FOOD FORTIFICATION TO PREVENT AND CONTROL IRON DEFICIENCY[+]

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ABSTRACT

Iron deficiency anaemia, one of the most prevalent problems of micronutrient malnutrition, occurs in many developing countries. Causes of the problem are many, but one of the major causes is low bioavailability of food iron. An increase in the supply of absorbable iron-rich food in the diet should decrease the prevalence of iron deficiency anaemia. One of the strategies to overcome the high prevalence of iron deficiency anaemia in developing countries is to fortify food products with iron, with the goal of increasing the level of iron consumption resulting in improved nutritional status. Food fortification is the most cost effective, sustainable and optimal approach in the battle against iron deficiencies in developing countries. Iron fortification does not have the gastro-intestinal side effects that iron supplements often induce. Fortification iron can be divided into two main forms namely haem iron and non-haem iron. Non-haem iron is more often used for fortification purposes because of availability of and lower cost. Most iron-fortified foods contain potential absorption inhibitors, for example, phytates, polyphenols containing galloyl groups, oxalates and calcium. It is essential to prevent the fortification iron from reacting with the absorption inhibitors. To ensure adequate absorption therefore, various factors must be considered before initiating a fortification programme. These include cost effectiveness of fortification in increasing absorbable iron, palatability of the fortified food and the etiology of iron deficiency. It is thus important to carefully select the food vehicles to be fortified as well as the iron fortificants to be added. A successful iron fortification program depends heavily upon the absorption of the added iron and its protection from some absorptive inhibitors. This paper focuses on the latest technical advancement ruling the selection of food vehicles and iron fortification compounds with the aim of ensuring adequate absorption of fortified iron. The optimization of the iron fortification compounds with the highest potential absorption causing the least subsequent organoleptic problems in the food vehicles is first discussed, followed by a description of ways of protecting and enhancing the absorption of fortification iron, such as applications of acidifiers, haemoglobin, sodium iron ethylene diamine tetra-acetate and amino acid-chelated iron. Finally, the major foods that are used as iron fortification vehicles in South Africa are discussed.

Key words: iron deficiency, anaemia, iron fortificants, food fortification, micronutrient deficiencies

FORTIFICATION DES ALIMENTS POUR PREVENIR ET REDUIRE LES INSUFFISANCES DU FER

RÉSUMÉ

FRENCH

L'anémie causée par l'insuffisance du fer, l'un des problèmes les plus fréquents de la malnutrition liée aux micro-nutriments, se produit dans beaucoup de pays en développement. Les causes de ce problème sont nombreuses, mais l'une des causes majeures est le niveau bas de la disponibilité biologique du fer dans les aliments. Une augmentation dans l'approvisionnement d'aliments riches en fer absorbable dans le régime alimentaire devrait faire baisser la prévalence de l'anémie causée par l'insuffisance du fer. L'une des stratégies visant à réduire la prévalence élevée de l'anémie causée par l'insuffisance du fer dans les pays en développement est de fortifier les produits alimentaires avec du fer, dans le but d'augmenter le niveau de la consommation du fer et, de ce fait, l'état nutritionnel sera amélioré. La fortification des aliments est l'approche la plus rentable, viable et optimale dans la lutte contre l'insuffisance du fer dans les pays en développement. La fortification du fer n'a pas les effets secondaires gastro-intestinaux que les suppléments de fer provoquent souvent. La fortification du fer peut être divisée en deux grandes formes, à savoir le fer avec haem et le fer sans haem. Le fer sans haem est plus souvent utilisé dans le processus de fortification à cause de la disponibilité des ressources et du coût abordable. Comme la plupart des aliments fortifiés avec du fer contiennent des inhibiteurs possibles de l'absorption, par exemple, la présence des phytates, des poly-phénols contenant des groupes de galloyl, les oxalates et le calcium affectent négativement la bio-disponibilité des fortifiants du fer sans haem, il est essentiel d'empêcher au fer de fortification de réagir avec les inhibiteurs de l'absorption en vue d'assurer une absorption adéquate. De nombreux facteurs doivent être pris en considération avant d'initier un programme de fortification. Ces facteurs sont notamment la rentabilité de la fortification en augmentant le fer absorbable, le goût agréable des aliments fortifiés et l'étiologie de l'insuffisance du fer. Il est donc important de sélectionner attentivement les véhicules alimentaires qu'il faut fortifier ainsi que les fortifiants de fer qu'il faut ajouter. Un programme efficace de fortification de fer dépend étroitement de l'absorption du fer ajouté et de sa protection contre certains inhibiteurs de l'absorption. Ce document est axé sur le progrès technique le plus récent qui oriente la sélection des véhicules alimentaires et les composés de la fortification du fer dans le but d'assurer une absorption adéquate du fer fortifié. L'optimisation des composés de la fortification du fer avec le degré le plus élevé d'une éventuelle absorption qui cause le moins de problèmes organoleptiques ultérieurs dans les véhicules alimentaires est analysée en premier lieu, suivie d'une description des moyens de protéger et d'accroître l'absorption du fer de fortification, tels que les applications d'acidifiants, l'hémoglobine, le Tétra-acétate de diamine d'éthylène de fer et de sodium ainsi que le fer amino-acide-chélaté. Enfin, les principaux aliments qui sont utilisés comme véhicules de fortification du fer en Afrique du Sud sont passés en revue.

Mots clés: insuffisance en fer, anémie, fortifiants du fer, fortification des aliments, insuffisances en micro-nutriments

INTRODUCTION

At the International Conference on Nutrition that was sponsored by the Food and Agriculture Organization (FAO) and World Health Organization (WHO) in Rome during 1992, 160 heads of state and government established global goals for the virtual elimination of vitamin A deficiency (VAD) and iodine deficiency disorders (IDD), as well as the reduction of iron deficiency anaemia (IDA) by one third before the end of 2000. Since then, outstanding progress has been made toward the elimination of iodine deficiency through universal salt iodisation. Vitamin A deficiency is being addressed through food diversification, supplementation programmes and fortification of foods. Iron deficiency anamia is, however, the most prevalent of the three deficiencies and affects about one-third of

the world's population [1], but too little progress has been made toward the global elimination of iron deficiency (ID) and IDA control has thus been the least successful during this same period. The reasons for this lack of action may be that IDA has few overt symptoms, coupled with a general lack of knowledge of the serious and often permanent consequences to the cognitive development of young children and the negative impact on health.

The global prevalence of ID is estimated at 3.5-5 billion people, 2.2 billion people with IDD and 140-250 million deficient in vitamin A [2]. In Africa, 59.4 million women aged between 15 and 49 years are affected. Anaemia is so pervasive in the developing

world, and its intergenerational effects so devastating, that there need be no further justification for concerted action now. The consequences associated with anaemia include debilitating fatigue, compromised immune function, widespread maternal death in childbirth, damage to the foetal brain, premature delivery, intrauterine growth retardation, raised perinatal mortality, and the failure of the child to grow well and develop physically and mentally.

Fortification, one of the strategies to address IDA, is the addition of vitamins and/or minerals to a vehicle with the goal of increasing the nutritional content. Clear evidence exists that fortification is the most cost effective and sustainable strategy in the battle against micronutrient deficiencies, and iron fortification the optimal approach for reducing ID in developing countries [3]. An advantage of iron fortification is that it does not have the gastro-intestinal side effects that iron supplements often induce. The current incidence of IDA in fertile US women is reported at 2.9 % and could be the result of consumption of iron-fortified foods in the United States [3] as the fortification of products such as white bread, rolls, crackers, fish sauce, corn flour, corn grits, pasta and breakfast cereals is widespread, and about 20 % of the total iron intake could be from the fortified iron in these products [4].

Although pilot fortification trials in the developed world reported positive and promising results, no major success examples in the developing world have been reported to date, except perhaps for Chile [5,6]. The reasons could be a lack of political commitment, insufficient funding, not enough technical support from research institutions or industries, poor distribution networks or lack of nutrition education programs for the consumers, all of which are considered necessary for a successful fortification program. Another reason could be poverty resulting in a lack of purchasing power to afford foods containing haem iron. Other contributing factors could be lack of money to afford antenatal services, poor access to health services, inadequate water supply, poor sanitation. All these factors coexist in poor households living in marginalised environments where anaemia rates are reported to be most prevalent [7]. The poor social status of people is another relevant basic cause. At more immediate levels, low iron intake, poor bioavailability of dietary iron, VAD and infections (cholera, Congo fever and parasitic infestation) combine in jeopardising an individual's iron status [8]. However, should low bioavailability of food iron be the major determinant of IDA in the developing world, an increase in the supply of absorbable food iron should decrease the prevalence of IDA.

It is thus important to carefully select the food vehicles to be fortified as well as the iron fortificants to be added. The iron fortificant should, however, be optimised

with respect to relative bioavailability before it is added to the food vehicle. It is also true that if potential absorption inhibitors are present in the food vehicle, the added and native iron, will be poorly absorbed, and thus there will be little or even no impact on the consumers' iron status. A successful iron fortification program thus depends heavily upon the absorption of the added iron and its protection from some absorptive inhibitors.

This paper will focus on the technical advancement ruling the selection of food vehicles and iron fortification compounds with the aim of ensuring an adequate absorption of fortified iron. The optimisation of the iron fortification compounds in relation to bioavailability and organoleptic problems will first be discussed, followed by a description of protective methods that can be used to protect the fortified iron from absorptive inhibitors. Finally, the major foods that are used as iron fortification vehicles in South Africa (SA) are discussed.

OPTIMIZATION OF THE IRON FORTIFICATION COMPOUNDS

Features of the most commonly used iron fortificants are shown in Table 1 [3,9]. Iron fortificants are usually classified according to solubility, namely those that are (a) water-soluble; (b) poorly water soluble but soluble in dilute acids; (c) water-insoluble but poorly soluble in dilute acids; and (d) protected iron compounds. In general, the more soluble in water or gastric juice, the higher the bioavailability of the iron fortificant. Fortificants poorly soluble in diluted acids have a low to moderate bioavailability due to the variable dissolution in gastric juice owing to both the characteristics of the fortificant and the meal composition.

Although it would be argued to use the most bioavailable iron fortificants, these fortificants often cause unacceptable flavours and colours in many food vehicles. Optimisation is, therefore, choosing an iron fortificant with the highest potential absorption causing the least subsequent organoleptic problems in the food vehicles.

Bioavailability

During the past 35 years considerable progress has been made in understanding iron absorption by employing iron radioisotopes in human and animal subjects or by *in vitro* assay. The isotopes, initially incorporated into vegetables were studied by hydroponic methods whereas biosynthetic techniques were applied for animal foods. Considerable absorption variations in the different food items were observed. Iron derived from animal tissue was generally better absorbed than iron from vegetables. Studies also showed that in meals containing two food items, labelled with separate iron isotopes, the absorption of iron from each food item was modified by the other

[10]. This led to the important discovery that overall meal composition determines bioavailability and that it is not a unique property of the food source in most circumstances. Further studies refined the current concept of the behaviour of iron destined for absorption in the lumen of the upper small bowel prior to its entrance into mucosal cells [11]. Studies also demonstrated that the measurement of dialysable iron in vitro is a good predictor of iron bioavailability in humans [12]. The relative bioavailability (RBV) of many commercially available iron fortificants is well known (Table 1). Animal or in vitro assays can be used for screening new iron compounds, although human studies are ultimately necessary.

Fortification iron absorption depends primarily on its solubility in gastric juice. Water-soluble fortificants, such as ferrous sulphate, dissolve instantaneously in gastric juice. The absorption of the insoluble or poorly soluble iron fortificants can be improved by reducing particle size, but this is accompanied by an increased reactivity in deteriorative processes. Once dissolved, however, fortification iron enters the common pool, where its absorption (like that of all pool iron) depends on the content of enhancing (such as vitamin C) or inhibitory ligands (such as phytates and polyphenols) in the meal. Iron status is also a determining factor of iron absorption as a satisfactory iron status will diminish and a low iron status will enhance absorption.

Organoleptic problems

Although discolouration and off-flavour development are some of the most frequent problems encountered when adding iron fortificants to food, appearance of specks, segregation, sedimentation, sandy texture, lipid oxidation and vitamin degradation may also occur. Many iron fortificants are coloured and this colour is often a critical factor when fortifying lightly coloured foods. The use of soluble iron fortification compounds often results in changes in colour and flavour due to reactions with other components in the food, but it has the advantage of being highly bioavailable.

Iron fortificants may cause a metallic flavour, especially in liquid products. A change in flavour is mostly the result of lipid oxidation catalysed by iron. Pentane formation can be measured in the headspace of sealed cans, containing iron-fortified products, to determine the potential ability of the iron fortificant to promote fat oxidation in cereals [13]. By coating the fortificant with hydrogenated oils or ethyl cellulose, some of the undesirable interactions with the food matrix can be avoided [14].

Water-soluble fortificants

Water-soluble iron fortificants are the most bioavailable.

Ferrous sulphate is usually the relative standard of bioavailability for other iron fortificants. This group of fortificants is, unfortunately, also the most chemically reactive and likely to promote unacceptable colour and flavour changes. Desiccated ferrous sulphate is the cheapest fortificant, mostly used to fortify infant formulae and low acid foods, such as pasta, cereal flour and bread that are stored for only short periods. Colour changes can be prevented if the food is slightly acid because ferrous sulphate turns food brown above pH 6.3. Other possibilities are ferrous gluconate, ferric saccharate, ferric ammonium citrate, ferric glycerophosphate, and ferrous lactate. Ferrous lactate is highly hygroscopic and can, therefore, not be used in dry foods. It is the preferred iron source for liquid foods such as UHT (ultraheat treat) milk and liquid formulae diets [15].

Compounds poorly soluble in water, but soluble in dilute acids

Ferrous citrate, ferrous fumarate, ferrous tartrate and ferrous succinate form part of this group and cause fewer organoleptic problems than water-soluble fortificants and readily enter the common iron pool during digestion. These are mostly used in infant cereals [13] and chocolate drink powder [16].

Extensive tests have shown that ferrous fumarate is suitable for fortification of cereal-based weaning foods, biscuits, and wafers, but because of its brown colour and insolubility, it is not appropriate for fortification of milk and white or off-white foods [17,18].

Compounds water-insoluble and poorly soluble in dilute acids

Water-insoluble, but poorly soluble in dilute acids fortificants include ferric orthophosphate, ferric pyrophosphate, and reduced elemental iron. These are the most often-used compounds in food fortification as no organoleptic problems are caused. A disadvantage, however, is that these fortificants have a variable absorption because of the poor gastric juice solubility. Animal studies indicated that commercial compounds have 50 % absorption compared to ferrous sulphate [13]. Human studies, however, have given variable and conflicting results (Table 1). This could be due to different physiochemical characteristics in the compounds tested, or the influence of different meals on the dissolution of the compounds in gastric juice are different.

Reduced iron is used to fortify wheat and added to flour and ready-to-eat cereals in combination with vitamin B1, B2, B6, and niacin. The amount of reduced iron actually absorbed from fortified flour depends on the diet composition [19,20]. However, ferric pyrophosphate interacts the least with food components, and has a good

bioavailability. It can be dispersed and suspended in a liquid food and is used to fortify cereals, pasta products, milk powder, liquid diets, infant formulae and cocoa drinks.

Microencapsulated iron compounds

New micro-encapsulation technologies render iron fortificants that are more resistant to interaction with other components in the food vehicles, thus minimising organoleptic changes, increasing shelf-life and maximising consumer acceptance. Most of the iron compounds can be micro-encapsulated, but the most available products are the microencapsulated form of both ferrous sulphate and ferrous fumarate. The coatings are usually a mixture of phospholipid, polysaccharides, protein or partially hydrogenated oils. Figure 1 is a schematic view of micro-encapsulation. Micro-encapsulation has little influence on RBV [21], and the main advantages are that few organoleptic changes are caused and a prolonged shelf life of fortified foods. This is a result of the bilayer coating, protecting against the interaction between iron and absorption factors in the fortified foods [22].

Fig. 1: *A longitudinal view of microencapsulation*

Hydrophilic polar heads

Microencapsulated substance

Hydrophilic tail
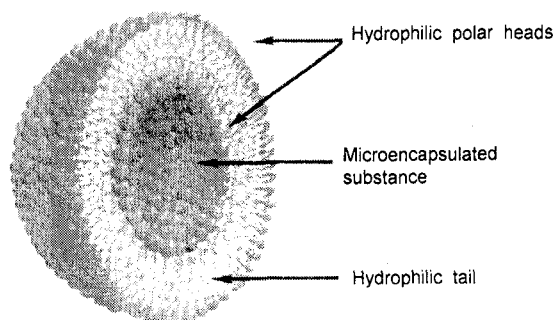
PROTECTING AND ENHANCING THE ABSORPTION OF FORTIFICATION IRON

Food iron exists in two main forms, namely haem iron found in meat as part of haemoglobin and myoglobin, and non-haem iron naturally present in cereals, vegetables and other foods. Haem and non-haem iron are absorbed by different pathways with different degrees of efficiency depending on the chemical form, other dietary constituents and the level of iron stores in the individual. Between 20 % and 30 % of haem iron is absorbed and this is a constant figure, being relatively unaffected by other dietary or physiological variables such as body iron stores [23]. A large number of dietary variables that enhance or inhibit non-haem iron absorption have been identified, however [24]. These include chemical

reactions in the digestion, such as chelation and changes in iron valency, effects on intestinal or mucosal function, and competition with other minerals for transport protein. The presence of phytates, polyphenols containing galloyl groups, oxalates and calcium are known to adversely affect the bioavailability of non-haem iron fortificants. Their inhibitory effect is usually due to the formation of large insoluble polymers. Many food vehicles for iron fortification contain some substances that inhibit iron absorption. For example, cereals contain polyphenols and phytic acid, milk contains calcium and casein, while coffee, cocoa and tea drinks contain polyphenols. In addition, many diets in developing countries to which fortified salt, sugar or other condiments are added, often have high levels of phytate, oxalic acid and polyphenols from cereal and legume foods. To ensure a high enough level of absorption to improve or maintain iron status, it is necessary to prevent the fortification iron from reacting with the absorption inhibitors.

Acidifier

Acidification of foods represents an important strategy to increase iron bioavailability. Organic acids, such as ascorbic, citric, malic, tartaric and lactic acid form soluble complexes with iron, thus preventing precipitation or polymerisation and thus promoting iron absorption [19,25]. Ascorbic acid is the most common organic acid enhancer, increasing the absorption of both native iron and fortification iron several fold when added to foods. Its effect appears to be related to its ligand action and reducing power. It can change the valency of iron from Fe^{3+} to Fe^{2+} and/or maintain Fe^{2+} in the ferrous state and thus prevent or decrease the formation of insoluble complexes with absorption inhibitors or with hydroxide ion in the gut. In addition, it can form soluble complexes with iron at low pH that remain soluble and absorbable at more alkaline duodenal pH.

Research conducted in Chile showed that the prevalence of anaemia in children between 3 and 15 months old fed iron-fortified milk was reduced from 36 % to 13 %. In children fed with both iron- and vitamin C-fortified milk, anaemia prevalence was reduced from 28 % to 2 %. The data (Figure 2) confirmed that vitamin C and iron together were more effective in reducing anaemia than iron fortification alone [26]. Hallberg *et al* [20] studied the inhibitory effect of phytate on iron absorption from bread rolls. Increasing the amount of phytate in bread rolls decreased the ratio of iron absorbed from 80 % to 20 %. The inhibitory effect of phytate (25 mg) was neutralised by taking 100 milligram (mg) vitamin C in a beverage with the bread roll.

Haemoglobin

Haemoglobin (Hb) is a form of food iron that is

Figure 2: *Prevalence of anemia in children aged 3 to 15 months fed on iron and iron/vitamin C-fortified milk*
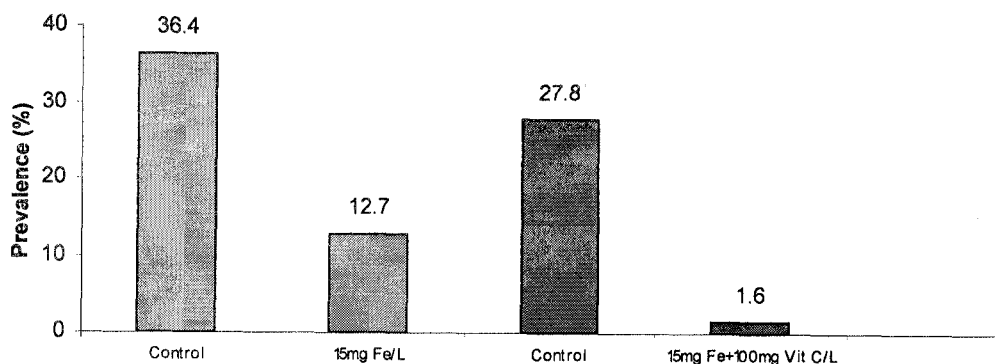
naturally protected from major iron absorption inhibitors such as phytic acid and polyphenols. The iron is contained within the porphyrin ring of the haem molecule, which is split from the globin moiety during digestion, and is taken up intact into the mucosal cells. The iron is released within the mucosal cell by the action of haem oxygenase and is prevented from reacting with the inhibitory and enhancing ligands within the intestinal lumen.

Haemoglobin is added in the form of dried red blood cells when used as a food additive and its main advantage is a relatively high and predictable iron absorption. Although the absorption varies little with the composition of a meal and to some extent with the iron status of the subject, this variation is less than with non-haem iron [27]. In Latin American countries where the supply of animal blood is plentiful, two field trials demonstrated the potential usefulness of dried red blood cells as an iron fortificant. In the first study with 1000 participants [6], three 10 g wheat flour biscuits containing 6 % bovine Hb concentrate were consumed as part of the Chilean school lunch program over a period of three years. The prevalence of anaemia in 10-16 year old girls decreased from 1.3 % to 0.5 %, and in boys from 0.8 % to 0.4 %. In another study [28], 30 gram (g) extruded rice, containing 5 % bovine Hb concentrate, was fed to infants, 4-12 months old (experimental group). Their iron status was compared with those of infants fed on regular solid foods such as vegetables and meat (control group). In the control group after 12 months, the prevalence of IDA was 17 % compared with 6 % in the experimental group.

The main disadvantage of Hb iron is the low iron content (Table 1) and the intense red-brown colour. Other disadvantages are the difficulties in collecting, drying and storing animal blood, especially in countries where meat is not widely consumed or when religious beliefs forbid the consumption of blood.

Sodium iron ethylene diamine tetra-acetate

Ethylene diamine tetra-acetic acid (EDTA) is a hexadentate chelate compound with four negatively charged carboxylic acid groups and two amine groups. It can combine with virtually every metal ion in the periodic table. Sodium iron ethylene diamine tetra-acetate (NaFeEDTA) is one of many EDTA-chelated compounds. The International Nutritional Anaemia Consultative Group (INACG) recommends NaFeEDTA as a suitable iron fortificant for developing countries [29]. Clinical trials in Guatemala, Venezuela, Thailand and South Africa demonstrated that NaFeEDTA fortification could successfully reduce IDA [30-32]. Advantages of NaFeEDTA include:

- promoting the absorption of intrinsic food iron in a meal with low iron bioavailability;
- providing a highly bioavailable form of iron compound;
- stability;
- bioavailability of iron not affected by adverse storage conditions or by food preparations such as cooking; and
- fewer undesirable characteristics such as rancidity and organoleptic problems than other water-soluble fortificants.

It is, however, not suitable to fortify all staple foods with NaFeEDTA as unwanted colour changes may be caused. Sugar fortified with NaFeEDTA is slightly yellow in colour and when added to tea and coffee, resulted in black tea and deep blue coffee. Similarly, when added to maize starch puddings and gruels, a pinkish-violet colour is the result [33]. In long-term trials conducted in Guatemala, sugar was fortified with NaFeEDTA and consumed for a four-year period [34]. NaFeEDTA was apparently partly hydrolysed in the gut with subsequent partial absorption of the EDTA. Since

free EDTA binds divalent cations in the body and is itself not metabolised, there was an increase in urinary excretion of zinc, copper and iron [34]. These results thus indicated a limited use of NaFeEDTA as iron fortificant.

Amino acid-chelated iron

As a solution to the co-chelation problems of NaFeEDTA, different iron chelates were developed using amino acid as ligands. Amino acid chelates could be absorbed like a peptide in the jejunum rather than as non-haem iron in the duodenum. This alternative mechanism has raised concern about the role of iron stores in iron absorption regulation from the amino-chelate.

Ferrous bis-glycinate is formed by two glycine molecules bound to a ferrous cation, resulting in a double heterocyclic ring compound. The carboxyl group of glycine is linked with iron by an ionic bond, whereas the -amino group is joined with the metal by a coordinate covalent bond. The structure shown in Figure 3 was elucidated by X-ray diffraction and infrared spectrometry in which the metal was complexed by two bidentate glycine ligands with a nitrogen atom and a an oxygen atom of each glycine unit acting as donor atoms. It has been proposed that this configuration protects the iron from dietary inhibitors and intestinal interactions [35].

Figure 3: *Molecular structure diagram for ferrous bis-glycinate*
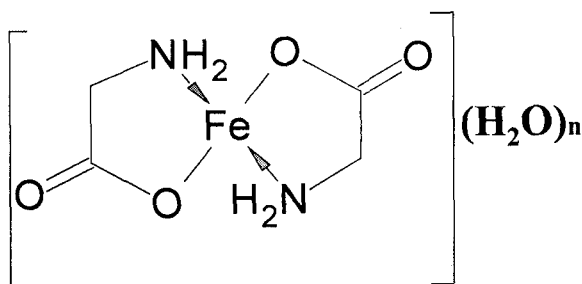
Ferrous bis-glycinate has been successfully used for fortification of whole cow's milk and maize and wheat flours [36]. Field studies, using milk fortified with 3 mg of ferrous bis-glycinate without addition of ascorbate, have shown that up to 40 % of the amino acid chelate is absorbed [37,38]. Studies using water solutions of 55Fe-labelled bis-glycine chelate proved better absorption than ferrous ascorbate, and that its absorption is regulated by the iron stores of the body [35]. In addition, its low pro-oxidant or rancidity properties are advantageous when used as a fortificant in fluid, high

fat vehicles. Ferrous bis-glycinate is stable in the ferrous form when exposed to ambient air and temperature between pH 3 and 10. When stored in tetra-pack containers, it has a shelf life of over six months at room temperature.

More recently, a new tasteless chelate, in which iron is chelated with three molecules of glycine (ferric tris-glycinate), has been used successfully to fortify sugar for industrial use in Brazil [37]. This tris-glycine chelate causes no organoleptic changes.

Bovell-Benjamin *et al.* [39] compared the absorption of iron from ferrous sulphate, ferrous bis-glycinate and ferric tris-glycinate added to a whole-maize meal and concluded that better iron absorption was obtained from ferrous bis-glycinate than from ferric tris-glycinate or ferrous sulphate. It was also concluded that ferrous bis-glycinate was an effective and safe source of iron, particularly useful as an iron fortificant in phytate-rich diets.

At present, whole fluid milk and other dairy products, fortified with iron bis-glycine, are available in many countries of Latin America and Europe. Although more expensive by weight, this advanced fortificant can be used more sparingly and can thus be more cost-effective in delivering essential micronutrients to the consumer.

FOOD VEHICLES USED FOR IRON FORTIFICATION IN SOUTH AFRICA (SA)

One of the major problems frequently encountered in iron fortification is the choice of the form of iron to be added. There are only a few successful applications of iron fortification in South Africa. Table 2 is the latest results of an investigation on food products with added iron available in SA. Cereal products are the most widely used vehicles for iron fortification. Since reduced iron is inert organoleptically, it is used to fortify ready-to-eat breakfast cereals and maize meal, though it has a relatively low absorption. Desiccated freely soluble ferrous sulphate is the best absorbed, but is also the most chemically reactive, producing off flavours and colour and is used to fortify low acid foods and infant formulae and cereals. Ferric pyrophosphate interacts least with food components, and its bioavailability is considered to be good. In the acid environment of the stomach, its solubility and, thus, bioavailability is increased. The compound can be dispersed and suspended in a liquid food. In SA it is used to fortify a malted drink. Ferrous fumarate is better absorbed and found to be suitable for fortification of cereal-based weaning foods.

Like other developing countries, food fortification is an essential element in nutrition strategies to alleviate micronutrient deficiencies in SA. It is a dynamic area

developing in response to the needs of population groups and industry. In SA, the Directorate of Nutrition within the Department of Health (DOH) spearheaded mandatory food fortification by establishing a food fortification task group (FFTG). The FFTG, comprising of representatives from DOH, industry, consumer organisations, professional associations and international organisations was established to assist the DOH with a food fortification programme for SA. The FFTG developed a framework with all the activities to be conducted, for example, situation analyses, feasibility studies and plan development. Efforts should continue to develop improved and new systems of delivering micronutrients to target populations through appropriate fortification procedures.

CONCLUSION

Iron deficiency, one of the most prevalent problems of micronutrient malnutrition, occurs in many developing countries. The impact of iron deficiency and IDA on the individual can result in lifelong disadvantages. Causes of the problem are many, but the principal cause is lack of iron-rich food in the diet. One of the best strategies to eliminate or markedly reduce iron malnutrition is through food fortification, with the goal of increasing the level of iron consumption to improve nutritional status. Several options exist with respect to iron fortificant and food vehicle selection. Various factors must be considered before initiating a fortification programme. These include cost effectiveness of fortification in increasing absorbable iron, palatability of the fortified food and the etiology of iron deficiency. As most iron-fortified foods contain potential absorption inhibitors, it is essential to protect the fortification iron to ensure adequate absorption.

In recent years, food fortification has become a more realistic and accessible option for SA to end micronutrient malnutrition. Like in other developing countries, iron fortification is the optimal approach to reducing the prevalence of ID in SA. To improve the effectiveness of the micronutrient interventions, a number of foods have successfully been fortified with different iron fortification compounds. The iron-fortified products in SA include ready-to-eat foods, such as baby formulae, weaning foods, breakfast cereals, and some nourishing powdered drinks. The iron fortificants used in SA include reduced iron, dried ferrous sulphate, ferrous fumarate and ferric pyrophosphate. All these fortificants have a relatively good bioavailability of iron. However, prevalence rates of ID continue to be high in SA. It is, therefore, necessary to increase efforts in developing improved iron fortification interventions, research and produce more iron fortified staple foods and to select more appropriate iron fortificants for different foods in a combined strategy to prevent and control iron deficiency.

When establishing strategies for anaemia prevention, it is important to realise that micronutrients, other than iron, are important in anaemia prevention. In addition to iron, copper, vitamins A, B2, B12, C, and folate are essential for Hb formation and it is thus essential to consider the total diet and not concentrate in iron alone when addressing anaemia prevention. The premise of any fortification program should be to design a diet to increase the availability of nutrients needed to maintain good iron status.

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Table 1

Characteristics of commercially available iron compound (fortificants)

Iron compounds	Appropriate Fe content (%)	Average relative bioavailability Human	Animal
Freely water-soluble			
Ferrous sulphate $7H_2O$	20	100	100
Ferrous gluconate	12	89	97
Ferrous lactate	19	106	--
Ferric ammonium citrate	18	--	107
Dried ferrous sulphate	33	100	100
Ferric glycerophosphate	15	100	100
Ferric saccharate	10	74	92
Poorly water-soluble/soluble in dilute acids			
Ferrous citrate	24	59	63
Ferrous fumarate	33	100	95
Ferrous tartrate	22	73	79
Ferrous succinate	35	92	119
Water-insoluble/poorly soluble in dilute acids			
Ferric pyrophosphate	25	21-74	45-58
Ferric orthophosphate	28	25-32	6-46
Reduced elemental iron:			
- by electrolysis	98	5-100	44-48
- by hydrogen	97	13-148	24-54
- carbonyl iron	98	5-20	39-66
Protected compounds			
NaFeEDTA	13	28-416	--
Haemoglobin	0.34	100-700	--
Ferrous bis-glycinate	18	100-400	--
Ferric tris-glycinate	13.8	100-400	--

Table 2

The latest results of investigation on supermarket products with added iron in South Africa

Trade name	Iron form(s) added	Manufacturer
Baby powdered formulae Pre-Nan Nan 1 Nan 2 Lactogen 1 Lactogen 2 Perlargon Al 110	Ferrous sulphate dried powder	Nestle
Cereals Nestum 1 Nestum 2 Nestum 3 Cerelac	Ferrous sulphate dried powder Ferrous fumarate	
Complimentary feeds Build up	Ferrous sulphate dried powder	
ACE mieliemeal Super mieliemeal	Reduced iron	Tiger milling
All cereals		Bokomo Smith
Horlicks	Ferric pyrophosphate	Kline Beecham