted by the quantity and availability of iron in the diet [8]. Body absorbs iron from plant sources better when eaten with meat, poultry, seafood, and foods that contain vitamin C, like citrus fruits, strawberries, sweet peppers, tomatoes, and broccoli [5].

The diets of omnivores contain relatively small quantities of haem iron derived from meat and fish, which is always well absorbed [7, 8]. The remainder of the soluble iron forms a common non-haem iron pool and absorption is very variable, depending on meal composition, but its absorption is strongly controlled by iron stores [8].

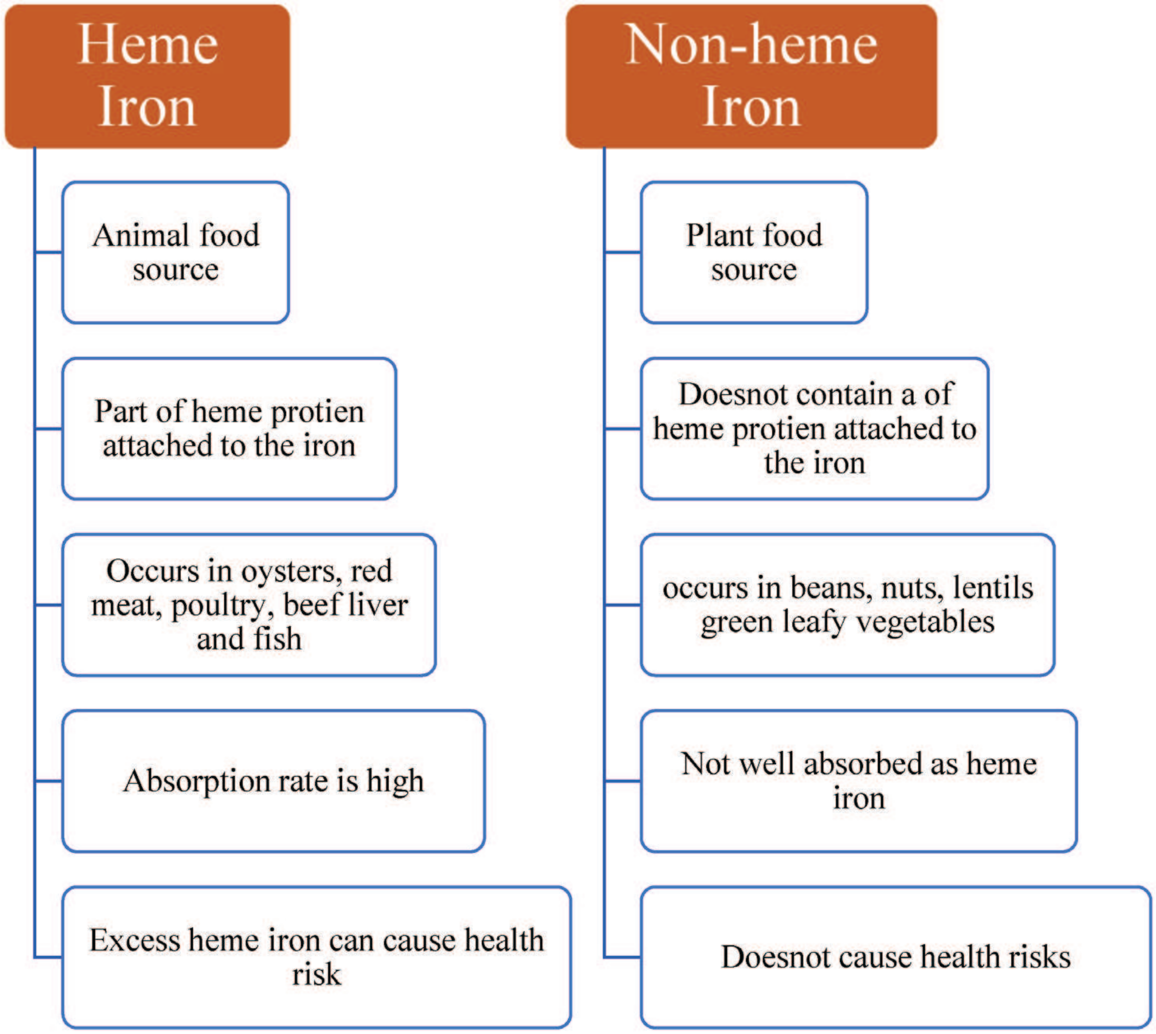

Figure 1.
Types of iron.

3. Sources of iron

3.1 Non-haem sources of iron

High nutrition benefits of coarse cereals point to the need for an increase in their consumption and even higher production (**Figure 1a**).

Top five pulses with respect to iron content are horse gram dal, soybean, moth beans, lentil (whole), and Bengal gram (whole). Horse gram dal, soybean, and moth beans provide as much as twice the iron in comparison to green gram dal and red gram dal. Arhar and moong, though lowest in iron content.

Bajra, ragi, rice flakes (poha) wheat flour, and jowar provide a higher amount of iron than maize and rice. Rice has the lowest iron content.

Green leafy vegetables are considered to be rich sources of iron and calcium. For example, beet greens, pumpkin leaves, colocasia leaves, and radish leaves having very high-iron content is usually not consumed by people and rather discarded as waste. There are others such as curry (8.7 mg/100 g), mint (8.6 mg), parsley (5.5 mg), coriander (5.5 mg), and drumstick (4.6 mg) though high in iron content, are consumed either less frequently or in small quantities. Greens like spinach, mustard leaves, and bathua leaves though popular are those with the least iron content [3].

Some of the nuts and oilseeds such as gingelly seeds (14.9 mg), mustard seeds (13.5 mg), cashew nuts (5.9 mg) and almond (4.5 mg), are fairly rich sources of dietary iron. Most of the fruits and vegetables, except lotus stem (3.3 mg iron/100 g), are a poor source of iron.

Jaggery, though rich in iron (4.6 mg iron per 100 g), is usually consumed in small amounts. Promoting traditional Indian snacks like gur chana or tilbugga prepared from jaggery and Bengal gram or gingelly seeds can contribute to significantly higher intake of jaggery and thus iron [5, 7].

3.2 Haem sources of iron

Among poultry, chicken liver is the richest source of iron (9.9 mg/100 g) followed by duck meat (4.3 mg/100 g) (**Figure 2b**).

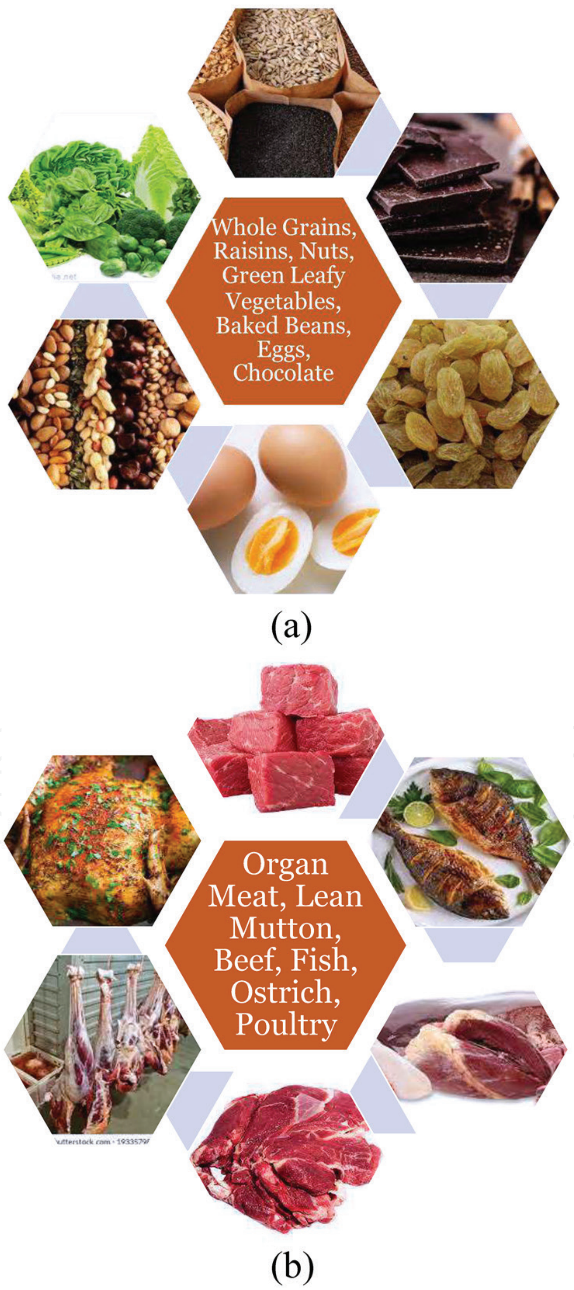

Figure 2.
a. Sources of non-heme iron. b. Sources of heme iron.

Animal meat, particularly liver and spleen, is very rich source of iron.

Boiled egg yolk is rich in iron as compared to egg white.

Fish on the contrary are not a very good source of iron [3].

Iron is present in a variety of foods, so eating a varied and healthful diet is important. Since Vitamin C enhances the absorption of iron, eating iron rich foods along with a source of vitamin C (citrus fruits and juices, etc.) can help replenish your body's iron stores. Nevertheless, iron may be absorbed into foods that have been cooked in iron cookware [9].

Common sources of Iron are depicted in **Table 1**.

- Iron contamination: For cooking, sometimes an iron skillet is a utensil used for cooking vegetables and other food to increase iron content in that food. Such a source of contaminated iron is sometimes practiced in some regions of the world [1].

Common Sources of Vitamin C are depicted in **Table 2**.

Victuals	Portion size (approx.)	Amount of iron
Haem sources		
Beef liver	85 g	5.2 mg
Beef-ground	85 g	2.2 mg
Canned clams	85 g	23.8 mg
Chicken breast	85 g	1.1 mg
Chicken liver	85 g	10.8 mg
Fish, tuna canned	85 g	1.3 mg
Lamb	85 g	3.0 mg
Large egg	1	1.0 mg
Oysters	85 g	13.2 mg
Pork	85 g	2.7 mg
Sirloin streak	250 g	1.6 mg
Shrimp	85 g	2.6 mg
Salmon	100 g	1.28 mg
Tofu	100 g	8 mg
Turkey, dark meat	85 g	2.0 mg
Turkey,light meat	85 g	1.1 mg
Non haem sources		
Greens/veggies:		
Beets, canned	64 g	1.5 mg
Brussel sprouts	64 g	2.0 mg
Collards or beet	64 g	1.2 mg
Dried thyme	5 g	1.2 mg
Greens	125 g	2.2 mg
Mushrooms	64 g	1.4 mg

Victuals	Portion size (approx.)	Amount of iron
Peas, frozen	64 g	1.2 mg
Potato, baked with skin on	Medium size	1.9 mg
Swiss chard	64 g	2.0 mg
Spinach cooked/raw	64 g/128 g	3.0 mg
Sweet potato, baked with skin on	Medium size	1.1 mg
Sauerkraut, canned	64 g	1.7 mg
Tomato Sauce	64 g	1.3 mg
Nuts		
Almonds or pistachios	32 g	1.3 mg
Walnuts	85 g	1.0 mg
Dried peaches	64 g	1.6 mg
Dried raisins	64 g	1.4 mg
Dried plums	64 g	1.3 mg
Dried apricots	64 g	1.2 mg
Pine or cashews	85 g	1.6 mg
Prune juice	125 g	3.2 mg
Strawberries	1 pint	1.5 mg
Beans:		
White	100 g	5.8 g
(Black, pinto)	64 g	1.6–1.8 mg
(Kidney, lima)	64 g	2.6–3.9 mg
Soybeans	64 g	4.4 mg
Tofu, firm	64 g	3.4 mg
Chickpeas	100 g	2.4 mg
Double beans (cooked)	125 g	4.5 mg
Tomato (sun dried)	125 g	4.9 mg
Soy milk	300 ml	2.7 mg
Quinoa	125 g	2.8 mg
Kale	125 g	1.1 mg
Grains:		
Lentils	64 g	3.5 mg
Pumpkin seeds	28 g	4.2 mg
Cereal	64 g	2–12 mg
Cream of wheat	64 g	5.2 mg
Oat meal	64 g	1.7 mg
Oatmeal Instant fortified with iron	64 g	5.0 mg

Table 1.
Sources of iron [9, 10].

Fruits	Vegetables
Amla,	Amaranthus
Cashew fruit,	Agathi
Guava,	Brussels
Lakuch,	Carrot
Korukkapalli,	Coriander
Papaya,	Cabbage
Lime, sweet (Malta)	Drumstick,
Musambi,	Fetid cassia,
Lemon,	Knol-khol radish,
Muskmelon	Turnip,
Orange	Parsley
Pineapple	*Sprouts are richer source of ascorbic acid.
Ripe tomato	
Zizypus	

Table 2.
Sources of vitamin C [7].

4. Bioavailability: dietary iron absorption

The bioavailability of dietary iron is the proportion of iron that is actually available for absorption and utilization by the body (**Figure 3**) [11]. In humans, haem iron is well absorbed and its absorption varies little with the composition of the meal. Absorption is inversely related to the quantity of iron stores in the body [6].

4.1 Factors influencing dietary iron absorpion

4.1.1 Haem iron absorption

- Iron status of subject: absorption ranges from 15 to 25 percent in normal subjects and 25–35 percent in iron-deficient subjects.
- Amount of dietary haem iron, especially from meat
- Content of calcium in meal (e.g. milk, cheese)
- Food preparation (time, temperature): Baking and prolonged frying have been shown to reduce haem iron absorption by about 40 percent.

4.1.2 Non-haem iron absorption

- Iron status of subject: The absorption of non-haem iron ranges from 2 to 20 percent. Severely iron-deficient individuals absorb non-haem iron at higher rates than those with normal iron levels. Absorption was shown to be the highest (5–13 percent) in pregnant anemic women.
- Concomitant diet: The specific rate of absorption of non-haem iron is highly dependent on the effect of concomitantly ingested dietary components (reducing substances such as ascorbic acid keep iron in the reduced ferrous form) and the amount of body iron stores.

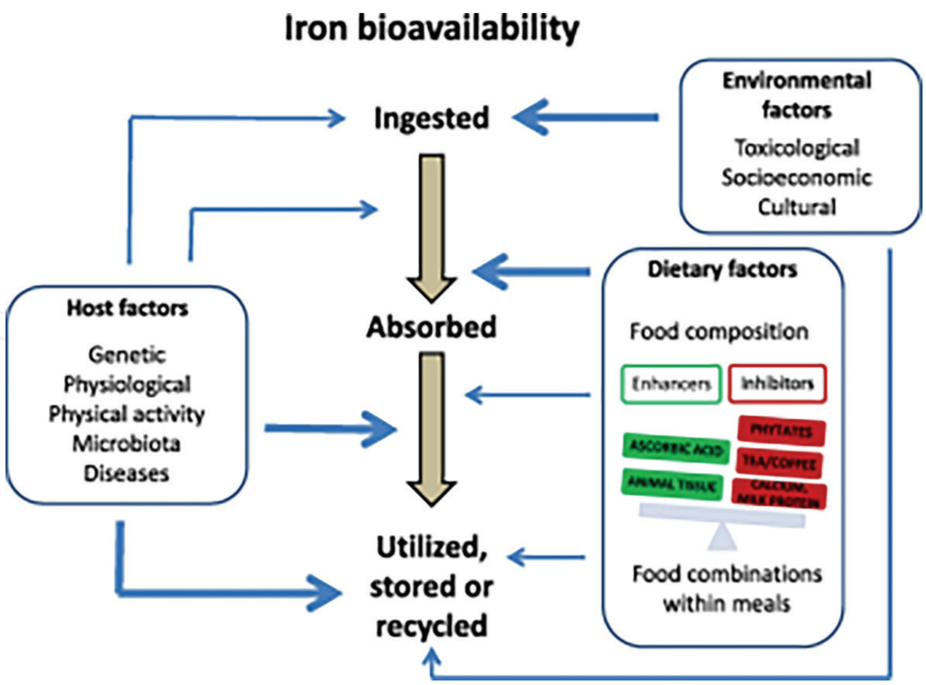

Figure 3.
Iron bioavailability.

- Food preparation (time, temperature): Cooking of cereals and pulses was shown to cause a loss of 22–24 percent of their iron, however, baking chapatti on an iron plate raised the iron content by 19 percent.

- Fermentation can degrade the phytate and increase the bioavailability of iron in bread made from whole wheat flour.

- Household processes such as germination, malting of grains/pulses and fermentation should be used to over come phytates and enhance the ascorbic acid and B-vitamins.

- Amount of potentially available non-haem iron (adjustment for fortification iron and contamination iron).

4.2 Factors effecting bioavailibility

Many different dietary components either enhance or inhibit dietary iron absorption when they are simultaneously present in the diet [1]. The bioavailability of food and dietary iron is influenced by certain factors, some of which are briefly described below [6].

4.2.1 Enhancers

Iron Absorption Enhancers foods are those, when you eat them together with a natural source of iron or an iron supplement, they help aid body's ability to effectively absorb the iron into body system [1]. There's no point in ingesting iron if the body cannot absorb it [10].

1. Meat/fish/poultry—these are also sources of the most potent form of iron (haem iron)

2. Acidic fruits—oranges/orange juice /cantaloupe/strawberries/grape fruit etc.

3. Vegetables—broccoli/brussels, sprouts/tomatoes/tomato Juice/potatoes/green and red peppers etc. [6, 10]

4. Fermented vegetables (e.g. sauerkraut), fermented soy sauces, etc. [6]

4.2.1.1 Mechanism

1. MFP Factor: It is a peptide present in meat, fish, and poultry. It enhances the absorption of non-haem iron present in the same meal. The detailed underlying mechanism is still not known. However, evidence suggests that cysteine-containing peptides present in the meat act by inhibiting luminal inhibitors and eventually form luminal carriers for iron transportation.

   - Studies consistently showed an enhanced effect on vegetarian iron absorption by 2-3-fold by adding animal proteins.

2. Ascorbic Acid (Vit C): This effect is mainly due to its iron-chelating and reducing abilities, converting ferric iron to ferrous iron, which has higher solubility and better absorption by 75–98 percent. The addition of ascorbic acid to cereals and pulses enhanced the available iron. [6] Vitamin C also has been shown to have an inhibitory effect on iron absorption inhibitors such as phytate, polyphenols, and calcium. Studies have convincingly shown the dose-dependent enhancing effect of natively present or added vitamin C on iron absorption [1].

   - The comprehensive review has shown that a food source containing 50 mg of ascorbic acid consumed with the main meal providing most of the daily intake of iron enhances iron bioavailability significantly.

Examples
Meat, fish, poultry

- The addition of 90–100 g of meat, fish or poultry to the daily diet, significantly improves the bioavailability of iron. Meat and fish taken even in small amounts markedly improve the bioavailability of non-haem iron.

- A non-vegetarian diet containing 3 oz. (approximately 85 g) of meat provides the same increase in non-haem iron absorption as 75 mg of ascorbic acid

- Eggs are rich in iron content, but its bioavailability is poor. However, as a source of iron, eggs should be eaten along with a fruit or any other source containing 100 mg of ascorbic acid, or between meals [6].

Vitamin C

- In cereal-based diets, absorption was the best for rice and vegetable combinations, which may result from ascorbic acid present in the vegetables. Children who consumed GLV once a week or more frequently had higher iron levels than non-consumers.

- Daily intake of guava fruit with the two major meals by young anemic women shows significant increase in iron.

- In regional meals, the addition of citrus fruit juices or a portion of potato, cauliflower or cabbage increases iron availability markedly [6].

- If 25 mg of ascorbic acid as lemonade is consumed at two meals a day, it doubles the absorption of iron from a meal and improves the iron status [6].

- The enhancing effect of ascorbic acid is dose-dependent, but little extra benefit is derived by increasing the intake of ascorbic acid beyond 100 mg in a meal. The influence of ascorbic acid is greatest on meals with low iron bioavailability, such as vegetarian meals [6]. It also improves the availability of iron from fortified foods.

4.2.2 Inhibitors

The following are Iron Absorption Inhibitors. i.e. when you have them together with a source of iron, they will either inhibit (limit) or prevent your body from absorbing the iron, you ingested, these foods should be avoided when taking iron rich foods in diet. This also includes any supplementations.

1. Coffee and tea [6, 10] cocoa, certain spices, certain vegetables and most red wines. (Iron-binding phenolic compounds) [6]

2. Vegetables—spinach*/chard/beet greens/rhubarb/sweet potatoes whole grains and bran [6, 10].

3. Bread made from high-extraction flour, breakfast cereals, oats, rice [especially unpolished rice], pasta products, cocoa, nuts, soybeans and peas

4. Calcium (e.g. milk, cheese) [6].

5. Isolated soy ingredients—products made with soy flour and isolated soy protein concentrate [6, 10].

4.2.2.1 Mechanism

- Phytates: they are known inhibitors of non-haem iron absorption [10]. Food sources high in phytates include soybean, black beans, lentils, mung beans, and split beans. Unrefined rice and grains also contain phytate [1]. Phytates can decrease non-haem iron absorption by 51–82 percent, and are found in higher concentrations in unrefined, non- or under-milled cereals than in refined, milled cereals [6].

- Polyphenols: they are commonly found in tea as tannic acid and also in red wine and oregano. They inhibit non-haem iron by binding within the intestine [1, 6, 10].

- Calcium: calcium has been found to have an inhibitory effect on both haem and non-haem iron absorption. Its exact mechanism is unclear [1, 6]. The first 40 mg of calcium in a meal showed no inhibiting effect, whereas 300–600 mg of calcium inhibited iron absorption by 60 percent, which is the maximum inhibition of iron. Studies showed that about 30–50 percent more iron was absorbed when no milk or cheese was served with the main meal, which provided most of the dietary iron [6].

Examples

- Approximately 250 ml of black tea can inhibit non-haem iron absorption by approximately 50 percent even when drunk 1 hour after consuming the meal; however, it has no effect when consumed between meals. This inhibition is strongly dose-related, which can be reduced to some extent by serving tea with lemon or adding sufficient milk (100 ml) to the cup of tea [6].

- Iron absorption is affected less by coffee than tea.

- To overcome the inhibitory effects, tea or coffee should not be consumed with the main iron-containing meals [6].

- Milk is better to be avoided with the main meals that contribute most of the daily iron intake, however it can be taken at breakfast, in the evening or at bedtime. Milk intake may be increased to as much as 400 ml per day provided it is distributed as suggested.

- The high iron availability of breast milk, which averages 50 percent (compared to 10–20 percent in cow's milk), is reduced when breast milk is taken together with cow's milk or weaning foods. Hence weaning foods are recommended to be given separately from the breast milk [6].

- Spinach is a good source of iron, too, but it is best to cook the spinach first—it unlocks much of the iron potential for it.

- Practical solutions for the competition of calcium with iron is to increase iron intake, increase its bioavailability or avoid taking calcium and iron-rich foods at the same time [6].

- The presence of carotene in rice-, wheat- and corn-based diets improved iron absorption from one to more than threefold suggesting that both ascorbic acid and carotene prevented the inhibitory effect of phytates on iron absorption [6].

Dietary factors that influence iron absorption, i.e. enhancers and inhibitors, have been shown repeatedly to influence iron absorption in single-meal isotope studies, whereas in multimeal studies with a varied dietary factor, the effect of single components have been, as expected, more modest [2].

The iron status of the individual and other host factors, such as obesity [2] and medical problems like malabsorptive disorder, Celiac disease, Crohn's disease and those with history of gastric bypass surgery interferes with iron absorption, play a key role in iron bioavailability, and iron status generally has a greater effect than diet composition. Hence to develop a range of iron bioavailability factors based not only on diet composition but also on subject characteristics, such as iron status and prevalence of obesity is the need of the time [1].

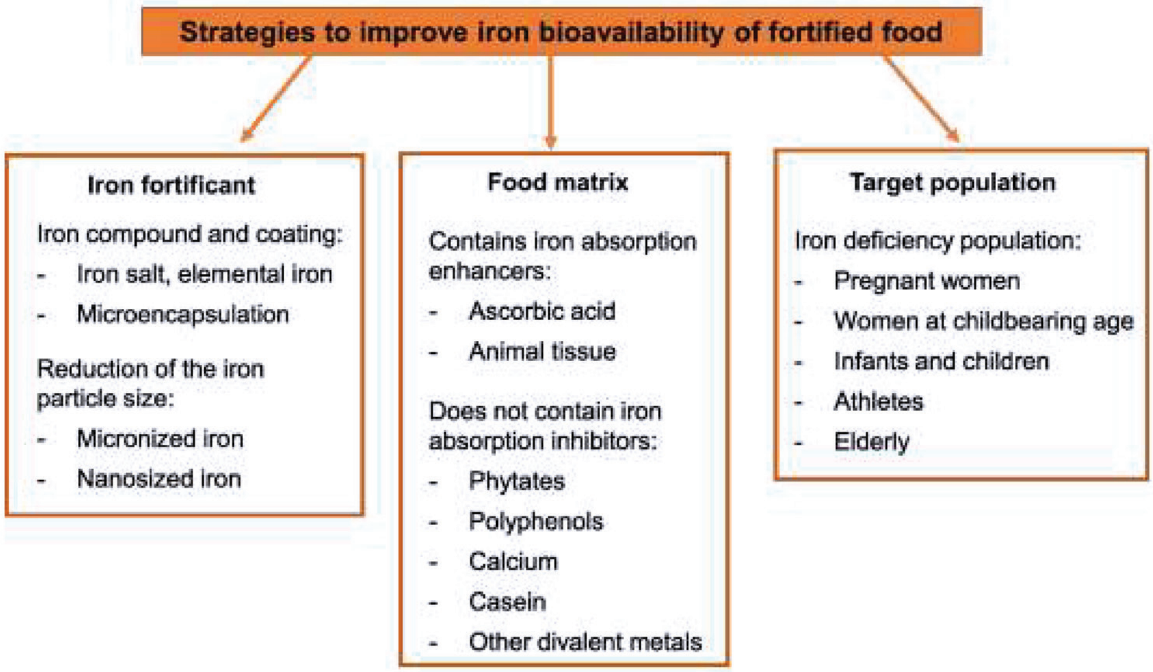

Figure 4.
Strategies to improve iron bioavailability.

The bioavailability of iron differs in various food sources depending on the types of dietary iron and the presence or absence of iron absorption enhancers or inhibitors among others (**Figure 4**) [2, 11].

5. Fortification

Food fortification is the addition of micronutrients at the point of manufacture to enhance the nutritional content of the food items, such as meal ingredients or condiments [12].

Fortification is a medium-to-long-term approach that requires a suitable food vehicle and organized processing facilities. About 34 current evidence indicates that food fortification is an effective and cost-effective strategy for reducing the prevalence of iron deficiency. [8, 13, 14] providing extremely good value, with its benefits far outweighing the costs [13] in populations that consume diets containing suboptimal quantities of bioavailable iron [9] and WHO/FAO recommends that the level of fortification is based on the estimated daily iron intake deficit adjusted for bioavailability [8].

Since iron-deficiency anemia is a main indicator of micronutrient deficiencies, one of the safest strategies available to reduce the risk of iron deficiency is fortification with low doses of iron homogeneously diluted in a larger mass of food remains. These considerations are important in the context of the United Nations Sustainable Development Goals, alongside the several servings of iron per day. Unlike supplementation, iron fortification at the point of manufacture enables the delivery of small doses of the micronutrient in a food vehicle. It is slower to raise body iron levels compared with iron supplementation or iron therapy, but it might be safer [8].

Iron fortification can be done through staple food items such as rice, oils, and wheat; condiments such as fish sauce, soy sauce, lentils (**Figure 5**) [15], salt and sugar; and lastly through processed commercial food items, including infant complementary foods, dairy products, and noodles.

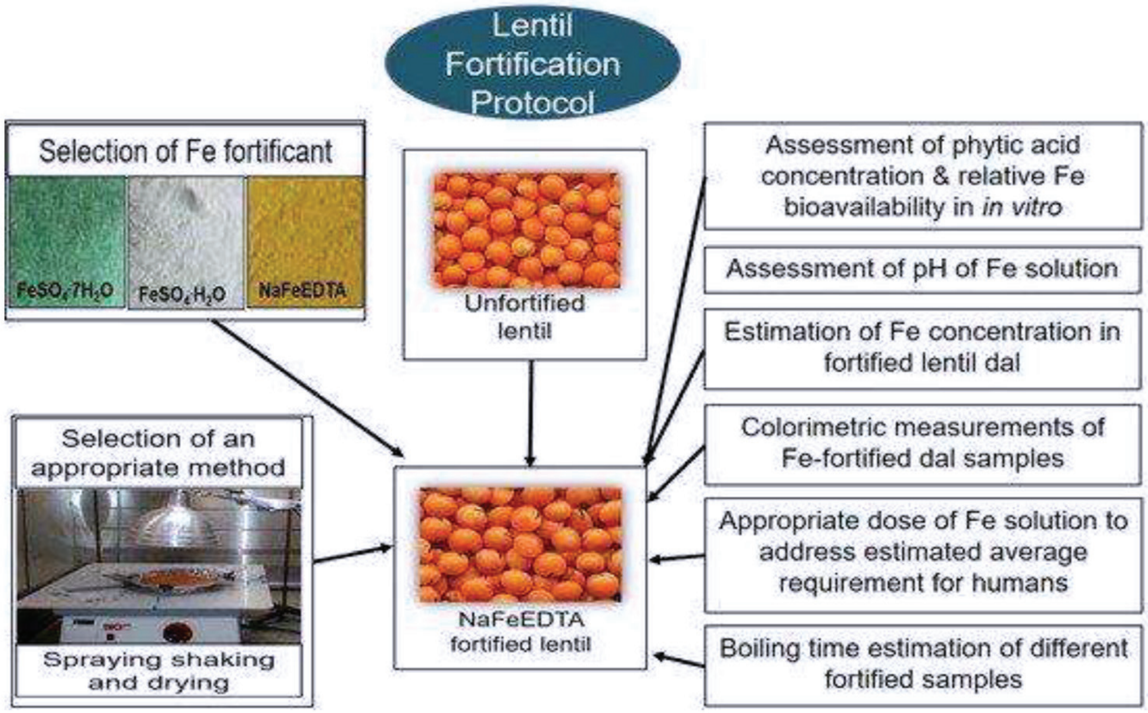

Figure 5.
Lentil iron fortification.

Compared to supplements, the use of fortified complementary foods has been shown to be safer and more effective, since the limitations associated with supplementation includes the need to purchase iron supplements and the need for a higher degree of treatment compliance [13]. The high compliance to fortification is due to the ease of substitution of unfortified staples with fortified foods 34.

Iron salts recommended by WHO for fortification include ferrous sulphate, ferrous fumarate, ferric pyrophosphate, and electrolytic iron powder [2, 13].

The WHO drew up Guidelines for food fortification which included fortification with iron [14]. In a recent directive, the WHO and partner organizations, while providing guidance on national fortification of wheat and maize flours, have endorsed NaFeEDTA to be the only Fe fortificant suitable for use in high-extraction flours [16].

Wheat is currently the primary staple food for nearly one-third of the world's population. NaFeEDTA protects iron from the phytic acid present in foods by binding more strongly to ferric Fe at the pH of the gastric juice in the stomach and then exchanging the ferric Fe for other metals in the duodenum as the pH rises [12]. It is 2- to 4-fold more bioavailable than ferrous sulfate, particularly in meals with a high-phytate content, thereby making it ideal for use in whole wheat flour [16].

Many research studies were undertaken globally on food fortification with iron; with wheat flour fortification the evidence for reducing iron deficiency among women in reproductive age (WRA) is consistent but on reducing anemia is limited [14].

The three reviews wherein multiple vehicles and various iron sources including electrolytic iron have been used concluded that consumption of iron fortified foods results in:

1. Improvement in weighted mean difference (WMD) in Hb of 0.42 g/dL, increase in serum ferritin of 1.37 μg/L and reduced risk of being anemic and iron deficient in children;

2. Improvement in standardized mean difference (SMD) in Hb of 0.55 and 0.64 g/dL, serum ferritin of 0.91 and 0.41 μg/L and reduced risk of being anemic RR 0.55 and 0.68 in children <15 8 years and WRA, respectively;

3. Improvement in WMD in Hb of 0.51 g/dL in children <10 years [14].

Efficacy of NaFeEDTA, as a fortificant has also been demonstrated in food vehicles such as curry powder, sugar, fish sauce, and maize flour [11, 13, 14, 16].

Salt: The National Institute of Nutrition had developed a technology for fortification of salt with iron and extensively tested its safety and efficacy. Fortification standards were formulated to provide 1 mg of iron (and 15 μg of iodine) per gram of salt which provides about 30–60% of RDA of 17 mg of an adult man consuming 5–10 g salt per day (FSSAI) [14].

Fortification of salt with iron is preferred because it requires only a relatively small volume of the food stuff to be fortified, unlike fortification of cereals. Currently iodisation of salt is nearly universal and using this platform it will be possible to scale up production, distribution and marketing of DFS. Double fortified salt-Iron fortified Iodized salt (providing about 10 mg of iron/day).

The studies on impact of fortified salt with three types of technologies ($FeSO_4$, 13 encapsulated ferrous fumarate and ferric pyrophosphate) showed;

1. improvement in SMD of Hb of 0.44 g/dL and ferritin 0.62 μg/L,

2. anemia risk reduction ratio of 0.16 and IDA 0.20 [14].

Since haem iron is readily bioavailable, there have been some instances of the use of meat-derived products in packaged food as fortificants [12].

Iron fortification is not a standalone strategy to correct iron deficiency. There is a need to improve dietary diversification especially consumption of vitamin C rich fruits along with meals so that iron bioavailability is improved [14]. Point-of-use fortification employs micronutrient powders in the form of packed, single-dose sachets that can be added to prepared food to improve its nutrient value [12].

5.1 Benefits of iron fortification

Food fortification offers many health benefits.

1. Iron fortification in children led to improvement in iron and hemoglobin status.

2. Hemoglobin levels significantly increased by 6.2 g/L and the risk of anemia was 50% lower in children receiving fortified milk or infant cereals [13]. Use of fortified milk and cereal-based products are more effective in reducing anemia in young children in developing countries, compared to the use of non-fortified products.

3. Cereal flour fortification with Fe is the most cost-effective and sustainable way to improve its status in deficient populations [16].

Food-fortification practices vary nationally and the need to adjust the dietary iron bioavailability factor for fortification iron will depend on the proportion of fortification iron in the total iron intake and the iron compounds used [13].

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Iron compounds used for the fortification of foods will only be partially available for absorption. Once iron is dissolved, its absorption from fortificants and food contaminants is influenced by the same dietary factors [7].

Bioavailability of fortification iron varies widely with the iron compound used, and foods sensitive to color and flavor changes are usually fortified with water-insoluble iron compounds of low bioavailability [2].

6. Biofortification: iron bio-fortified crops

Biofortification involves the targeted breeding of staple food crops in order to increase their intrinsic content of micronutrients, including iron. By combining traditional breeding with modern techniques, biofortification blends the traits of high-yield crop varieties with high iron varieties (**Figure 6**) [12, 17].

The levels of iron for wheat and rice fortification is similar and permit additions ranging from a minimum of 33% to a maximum of 100% of RDA of 17 mg [14].

The use of biofortified crops address micronutrient deficiencies by enriching the staple food items that constitute the main portion of the diet. Iron biofortification is applicable to cereals like wheat, rice, and millet [12, 14] and to pulses like beans, peas, and lentils [12].

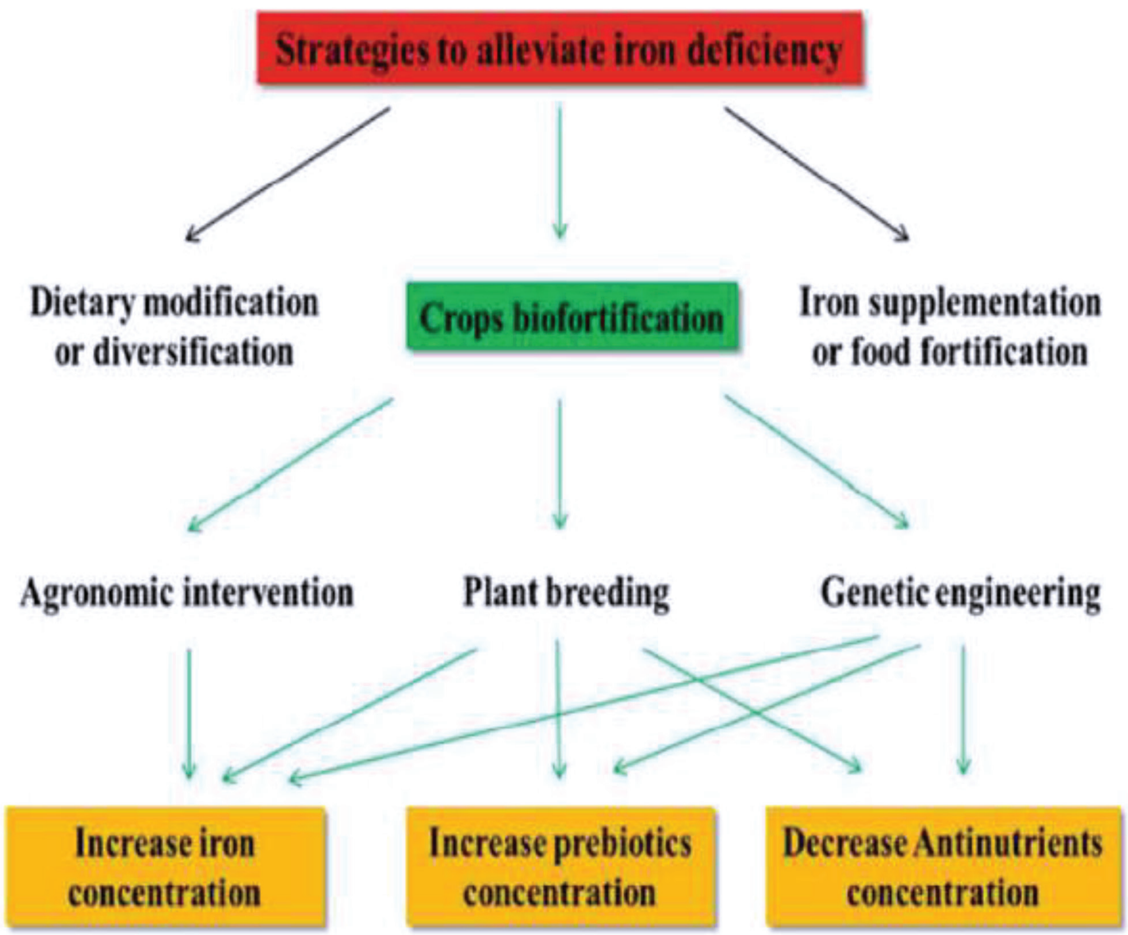

Figure 6.
Biofortification.

Therefore, even very small amounts of micronutrients could have a positive impact over time. Secondly, if biofortified crops also possess excellent agronomic characteristics, a self-sustaining public health intervention will result because farmers will favor such crops.

Iron-biofortified millet contains higher concentrations of iron. Iron levels in this type of millet reaches 90 ppm, whereas levels in nonbiofortified millet are around 20 ppm. Several studies indicate that regular intake of biofortified millet can be efficacious against iron deficiency [12].

A pearl millet variety was studied among 12–16 year adolescent girls consuming 200–300 g of pearl millet during lunch and dinner for 4 months revealed the following:

a. There was no difference in Hb

b. Ferritin increased significantly and

c. Positive impact on cognitive function [14].

Biofortified pulses, containing 100 ppm or more, have the highest concentrations of iron. Several studies have examined the bioavailability or efficacy of iron in biofortified beans consumed in developing countries; though phytic acid is present in beans, a high proportion of the iron is contained in phytoferritin. Iron from ferritins has been shown to be highly bioavailable [12].

7. Conclusion

The overall intake of iron from iron rich foods together with Vitamin C needs to be increased to obtain the optimum level of recommended dietary allowance of iron. This increase should be merged with efforts to cartel appropriate foods in the diet to enhance the bioavailability of iron and reduce inhibitory factors. Even without the haem iron found in fish or poultry, vegetarians are not at greater risk from iron deficiency than non-vegetarians. Cereals and millets, pulses and legumes, Green Leafy Vegetables, nuts and oilseed are good sources of iron.

The food combinations should be designed on the basis of foods that are normally consumed, accustomed, locally available and low-cost; comprising enhancing factors and limiting inhibitors to the extent possible and providing an overall balanced diet to provide all the major nutrients required by the body. In addition, combinations and proportions of foods on the basis of the factors influencing dietary iron absorption, a balanced diet has to be calculated.

Dietary consumption of iron and ascorbic acid could be increased by encouraging the production, processing, marketing and consumption of foods rich in these nutrients. Vitamin C-rich foods must be consumed at the same meal that contributes the major part of daily dietary iron.

Nutrition education could be a means for further promotion of dietary iron.

Conflict of interest

"The authors declare no conflict of interest."

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